ECO-SOCIAL FACETS OF RICE PEST MANAGEMENT IN SELECTED RICE ECOSYSTEMS OF NORTH KERALA

Thesis submitted for the degree of

DOCTOR OF PHILOSOPHY IN ZOOLOGY

By

SREEJINA SREEDHARAN K

DEPARTMENT OF ZOOLOGY
UNIVERSITY OF CALICUT
KERALA, INDIA
2024

Department of Zoology

UNIVERSITY OF CALICUT

M. NASSER Ph.D.
Professor (Retd.)

Division of Entomology
Department of Zoology
University of Calicut
Kerala, India – 673 635
Phone: 0494-2401144 419 420
Fax: 0494 2400269
Grams: UNICAL
e-mail: drnasher@gmail.com
Mob: 8547560471

CERTIFICATE

This is to certify that this thesis entitled **"Eco-social facets of rice pest management in selected rice ecosystems of North Kerala"** is an authentic work carried out by **Ms. Sreejina Sreedharan K**., in the department of Zoology, University of Calicut under my supervision and guidance and no part thereof has been presented earlier for any degree. I also certify that this thesis is free from plagiarism after having checked using **iThenticate** and that no sentence, equation, diagram, table, paragraph, or section has been copied from previous work of others verbatim except a very minimal level with due acknowledgement of the original sources. The similarity found by running the plagiarism software is well within the stipulated level of 10%.

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C.U. Campus **Sreejina Sreedharan K**



Dr. M Nasser
Professor (Retd.)
Department of Zoology
University of Calicut



To the unsung heroes, the diligent farmers whose toil sustains our very being, I dedicate my thesis with the deepest gratitude and admiration.

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ABSTRACT

This research employs a trans-disciplinary methodology for rice pest management, centered on pest-parasitoid associations. By integrating entomology, ecology, socio-economic aspects, and policy research, the study aims to identify sustainable solutions and promote social learning. Effective collaboration among scholars, farmers, multidisciplinary scientists, and stakeholders is crucial.

The first part of the study explores tri-trophic interactions within rice agro-ecosystems in North Kerala, focusing on relationships among insect pests, their parasitoids, and the defense strategies of lepidopteran pests. Key findings include:

1. **Species Composition**: Identification of a diverse range of insect pests and parasitoids, with prominent species like *Cnaphalocrocis medinalis* and *Parapoynx stagnalis*, and significant biological control potential from parasitoid families Ichneumonidae and Braconidae.

2. **Seasonal Variation**: Seasonal changes significantly impact insect species composition, with higher populations during wet seasons due to increased resource availability.

3. **Zone-specific Preferences**: Certain insect species show preferences for specific ecological zones, underscoring the need for tailored pest management strategies.

4. **Host-Parasitoid Associations**: Complex interactions between pests and parasitoids were noted, with diverse parasitic strategies employed by parasitoid wasps influencing pest control.

5. **Anti-Parasitoid Defense Strategies**: Lepidopteran pests exhibit various defense mechanisms against parasitoids, affecting parasitism rates.

The second part of the study underscores the transition to sustainable agricultural practices. It analyzes community structure, spatio-temporal variation, and factors influencing pest and parasitoid populations:

1. **Abundance and Species Richness**: Significant variations in pest and parasitoid populations across different zones and seasons were observed.
2. **Effects of Crop Age and Farming Practices**: Insect pest diversity varies with rice growth stages, and pesticide usage impacts pest and parasitoid abundance, highlighting the need for eco-friendly practices.
3. **Climatic and Agricultural Factors**: Climatic factors and agricultural practices significantly influence pest and parasitoid dynamics, with ecological niche modeling providing predictive insights for integrated pest management.

The third part highlights traditional pest management practices among small-scale farmers in North Kerala. Combining traditional wisdom with modern scientific assessments can enhance sustainable pest management strategies:

1. **Farmers' Knowledge and Perceptions**: Limited knowledge about pests and natural enemies hampers effective management, emphasizing the need for educational programs.
2. **Social Dynamics and Information Sources**: Training and social connections influence farmers' awareness and adoption of pest management techniques.
3. **Socio-Economic and Cultural Influences**: Traditional farming communities rely on empirical knowledge, while modern communities show greater social engagement and reliance on external sources.

The study calls for collaborative efforts to promote sustainable pest management, reduce dependency on chemical pesticides, and safeguard environmental and public health. Addressing knowledge gaps, enhancing farmer participation, preserving traditional knowledge, and reforming government policies are essential for sustainable agriculture in North Kerala.

Keyword: Trans-disciplinary research, Sustainable pest management, Rice pest control, Socio-ecology, Sustainable agriculture

സംഗ്രഹം

ഈ ഗവേഷണം നെൽ കീട നിയന്ത്രണത്തിന് ഒരു ട്രാൻസ്ഡിസിപ്ലിനറി സമീപനം ഉപയോഗിക്കുന്നു, പ്രത്യേകിച്ച് കീടപാരസൈറ്റോയ്ഡ് ബന്ധങ്ങളെ കേന്ദ്രീകരിച്ചാണ്. കീടശാസ്ത്രം, പരിസ്ഥിതിശാസ്ത്രം, സാമൂഹികസാമ്പത്തികം, നയ ഗവേഷണം എന്നിവയുടെ സംയോജനം വഴി സുസ്ഥിര പരിഹാരങ്ങൾ കണ്ടെത്താനും സാമൂഹിക പഠനത്തിന് ഊന്നൽ നൽകാനും ലക്ഷ്യമിടുന്നു.

പഠനത്തിന്റെ ആദ്യ ഘട്ടം വടക്കൻ കേരളത്തിലെ നെൽ കാർഷിക മേഖലകളിലെ ട്രൈട്രോഫിക് ഇടപെടലുകൾ പരിശോധിക്കുന്നു. പ്രധാനമായും ഇല ചുരുട്ടിപ്പുഴു, കുഴൽപുഴു തുടങ്ങിയ ലെപിഡോപ്റ്ററൻ കീടങ്ങളും അവയുടെ പാരാസൈറ്റോയിഡുകളും തമ്മിലുള്ള ബന്ധമാണ് പരിഗണിക്കുന്നത്. പ്രധാന കണ്ടെത്തലുകൾ ഉൾപ്പെടുത്തുന്നു:

1. പ്രധാന കീടങ്ങളും പാരാസൈറ്റോയിഡുകളുമടങ്ങുന്ന സ്പീഷീസ് ഘടന.
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3. ഓരോ ജൈവഭൗതിക സോണുകൾക്കും പ്രത്യേക കീട മുൻഗണനകൾ കാണുന്നു.
4. കീടപാരാസൈറ്റോയിഡ് ഇടപെടലുകളിൽ നിലനിൽക്കുന്ന പ്രതിരോധ തന്ത്രങ്ങൾ.
5. ലെപിഡോപ്റ്ററൻ കീടങ്ങൾ പാരാസൈറ്റോയിഡുകളെതിരായ പ്രവർത്തനക്ഷമമായ പ്രതിരോധ സംവിധാനങ്ങൾ വികസിപ്പിച്ചെടുക്കുന്നു.

രണ്ടാം ഘട്ടത്തിൽ, വിവിധ സീസണുകളിൽ പെടുന്ന കീടപരാന്നഭോജി സമ്പത്ത്, വളർച്ചാ ഘട്ടങ്ങൾ, കീടനാശിനി ഉപയോഗം, കാലാവസ്ഥ, കാർഷിക രീതി എന്നിവയുടെ സ്വാധീനത്തെ അടിസ്ഥാനമാക്കിയുള്ള വിശകലനമാണ്.

1. കീടങ്ങളുടെയും പരാന്നഭോജികളുടെയും ജനസംഖ്യയിൽ സീസണൽ വ്യതിയാനം.
2. വിളയുടെ പ്രായം, കൃഷിരീതി, കീടനാശിനി ഉപയോഗം എന്നിവയുടെ സ്വാധീനങ്ങൾ.
3. കാലാവസ്ഥാ ഘടകങ്ങളും കാർഷികപരമായ ഇടപെടലുകളും ഇവയുടെ ജനസംഖ്യയെ സ്വാധീനിക്കുന്നു.

മൂന്നാം ഘട്ടത്തിൽ, ചെറുകിട കർഷകരുടെ കീടനിയന്ത്രണത്തിൽ പരമ്പരാഗത അറിവിന്റെ പങ്ക് പഠിക്കുന്നു. നാടൻ പരിഹാരങ്ങളും ശാസ്ത്രീയ മൂല്യനിർണയവും സംയോജിപ്പിച്ച് സുസ്ഥിര കീടനിയന്ത്രണ മോഡലുകൾ വികസിപ്പിക്കാനാവും.[66]

1. കർഷകരുടെ പരിമിത അറിവ് പരിശീലന ആവശ്യം വ്യക്തമാക്കുന്നു.
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3. സാമൂഹ്യ സാംസ്കാരിക ഘടകങ്ങൾ കൃഷിയിലെ അറിവ് കൈമാറലിനെ സ്വാധീനിക്കുന്നു.

പരിസര സംരക്ഷണവും പൊതുജനാരോഗ്യവും ഉറപ്പാക്കുന്നതിനും കീടനാശിനി ആശ്രിതത്വം കുറയ്ക്കുന്നതിനും ഈ പഠനം വൈജ്ഞാനികം, സാമൂഹികം, നയതലത്തിൽ സമന്വയപ്പെടുത്തിയ ഇടപെടലുകളുടെ ആവശ്യകത മുന്നോട്ടുവെക്കുന്നു.

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CONTENTS

Title		*Page No.*
GENERAL INTRODUCTION		**1-5**
Chapter 1	**SPECIES COMPOSITION OF INSECT PESTS AND PARASITOIDS, AND THEIR ASSOCIATIONS IN THE RICE AGRO-ECOSYSTEM**	**6-70**
	Introduction	6
	Review of Literature	9
	Study Area	22
	Materials and Methods	28
	Results	31
	Discussion	60
Chapter 2	**SPATIO-TEMPORAL VARIATION OF PESTS AND PARASITOIDS IN THE RICE ECOSYSTEM OF NORTH KERALA**	**71-199**
	Introduction	71
	Review of literature	74
	Study Area	85
	Materials and Methods	85
	Results	97
	Discussion	152
	Annexures	173
Chapter 3	**INSECT PESTS ASSOCIATED WITH THE TRADITIONAL RICE VARIETIES, AND THE SOCIO-ECOLOGICAL DIMENSIONS OF RICE PEST MANAGEMENT IN NORTH KERALA**	**200-345**
	Introduction	200
	Review of literature	205
	Study Area	242
	Materials and Methods	245
	Results	258
	Discussion	316
CONCLUSIONS		**346-355**
BIBILIOGRAPHY		**356-417**

LIST OF TABLES

Table No.	*Title*	*Page No.*
1.1	Sites in North Kerala, where the eggs, larvae, and pupae of rice pests were collected (2016–2020).	23 - 24
1.2	Details for the distribution and selection of the rice fields in three different ecological zones during 2017–2019 in North Kerala, South India.	28
1.3	The rice pests collected from the paddy fields of North Kerala.	32
1.4	Percentage species composition of rice pests in the dry season (2017–2019). The bold digits represent significant results.	37
1.5	Percentage species composition of rice pests in the wet season (2017–2019). The bold digits represent significant results.	38
1.6	Percentage composition of Ichneumonid wasps in the dry and wet seasons.	42
1.7	Percentage composition of parasitoids in the three agro-ecological zones of North Kerala (Dry season).	44
1.8	Percentage species composition of parasitoids in the three agro-ecological zones of North Kerala (Wet season).	44 - 45
1.9	Egg parasitoids reared from the rice pests of North Kerala.	46
1.10	The extent of egg parasitoid overlap among herbivores is depicted. It illustrates the count of shared egg parasitoid species between each potential pair of herbivore species.	47
1.11	Larval parasitoids reared from the rice pests of North Kerala	48 - 49
1.12	The extent of larval parasitoid overlap among herbivores is depicted. It illustrates the count of shared larval parasitoid species between each potential pair of herbivore species.	51
1.13	Pupal parasitoids reared from the rice pests of North Kerala	51
1.14	The extent of pupal parasitoid overlap among herbivores is depicted in the table. It illustrates the count of shared pupal parasitoid species between each potential pair of herbivore species.	52
1.15	Hyperparasitoids emerged from the primary parasitoids of rice pests of North Kerala.	53
1.16	Hyperparasitoid overlap among primary parasitoids.	54
2.1	The ranges of normalized difference vegetation index (NDVI) identified for the various landcover classes.	93

2.2	The relative density and frequency of major rice pests in the high hill region (2017–2019).	105
2.3	The relative density and frequency of major rice pests in the foothill region (2017–2019).	106
2.4	The relative density and frequency of major rice pests in the midland laterite region (2017–2019).	106 - 107
2.5	The relative density and frequency of major parasitoids in the high hill region (2017–2019).	111
2.6	The relative density and frequency of major parasitoids in the foothill region (2017–2019).	111
2.7	The relative density and frequency of major parasitoids in the midland laterite region (2017–2019).	112
2.8	Agro-ecological zone wise comparison of dry and wet seasonal variation of pests and parasitoid populations.	118
2.9	Pest diversity in the dry and wet seasons of three agro-ecological zones. The bold digits represent significant results.	119
2.10	Parasitoid diversity in the dry and wet seasons of three agro-ecological zones. The bold digits represent significant results.	121
2.11	Wilcoxon rank test for pests in the different seasons and agro-ecological zones between two independent groups (booting and ripening crop growth stage).	122
2.12	Diversity indices for pests in the booting and ripening rice growth stages concerning different agro-ecological zones (Dry season).	122
2.13	Diversity indices for pests in the booting and ripening rice growth stages concerning different agro-ecological zones (Wet season).	124
2.14	Mann–Whitney U test for the pests in the different seasons and agro-ecological zones between two independent groups (pesticide-treated and pesticide-untreated farming practices).	127
2.15	Diversity indices of pests in the pesticide-treated (PT) and untreated (PUT) rice fields with respect to different agro-ecological zones and seasons.	128
2.16	Mann–Whitney U test for abundance of parasitoids in different seasons and agro-ecological zones between two independent groups (pesticide-treated and pesticide-treated farming practices).	129
2.17	Diversity indices of parasitoids in the pesticide-treated (PT) and untreated (PUT) rice fields with respect to different agro-ecological zones and seasons.	129-130

2.18	The non-metric multidimensional scaling (NMDS) stress values for models with two and three dimensions, along with the analysis of similarities (ANOSIM) R-values and their significance (p), were computed for the species composition of both dry and wet seasons.	130
2.19	Spearman rank correlation coefficients (r) of trend (pest abundance versus climatic factors) in dry and wet seasons of three agro-ecological zones and their statistical significance.	135
2.20	Multiple linear regression analysis between climatic factors and pest populations on rice in three agro-ecological zones and two seasons.	135
2.21	Spearman rank correlation coefficients (r) of trend (parasitoid abundance versus climatic factors) in dry and wet seasons of three agro-ecological zones and their statistical significance.	137
2.22	Multiple linear regression analysis between climatic factors and parasitoid populations on rice in three agro-ecological zones and two seasons.	137
2.23	Spearman rank correlation coefficients (r) of trend (pest abundance versus agricultural practices) in dry and wet seasons of three agro-ecological zones and their statistical significance.	139
2.24	Multiple linear regression analysis between agricultural factors and pest populations on rice in three agro-ecological zones and two seasons.	140
2.25	Spearman rank correlation coefficients (r) of trend (parasitoid abundance versus agricultural factors) in dry and wet seasons of three agro-ecological zones and their statistical significance. The bold digits represent significant results.	141
2.26	Multiple linear regression analysis between agricultural factors and pest populations on rice in three agro-ecological zones and two seasons.	141
2.27	Spearman rank correlation values (r) and level of significance for different vegetation types on pest and parasitoid population.	142
2.28	The predictive accuracy of the maximum entropy model was assessed using AUC values in conjunction with the number of presence records for the major rice pests.	149
2.29	Percent contribution of environmental variables in the potential distribution of rice pests.	150
2.30	Relative density and frequency of rice pests in high hill 2017. The bold digits represent significant results.	173
2.31	Relative density and frequency of rice pests in high hill 2018. The bold digits represent significant results.	174

2.32	Relative density and frequency of rice pests in high hill 2019. The bold digits represent significant results.	175
2.33	Relative density and frequency of rice pests in foothill 2017. The bold digits represent significant results.	176
2.34	Relative density and frequency of rice pests in foothill 2018. The bold digits represent significant results.	177
2.35	Relative density and frequency of rice pests in foothill 2019. The bold digits represent significant results.	178
2.36	Relative density and frequency of rice pests in midland laterite 2017. The bold digits represent significant results.	179
2.37	Relative density and frequency of rice pests in midland laterite 2018. The bold digits represent significant results.	180
2.38	Relative density and frequency of rice pests in midland laterite 2019. The bold digits represent significant results.	181
2.39	Relative density and frequency of parasitoids in the high hill rice fields (2017). The bold digits represent significant results.	182 – 183
2.40	Relative density and frequency of parasitoids in the high hill rice fields (2018). The bold digits represent significant results.	184 - 186
2.41	Relative density and frequency of parasitoids in the high hill rice fields (2019). The bold digits represent significant results.	186 – 188
2.42	Relative density and frequency of parasitoids in the foothill rice fields (2017). The bold digits represent significant results.	188 - 190
2.43	Relative density and frequency of parasitoids in the foothill rice fields (2018). The bold digits represent significant results.	190 – 192
2.44	Relative density and frequency of parasitoids in the foothill rice fields (2019). The bold digits represent significant results.	192 - 194
2.45	Relative density and frequency of parasitoids in the midland laterite rice fields (2017). The bold digits represent significant results.	194 – 196
2.46	Relative density and frequency of parasitoids in the midland laterite rice fields (2018).	196 – 198
2.47	Relative density and frequency of parasitoids in the midland laterite rice fields (2019). The bold digits represent significant results.	198 - 199
3.1	Equations to calculate Pest Index (PI) of pest species in traditional rice varieties of Wayanad.	248
3.2	Scoring criteria utilized to assess farmers' understanding of insect pests.	252
3.3	Questionnaire structure employed to evaluate agro-ecological knowledge and pest management practices among farmer communities in North Kerala.	252 – 253

3.4	Existing cultural and mechanical insect pest management practices in North Kerala rice fields.	259 - 260
3.5	Plant and Animal products used to prepare the pesticide formulations to control rice insect pests in North Kerala.	261 – 262
3.6	Existing cultural and mechanical management practices of non-insect pests in North Kerala rice fields.	263
3.7	Rice pest management belief/ceremony of tribal farmers in the high hill region of North Kerala.	264
3.8	Comparison of pest resistance of both the traditional and high yield varieties based on the secondary information and the field observation.	265 – 266
3.9	Ranking of pest resistance of traditional rice varieties based on pest index.	267 – 268
3.10	Pearson correlation matrix of trend (rice morphological features versus yellow stem borer infestation) in the high hill region of North Kerala.	269
3.11	Loading scores of the principal component analysis (PCA) of the rice plant morphological characters in the traditional and high-yield rice varieties.	272
3.12	t-test for comparing yellow stem borer clutch size, area of egg mass, and the number of white ear heads in a mixed plot of Uma (high yield) and Gandhakasala (traditional) rice varieties.	273
3.13	t-test for comparing yellow stem borer clutch size, area of egg mass, and the number of white ear heads in the Uma rice variety in the presence or absence of Gandhakasala.	273
3.14	t-test for comparing yellow stem borer clutch size, area of egg mass, and the number of white ear heads in Gandhakasala rice variety in the presence or absence of Uma.	273
3.15	Socio-economic characteristics of the respondents in three agro-ecological zones of North Kerala.	276 – 277
3.16	Percentage of farmers citing various rice pests in three agro-ecological zones, viz., high hill (n=150), foothill (n=85), and midland laterites (n=105) of North Kerala during 2017–2019.	278
3.17	Farmers' understanding and perceptions of rice insect pests.	281
3.18	Farmer’s recognition of rice pests based on actual specimen or damage.	282
3.19	Perceived incidence of rice insect pests in three agro-ecological zones of North Kerala; percent respondents; n=340).	282
3.20	Farmers’ knowledge and perceptions of natural enemies of rice pests (N=340).	283

3.21	Perceived incidence of natural enemies of rice pests in three agro-ecological zones of North Kerala; percent respondents; n=340).	284
3.22	Correlation Analysis: Spearman rank correlation values (r) and significance levels for relationships between farmer knowledge of rice pests, natural enemies, perception of damage, and socio-economic characteristics. The bold digits represent significant results.	284
3.23	Rice pest management practices used by farmers (N=340).	285
3.24	Farmers' pest management practices using chemical pesticides (N=265).	286
3.25	Common chemical insecticides used by rice farmers in the three agro-ecological zones of North Kerala (N=265).	286
3.26	Information sources of the rate of pesticide application for the management of rice pests in three agro-ecological zone communities in the North Kerala.	287
3.27	Relationship between farmers' pest management practices, natural enemy awareness, pesticide alternatives, and conservation methods with primary information sources for rice pest management in North Kerala smallholder farmer communities (N=340).	289
3.28	Sources of information utilized by farmers to learn about alternative pest management techniques to chemical pesticides.	290
3.29	Information sources for the chemical pesticide alternative for managing rice pests in three agro-ecological zones in North Kerala.	290
3.30	Overview of pest management practices, natural enemy awareness, pesticide alternatives, and natural enemy conservation methods across farmer categories.	291
3.31	Spearman correlation matrix showing the relationship between farmers socio-economic characters with the knowledge of pests, knowledge of natural enemies and perception of pest damage.	293
3.32	Akaike's Information Criterion (AIC) model selection was conducted using logistic regression models to analyze the perception of rice pest damage in North Kerala rice ecosystems.	294
3.33	Collinearity Statistics to avoid multicollinearity.	295
3.34	Generalized linear model results for factors that influenced the perception of rice plant damage, North Kerala, India.	295

3.35	Analysis of insect pest tolerance level in various farmer communities (HH-high hill, FH-foothill, and ML-midland laterite) of North Kerala.	299
3.36	Extension workers recognition of rice pests based on actual specimen or damage.	311
3.37	Extension worker knowledge on natural enemies of rice pests.	312
3.38	Percentage of response to extension worker knowledge of chemical pesticide alternatives.	313

LIST OF FIGURES

Figure No.	*Title*	*Page No.*
0.1	Trans-disciplinary study carried out. The domains of Entomology (1), Ecology (2), social science and policy research (3) were addressed.	5
1.1	Count of parasitoid species by Family collected from the rice fields of North Kerala.	39
1.2	Trophic interactions between herbivores and egg parasitoids in the rice ecosystem of North Kerala.	47
1.3	Trophic interactions between herbivores and larval parasitoids in the rice ecosystem of North Kerala.	50
1.4	Trophic interactions between herbivores and parasitoids in the rice ecosystem of North Kerala.	52
1.5	Trophic interactions between primary parasitoids and hyperparasitoids in the rice ecosystem of North Kerala.	54
1.6	Biology of major rice insect pests in North Kerala	55
1.7	Major Parasitoids in the rice fields of North Kerala	56
1.8	Anti parasitoid defense strategy of herbivores in rice ecosystem. Morphological features such as larval body color, hair length, and larval exposure (based on the nature of larval shelters) summarize its effect on the parasitization rate in the rice ecosystem.	58
1.9	The relation between larval exposure and larval parasitism in rice pests.	59
1.10	The two aspects of the study carried out	60
2.1	Measuring of cultural data sets: a) water depth, and b) plant spacing	90
2.2	Participatory mapping campaign, a-d.	92
2.3	Agro-ecological zone wise distribution of rice pests: HH-high hill, FH-foothill, and ML-midland laterite region.	97
2.4	Agro-ecological zone wise distribution of parasitoids: HH-high hill, FH-foothill, and ML-midland laterite region.	98
2.5	Species accumulation curve for handpicking (a) and sweep netting (b) to collect pests in the dry season of the three agro-ecological zones: HH-high hill, FH-foothill, and ML-midland laterite regions.	99
2.6	Species accumulation curve for handpicking (a) and sweep netting (b) to collect pests in the wet season of the three agro-ecological	100

	zones: HH-high hill, FH-foothill, and ML-midland laterite regions.	
2.7	Species accumulation curve of sweep netting to collect parasitoids in the dry (a) and wet (b) seasons of the three agro-ecological zones of North Kerala: HH-high hill, FH-foothill, and ML-midland laterite regions.	101
2.8	The rank abundance plot illustrates the relative abundance of pest species concerning their rank in the high hill region during both the dry (a) and wet seasons (b).	102
2.9	The rank abundance plot illustrates the relative abundance of pest species concerning their rank in the foothill region during both the dry (a) and wet seasons (b).	103
2.10	The rank abundance plot illustrates the relative abundance of pest species concerning their rank in the midland laterite region during both the dry (a) and wet seasons.	104
2.11	The rank abundance plot illustrates the relative abundance of parasitoid species concerning their rank in the high hill region during both the dry (a) and wet seasons (b).	108
2.12	The rank abundance plot illustrates the relative abundance of parasitoid species concerning their rank in the foothill region during both the dry (a) and wet seasons (b).	109
2.13	The rank abundance plot illustrates the relative abundance of parasitoid species concerning their rank in the midland laterite region during both the dry (a) and wet seasons (b).	110
2.14	Quantitative food web showing the parasitoid and pest community composition in the high hill region: a) dry season, and b) wet season.	113
2.15	Quantitative food web showing the parasitoid and pest community composition in the foothill region: a) dry season, and b) wet season.	114
2.16	Quantitative food web showing the parasitoid and pest community compositionin the midland laterite region: a) dry season, and b) wet season.	115
2.17	Violin plots of dry and wet seasonal variation of pest populations. Box plots overlaid represent the quantile range.	116
2.18	Violin plots of dry and wet seasonal variation of parasitoid populations. Boxplots overlaid represent the quantile range.	117
2.19	Comparison of dry (D) and wet (W) seasonal variation of pest populations in the three agro-ecological zones: HH-high hill, FH-foothill, and ML-midland laterite region.	117
2.20	Comparison of dry (D) and wet (W) seasonal variation of	118

	parasitoid populations in the three agro-ecological zones: HH-high hill, FH-foothill, and ML-midland laterite region.	
2.21	Diversity index estimates for pests in the dry (D) and wet (W) seasons of the three agro-ecological zones: HH-high hill, FH-foothill, ML-midland laterite regions.	120
2.22	Diversity index estimates for parasitoid in the dry (D) and wet (W) seasons of the three agro-ecological zones: HH-high hill, FH-foothill, ML-midland laterite regions.	121
2.23	Diversity index estimates for pests in the Booting (B) and Ripening (R) crop growth stages of the high hill region.	124
2.24	Diversity index estimates for pests in the Booting (B) and Ripening (R) crop growth stages of the foothill region.	125
2.25	Diversity index estimates for pests in the Booting (B) and Ripening (R) crop growth stages of the midland laterite region.	125
2.26	Violin plots of variation of pest populations with respect to crop ages in dry and wet season in three agro-ecological zones, (a) high hill, (b) foothill, and (c) midland laterite regions.	126
2.27	Violin plots of variation of pest populations with respect to farming practices (PT-Pesticide Treated, and PUT-Pesticide Untreated) in the dry and wet seasons in three agro-ecological zones, (a) high hill, (b) foothill, and (c) midland laterite regions.	128
2.28	NMDS result of pest species composition from three agro-ecological zones; high hill (1), foothill (2), and midland laterite (3) in the dry (a) and wet (b) seasons.	131
2.29	NMDS result of egg parasitoid composition from three agro-ecological zones; high hill (1), foothill (2), and midland laterite (3) in the dry (a) and wet (b) seasons.	131
2.30	NMDS result of larval parasitoid composition from three agro-ecological zones; high hill (1), foothill (2), and midland laterite (3) in the dry (a) and wet (b) seasons.	132
2.31	NMDS result of hyperparasitoid composition from three agro-ecological zones; high hill (1), foothill (2), and midland laterite (3) in the dry (a) and wet (b) seasons.	133
2.32	Normalized difference vegetation index (NDVI) images of sampling sites in the high hill region generated from Landsat 8 cloud-free composite images.	143
2.33	Normalized difference vegetation index (NDVI) images of sampling sites in the foothill region generated from Landsat 8 cloud-free composite images.	144
2.34	Normalized difference vegetation index (NDVI) images of sampling sites in the midland laterite region generated from	145

	Landsat 8 cloud-free composite images.	
2.35	The relationship between patch richness of sampling sites and the abundance of pest (a) and parasitoid (b) population in the rice ecosystem of North Kerala.	146
2.36	Percentage composition of land use types surrounding the sampling sites in the high hill region.	147
2.37	Percentage composition of land use types surrounding the sampling sites in the foothill region.	147
2.38	Percentage composition of land use types surrounding the sampling sites in the midland laterite region.	148
2.39	Present and potential distribution of *Ampittia dioscorides.*	151
2.40	Present and potential distribution of *Cnaphalocrocis medinalis.*	151
2.41	Present and potential distribution of *Pelopidas agna.*	151
2.42	Present and potential distribution of *Parnara bada.*	152
2.43	Present and potential distribution of *Parapoynx stagnalis.*	152
2.44	The three aspects of the study carried out.	153
3.1	Paddy landscape of Wayanad, North Kerala (Adapted from Gopi et al., 2004).	244
3.2	Farmer survey; a-farm walk, b-focus group discussion, and c-interviewing farmers.	246
3.3	Master plan for data collection.	251
3.4	Traditional pest management calendar for traditional rice varieties in the high hill region.	264
3.5	The relationship between the number of white ear heads (a) and average clutch size (b) with the culm length of traditional (Chomala, Gandhakasala, and Jeerakasala) and high-yield rice varieties (Aathira, Aiswarya, Kanchana, and Uma).	269
3.6	The relationship between the number of white ear heads (a) and average clutch size (b) with the culm width of traditional (Chomala, Gandhakasala, and Jeerakasala) and high-yield rice varieties (Aathira, Aiswarya, Kanchana, and Uma).	270
3.7	The relationship between the number of white ear heads (a) and average clutch size (b) with the cultivar duration of traditional (Chomala, Gandhakasala, and Jeerakasala) and high-yield rice varieties (Aathira, Aiswarya, Kanchana, and Uma).	270
3.8	The relationship between the number of white ear heads (a) and average clutch size (b) with the average tiller number per hill of traditional (Chomala, Gandhakasala, and Jeerakasala) and high-	270

	yield rice varieties (Aathira, Aiswarya, Kanchana, and Uma).	
3.9	The relationship between the number of white ear heads (a) and average clutch size (b) with the panicle length of traditional (Chomala, Gandhakasala, and Jeerakasala) and high-yield rice varieties (Aathira, Aiswarya, Kanchana, and Uma).	271
3.10	Principal component analysis (PCA) biplot of the rice plant morphological characters that measure the susceptibility of yellow stem borer infestation in the traditional (Chomala, Gandhakasala, and Jeerakasala) and high-yield rice varieties (Aathira, Aiswarya, Kanchana, and Uma).	271
3.11	Comparison of clutch size of *Scirpophaga incertulas* in the high yield variety and traditional variety: (a) in the Uma rice variety (high yield variety) in the presence or absence of Gandhakasala, and (b) in the Gandhakasala rice variety as a mixed crop and a mono-crop.	274
3.12	Comparison of number of white ear heads formed in the high yield variety and traditional yield variety: (a) in the Uma rice variety (high yield variety) in the presence or absence of Gandhakasala, and (b) in the Gandhakasala rice variety in the presence Uma variety and a mono-crop.	274
3.13	Farmers' awareness of insect rice pests across three agro-ecological zones in North Kerala.	279
3.14	Farmers' awareness of natural enemies across three agro-ecological zones in North Kerala.	280
3.15	Socio-economic web that influence pest management decision in traditional rice farmers.	296
3.16	Socio-economic web that influence pest management decision in high-yield rice farmers.	297
3.17	Tolerance scale of major rice pests causing crop loss in various farmer communities in North Kerala (tribal farmers, farmers in the high hill, foothill, and midland laterite regions).	298
3.18	Forest plot showing the effect of different socio-economic variables on high tolerance level of high hill farmer community.	300
3.19	Forest plot showing the effect of different socio-economic variables on low tolerance level of high hill farmer community.	300
3.20	Forest plot showing the effect of different socio-economic variables on low tolerance level of Foothill farmer community.	301
3.21	Forest plot showing the effect of different socio-economic variables on low tolerance level of Midland laterite farmer community.	302
3.22	Factors affecting farmer choice of rice pest management in North Kerala.	303

3.23	Factors affecting pest abundance in the rice fields of North Kerala	304
3.24	Farmer's knowledge and source of knowledge on rice pest management in three agro-ecological zones (high hill, foothill, and midland laterite zones) of North Kerala.	307
3.25	Farmer participation gap in the pest management training in North Kerala.	309
3.26	Scientific validation gaps in traditional rice varieties and traditional rice pest management practices and the types of modern rice pest management practices and the features of high-yield varieties.	310
3.27	Challenges to effective extension services reported by the pest management experts of local agricultural institutions and research stations.	314
3.28	The gap of government policies on pest management in India.	315
3.29	The three aspects of the study carried out comprised (1) traditional rice pest management (2), factors influencing rice pest management (3), and the gaps in rice pest management domains in North Kerala.	316
3.30	Recommended solutions for the improvement of farmer knowledge of rice pest management in North Kerala.	337
3.31	Recommended solutions for the improvement of farmer participation of rice pest management training programs in North Kerala.	339
3.32	Recommended solutions for the effective extension services in rice pest management of North Kerala.	343

LIST OF MAPS

Map No.	*Title*	*Page No.*
1	Rice pest- parasitoid collection sites in North Kerala.	25
2	The map of experimental plots in four districts of North Kerala, South India (Classification of agro-ecological zones and map source: KSHIS, 2019)	27
3	Panchayats selected for the sampling in traditional rice varieties of Wayanad.	245

GENERAL INTRODUCTION



GENERAL INTRODUCTION

Oryza sativa L., a prominent member of the grass family Poaceae, stands as the predominant rice species worldwide. Its historical cultivation traces back to ten thousand years ago in the river valleys of Southern and Southeast Asia. The Indus Valley civilization, circa 3000–1500 BC, played a pivotal role in the domestication of rice in India. The journey of rice evolution saw the documentation of wild varieties such as *Oryza nivara* and *Oryza rufipogon* by 9000 BC, with *Oryza japonica* later introduced from China. This ancient grain underwent hybridization with *Oryza indica* around 4,000 years ago, solidifying its position as the primary food source and catalyzing human civilization and community growth (FAO, 2004).

The socio-cultural fabric of rural India intertwines deeply with paddy cultivation, with festivals like Kerala's Vishu, Assam's Bihu, and Tamil Nadu's Thai Pongal Karnataka's Makara Sankranthi, and West Bengal's Nabanna celebrations revolving around the paddy harvest (TOI, 2020). Rice's significance transcends cultural boundaries, serving as a vital component of global food safety and socio-economic policy. With almost half of the world's population relying on it as a staple diet (Skamnioti and Gurr, 2009; Hosseyni-Moghaddam and Soltani, 2013), Asia leads in rice consumption (Hosseyni-Moghaddam and Soltani, 2013; Muthayya et al., 2014), with India and China alone contributing 50 percent to both production and consumption (Muthayya et al., 2014). However, meeting the growing demand for rice necessitates an increase in production, a challenge compounded by various abiotic and biotic constraints faced by farmers (Dale, 1994).

Insect pests emerge as formidable constraints in Indian rainfed rice production (Singh et al., 2012), accounting for nearly 30 percent of the yield gap between potential and actual farm yield (Widawsky and O' Toole, 1996). The imperative to bridge this gap underscores the need for significant policy support to enhance long-term rice production. Thus, there is a call to shift policy focus towards various aspects, including production, irrigation infrastructure management, and integrated pest management, among others (Siddiq, 2000).

Rice fields, functioning as artificial wetlands, harbor a rich biodiversity that supports various wildlife habitats (FAO, 2004). This socio-ecological production landscape plays a crucial role in addressing diverse challenges such as climate change adaptation, flood management, and biodiversity conservation.

Over the centuries, countless rice varieties have been developed to meet environmental and cultural needs, although many traditional varieties remain undocumented and underutilized (Khush, 1997; Kumar et al., 2010). Several decades ago, India boasted an impressive array of 50,000 to 60,000 rice varieties, each cultivated for distinct socio-religious rituals, ceremonial occasions, dietary preferences, medicinal applications, and entrenched cultural beliefs. However, modern records reveal a stark decline, with fewer than a thousand varieties remaining accessible today. Primarily preserved through the concerted initiatives of individuals and non-governmental organizations (NGOs), these surviving varieties stand as a testament to ongoing efforts in conservation. There have been few efforts to record information about the traditional varieties, and even though some commendable attempts have been made in their ethno-cultural aspects, much is left to be studied and documented (Sebastian and Azeez, 2014).

The growth of rice plants unfolds through distinct vegetative, reproductive, and ripening stages, during which they are targeted by a plethora of pests, pathogens, and weeds (Reissig et al., 1986). Intense rice cultivation would contribute to a higher species richness of pests and natural enemies (Barrion and Litsinger, 1994). In India, insect pests like gall midge, white-backed planthopper, yellow stemborer, rice leaf folder, and brown planthopper are of national significance. Several insects previously considered minor pests have recently become dominant pests, despite a substantial reduction in the occurrence of a few others (Pathak and Dhaliwal, 1981). The Green Revolution of the 1960s brought about significant advancements in rice cultivation, yet overreliance on insecticides has led to pest resurgence and ecological imbalances (Norton et al., 2010). The management of rice pests has mainly depended on insecticides due to heavy insect pressure (Magallona, 1989). The yield of rice improved; however, overuse and

misuse of certain insecticides have resulted in growing pest resurgence problems, pesticide resistance, and the emergence of new pests, along with the destruction of beneficial insects (Pathak and Khan, 1994; Poolprasert and Jongjitvimol, 2014).

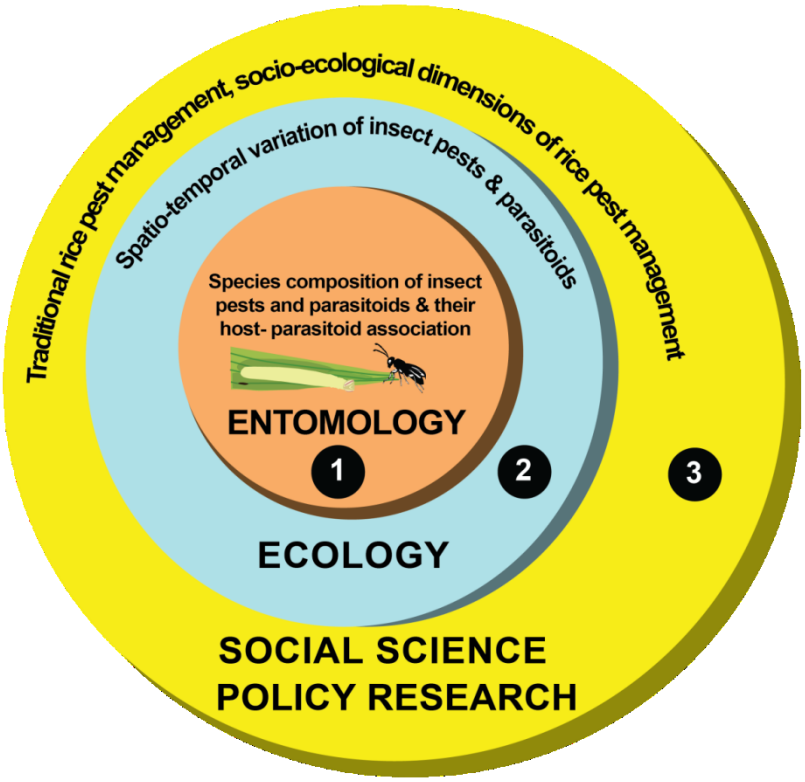
Thus, there arises a need for integrated pest management strategies encompassing mechanical, cultural, and biological controls. Cultural management practices reduce pest establishment, reproduction, dispersal, and survival (GWA, 2020). Biological control (biocontrol) is a safe, sustainable pest management technology that takes advantage of natural enemies present in agro-ecosystems (Wang et al., 2019). Natural enemies are the biotic component that manages the population of pest insects in the agro-ecosystem; comprised of predators and parasitoids that feed on various life stages of herbivorous insects (Jervis et al., 1996). They account for approximately 50–90 percent of the pest control in crop fields (Pimentel, 2005). *Trichogramma* wasps are successful biological control agents of lepidopteran pests (Landis et al., 2000; Kaur et al., 2008; Sherif et al., 2008; Ko et al., 2014; Lou et al., 2014). In Kerala, they were used to control leaf roller, stem borer, skippers, and cutworms in field trials.

Studies on rice pest management and the rice ecosystem mainly revolved around the pest-parasitoid diversity, taxonomy studies, socio-economic aspects of agriculture, or integrated pest management. Studies done so far on rice fields of Kerala were focussed on diversity of rice insects and natural enemies (e.g., Beevi et al., 2000; Premila, 2003; Sudhikumar, 2005; Ranjith et al., 2015b; Prabhakaran and Tharemmal, 2019), the effect of pesticide use (Devi, 2007), the taxonomy of rice insect fauna (e.g., Narendran and Fousi, 2002; Sheela et al., 2005; Sudhikumar, 2007), pest status (e.g., Raveendran et al., 1978; Ambikadevi et al., 1998), the biology of rice insects (Pillai and Nair, 1979), the effect of Integrated Pest Management (IPM) on rice fields (e.g., Latif and Wahab, 2007; Lyla et al., 2010; Karthikeyan and Jacob, 2010), rice varietal studies (e.g., Kumar et al., 2010; Beena et al., 2013; Vanaja, 2013; Bindu et al., 2014; Vanaja et al., 2015; Gopi and Manjula, 2018), the effect of climatic change in rice ecosystem (Saseendran et al., 2000; Sabale et al., 2010). Studies on rice pest management and the rice ecosystem

have predominantly focused on ecological or social aspects, necessitating an integration of both dimensions. Paddy fields, as human-modified ecosystems, are influenced by a myriad of socio-ecological factors, emphasizing the importance of transdisciplinary approaches in addressing sustainability challenges (Bianchi et al., 2006; Bommarco et al., 2013; Grab et al., 2019; Perez-Alvarez et al., 2018). Rice production depends not entirely on environmental factors but also on the farmer's socio-economic status, which influences their farming capacity (Wijnhoud et al., 2003).

In recent years, trans-disciplinary methods in agro-ecosystems have gained widespread appreciation worldwide, and limited attempts have been made to test their scope in Indian agriculture research. Wetland rice cultivation is widely appreciated as a unique socio-ecological production landscape with the potential to address issues of climate change adaptation and mitigation, flood management, food security, and biodiversity conservation (e.g., Gu and Subramanian, 2012; Ichikawa, 2013; Santiago and Buot, 2018). Unlike other ecosystems, factors of production in the rice ecosystem were derivatives of anthropocentric interactions. This research designed a trans-disciplinary methodology for rice pest management by considering pest-parasitoid associations as the central theme. Domains of entomology, ecology, socio-economic aspects, and policy research were addressed in subsequent layers (Fig. 0.1). Trans-disciplinary research focuses on identifying implementable solutions to overcome sustainability issues and encouraging social learning. So there should be a prerequisite for well-managed collaboration among scholars, farmers, multidisciplinary scientists, and sectorial stakeholders. Here we used a trans-disciplinary approach to find the gaps in rice pest management domains and recommend suggestions to solve rice farmer problems in North Kerala.

Fig. 0.1 Trans-disciplinary study carried out. The domains of Entomology (1), Ecology (2), social science and policy research (3) were addressed.



So, the thesis addresses the following main research questions:

1. To investigate the species composition of insect pests and parasitoids, and their associations in the rice agro-ecosystem.

2. To examine the spatio-temporal variation of pests and parasitoids in the rice ecosystem of North Kerala.

3. To study the insect pests associated with traditional rice varieties and the socio-ecological dimensions of rice pest management in North Kerala.

CHAPTER 1

SPECIES COMPOSITION OF INSECT PESTS AND PARASITOIDS, AND THEIR ASSOCIATIONS IN THE RICE AGRO-ECOSYSTEM



Introduction

Rice is a staple food in many nations and one of the most extensively consumed cereals globally (Bambaradeniya and Amerasinghe, 2003). A wide variety of insect pests infest rice. Many pest species, particularly lepidopterans, are prone to increase their abundance when favorable conditions are present, and they are significant risks to agriculture and the forest ecosystem (Elkinton and Liebhold, 1990; Devetak et al., 2015). Controlling rice insect pests is a significant issue in rice fields worldwide (Hassan, 1985). As chemical methods provide nearly instantaneous results, pesticides are the most popular method of managing rice insect pests. However, issues like pesticide resistance, residual contamination, and pest resurgence have arisen over the past few decades (e.g., Gill and Garg, 2014).

Biological control may overcome this problem by utilizing natural enemies such as parasitoids and predators to combat insect pests (Ooi and Shepard, 1994). Parasitoids are arthropods that develop on a single host and kill their hosts. Parasitic life is only found in the juvenile stages of rice insect pests. Adults are generally free-living and feed on nectar, honeydew, or the fluids of their hosts. The orders Hymenoptera and Diptera include the majority of parasitoids (Eggleton and Gaston, 1990; Eggleton and Belshaw, 1993; Fei et al., 2023). Many parasitoids can attack several host species, while others may only focus on one. Consequently, their population dynamics are closely tied to the availability of their hosts. This interdependence highlights the crucial role they play in pest control strategies (e.g., Hassell, 1980; Hassell and May, 1986; Barbosa and Benrey, 1998; Gagic et al., 2016). Several attempts have been made to integrate pest management (IPM) to merge non-chemical and chemical control methods. Natural enemies and insecticides were used together in one attempt (Van den Bosch et al., 1982). The benefits of biological approaches include selectively impaired targets, fewer side effects, and a lower cost than traditional chemical pest control. Preserving the natural enemy complex in the rice environment is one of the most effective biological management strategies. The significance of these populations of naturally occurring species remains little understood, although this strategy is much older than

those concerning imported species. It is essential to accurately identify natural enemies and recognize their needs when managing rice insect pests, through integrated pest management (IPM) (Rao, 2019). Thorough knowledge of the pest's biology, its natural enemies and identifying different life stages of relevant insects in the field is also needed for effective biological control. Field exploration of natural enemies is commonly used to track their activities, assess their effects on insect pests, and forecast other control strategies that may be required (Kiritani, 1979; Bambaradeniya et al., 2004). Our study focused on the association between hymenopteran and dipteran parasitoids and their hosts to fill in the dearth of information on parasitoids of rice pests in Kerala. Yet, to fully grasp the implications of these relationships for community organization and functioning, it is imperative to employ techniques that integrate and analyze the data effectively. Utilizing the trophic web, we can systematically map out all pertinent interconnections within a specific ecological system, shedding light on its intricate dynamics and functioning (Hall and Raffaelli, 1993). Ecologists and entomologists have closely examined the relationship between pest species and their parasitoids. Few studies, however, have focused on the tri-trophic levels of a food web, such as plants, herbivore insects, and parasitoids in specific agro-ecosystems (e.g., Shameer et al., 2018). As a result, studies on tri-trophic interactions between harmful insects and their natural enemies can provide a valuable foundation for developing an effective biological control method (e.g., Del-Claro, 2004). Furthermore, these findings may aid in improving the efficacy of biological control agents to suppress herbivore populations.

The presence of natural adversaries significantly undermines the fitness and survival of herbivorous insects across the board, profoundly influencing the evolutionary trajectory of Lepidoptera species. This phenomenon has been extensively documented in prior studies (Strong et al., 1984; Bernays and Graham, 1988; Stamp and Casey, 1993; Schoonhoven et al., 1998), underscoring its pivotal role in shaping the dynamics of insect populations. Caterpillars defend themselves against natural enemies by employing various strategies before, during, and after predator confrontations (Greeney et al., 2012). This defense could impact the rate of

parasitization in various caterpillar species. Larvae can defend themselves against predators using chemical, behavioral, or morphological strategies. Specialist caterpillars require chemical defenses, which have been found to work against various predators (Dyer, 1995). Many caterpillars absorb chemicals from their host plants and use aposematic colors to signal to predators that they are distasteful (Bowers, 1990; Dyer and Bowers, 1996; Grant, 2007; Lindstedt et al., 2008). To discourage predators, some caterpillars have defense glands, such as osmeteria, or employ fecal shields, foul scents, stomach regurgitation, or foam barriers in addition to sequestration (Damman, 1986; DeVries, 1991; Grant, 2006, 2007). Escape holes, head or tail wagging, suspension on silken threads, aggregation, frass ejection, frass chains, and the building of leaf shelters are all examples of behavioral defenses (Hunter, 2000; Machado and Freitas, 2001; Aiello and Solis, 2003; Reader and Hochuli, 2003; Weiss, 2003; Castellanos and Barbosa, 2006; Lill and Marquis, 2007).

Morphological defenses, such as cryptic color patterns, allow larvae to blend in with their surroundings, potentially reducing predator detection (Greene, 1989; Stamp and Wilkens, 1993). Other larvae imitate inedible objects found in their environment, such as bird droppings or even higher-order predators (Lederhouse, 1990; Wagner, 2005). In addition to scoli (bristle-bearing outgrowths on the integument) and sclerotized spines or hairs (secondary setae), morphologically defended larvae may have sticky integumental coating (Whelan et al., 1989; Dyer and Floyd, 1993; Epstein et al., 1994; Deml and Dettner, 2003; Lindstedt et al., 2008).

These protections allegedly keep predators at bay by disguising the larva, deterring predators, or directly safeguarding the larva after an attack has started. Little is known regarding the effects of herbivore defensive methods on predators or parasitoids at the field scale, especially in the case of rice pests and associated parasitoids. By considering all the above, there is a need for detailed studies on species composition, trophic level interaction, the nature of parasitization, and its avoidance strategies in each region. Such studies will give a holistic picture of the

pest-parasitoid relationship that will be crucial for developing pest management strategies. So, in this chapter, we aim to address the following questions:

1. How do pest and parasitoid composition vary with crop seasons in different agro-ecological zones?
2. What are the host-parasitoid associations existing in the given spatio-temporal scales?
3. What are the parasitoid avoidance strategies adopted by rice pests?

Review of Literature

Species composition of insect pests and parasitoids and the efficacy of parasitoids: *A world scenario*

This is one of the widely studied areas in parasitoid research in many parts of the globe, and researchers are still actively exploring this domain. Here we summarize the important studies carried out in major parasitoid families.

Bethylidae (Aculeata: Chrysidoidea)

Bethylid wasps, the most prevalent ectoparasitoids, parasitize Coleoptera and Lepidoptera larvae (Evans, 1964). Females of the Bethylidae search for hosts in hidden habitats and paralyze them by stinging. The number of eggs deposited on each host is adjusted according to the size of the host. *Goniozus indicus* (Ashmead), a gregarious ectoparasitoid, lays three eggs per day and 35 eggs during its lifetime (Kamal and Dyck, 1992). *Goniozus* sp. was shown to be parasitic on *C. medinalis* (Manisegaran et al., 1997). According to Gord et al. (1993), *Goniozus hanoiensis* parasitizes *C. medinalis* at a 1–20% rate.

Braconidae (Apocrita: Ichneumonoidea)

Braconids preferred to parasitise insect larvae and pupae (Matthews, 1974; van Achterberg, 1984). Rao (1963) claims that *Tropobracon schoenobii* (Viereck) parasitized 55.5% of *Tryporyza incertulas*. Kennard (1965) discovered 3.7–4.8 percent parasitism of *Ancyloxypha numitor* (Fabricius) by *Agathi*s species in

Louisiana. According to Hidaka (1965), *Microgaster russata*'s (Haliday) larval and pupal durations in *Chilo simplex* were 40–50 and 10.2 days, respectively. Ferino (1968) identified a parasitoid *Opius* sp from *Hydrellia philippina,* which parasitize 14% to 71.4% of the hosts.

According to Rao et al. (1970), *Rhysipolis hesperides* (Rohwer) parasitizes *P. mathias* at the rate of 45 percent. Kajita (1973) reported that the larval and pupal stages of *Apanteles chilonis* (Matsumura) take two months to mature, pupa two weeks, and have three generations each year in *Chilo suppressalis*. Hegazi et al. (1974) discovered that the egg and larval periods of *Chelonus inanitus* (Linnaeus) were 13.6 days, the pupal period was 11.4 days, and the developmental period was 25 days on *Spodoptera littoralis* (Boisduvel). According to Yasumatsu (1975), *A. chilonis* (Matsumura) parasitized *Chilo zonellus* (Swinhoe) at the rate of 50%. According to Zhang (1986), the total life cycle of *Cotesia ruficrus* (Haliday) was 13.2–30.8 days; egg 2.7 days; 5 larval instars; adult lifespan-female 1.5–4.3 days; male 1.2–4 days; 12 generations per year in the lab; four months overwintering as a pupa in the host *Mythimna separata* in the field (Walker). According to Pantoja and Fuxa (1992), *Chelonus insularis* (Cresson) parasitized *Spodoptera frugiperda* (Smith) at a rate of 5.5 percent. *Bracon antennatus* (Granger) and *Bracon testaceorufatus* (Granger) were gregarious larval parasitoid on *Scirpophaga* sp., and the latter was an ectoparasitoid (6–14 individuals per host). The developmental stage of *Chilo infuscatellus* lasted 12 days, and larval diapause was observed. *Rhaconotus carinatus* (Polaszek) is a gregarious larval ectoparasitoid with a 20-day developmental phase on *Chilo* sp. (6–27 individuals per host) (Polaszek et al., 1994). In Mexico, *Alabagrus stigma* (Brulle) parasitizes the same host at a rate of 21.2% (Pfannenstiel and Browing, 1995).

Ceraphronidae (Apocrita: Ceraphronoidea)

Ceraphronidae is poorly understood, but certain members evolve as endoparasites targeting Thysanoptera, Lepidoptera, and Neuroptera (Dessart and Cancemi, 1986). Polaszek et al. (1994) collected and identified two hyperparasitoids belonging to the family Ceraphronidae, *Aphanogmus fijiensis* (Ferriere)

and *Ceraphron* sp., from rice fields. Daniel et al. (2019e) surveyed Ceraphronoidae in rice ecosystems of Tamil Nadu, and they collected *A. fijiensis* (Ferriere) *Ceraphron* sp. and *Conostigmus nigrorufus* (Dessart).

Chalcididae (Apocrita: Chalcidoidea)

Members of the family Chalcididae are the most common parasitoids of Lepidoptera, Diptera, Coleoptera, and other Hymenoptera, with a few hyperparasitoids thrown in for good measure. According to Abraham et al. (1973), *Brachymeria excarinata* (Gahan) parasitized *C. medinalis* at a rate of 7.4 percent. Ambikadevi (1998) recorded *Brachymeria lasus* (Walker) from the rice ecosystem of Kuttanad, Kerala. Kanagarajan and Manickavasagam (2007) and Daniel and Ramaraju (2017) have recorded Chalcididae in various agro-ecosystems in Tamil Nadu's Cauvery delta and have recommended their inclusion in rice lepidopteran pest management programs with *Brachymeria* as the most dominant genera.

Dryinidae (Aculeata: Chrysidoidea)

According to Olmi (1984), dryinids attacked Auchenorrhynchous Homoptera (Cicadelloidea, Fulgoroidea), and certain female dryinids have chelate forelegs, which they utilize to catch their prey. Before oviposition, they temporarily paralyze the nymphal host. *Dicondylus indianus's* (Olmi) adult lifetime was shorter at low densities of its host, *N. lugens* (Currado and Olmi, 1979). According to Manjunath (1979), *Dryinus* sp. parasitizes *N. lugens* at a rate of 7.8%. Chandra (1979) conducted a study in the Philippines on the taxonomy and biology of Dryinidae, which parasitize leafhoppers on rice. Kitamura (1988) estimated that *Haplogonatopus apicalis* Perkins takes 32.4 days in *S. furcifera* and 30.4 days in *Laodelphax striatellus* (Fallen) to develop from egg to pupa. According to Chen (1989), *H. atratus* Esaki and Hashimoto parasitized 48.2 percent of rice delphacids. The developmental period of *Paragonatopus fulgori* (Nakagawa) (=*Pseudogonatopus fulgori*) in rice delphacids is 16 days. According to Chen (1989), *H. apicalis* parasitizes 36.5 percent of delphacids. *Paragonatopus fulgori* takes 25.9 and 26.1 days to develop in *S. furcifera* and *L. striatellus*,

respectively. Zhang and Jin (1992) reported that a female drynid may parasitize up to 16, *C. medinalis* larvae. An updated Oriental Dryinidae revision noted 368 species in seven subfamilies, 20 genera, and seven subfamilies. Xu et al. (2013) have described eight new species belonging to Dryinidae. Mita and Hong (2014) examined the parasitoid complex associated with rice planthoppers in a rice field in Vietnam. As a result, *Gonatopus lucens* (Olmi), *G. nigricans* (R. Perkins), *G. nudus* (R. Perkins), *G. flavifemur* (Esaki & Hashimoto), and *G. yasumatsui* (Olmi) were collected. Biological traits of the Pincer wasp *Gonatopus flavifemur* (Esaki & Hashimoto) associated with different stages of its host, the Brown planthopper, *Nilaparvata lugens* (Stål) was reported by He et al. (2020).

Eulophidae (Apocrita: Chalcidoidea)

Eulophidae consists mainly of primary parasitoids, with a few hyperparasitoids and phytophagous species (Bouček and Askew, 1968). According to Corbett (1933), *Tetrastichus schoenobii* (Ferriere) parasitized 50–70% of its host, *Schoenobius bipunctifer* (Walker). He also discovered that *Pediobius* sp. parasitizes *Pelopidas mathias* (Fabricius) to the extent of 62.5 percent and *C. medinalis* to the rate of 5.6 percent. *Tetrastichus fasciatus* parasitized an unidentified dipteran with 57.4 percent parasitism (Tiwari, 1972). Another species of *Tetrastichus*, *T. schoenobii* larva, required four *S. incertulas* eggs to complete development (Kim et al., 1986). *Tetrastichus schoenobii* parasitizes *Scirpophaga innotata* (Walker) at a rate of 14.7–45% (Mahrub, 1993). Pantoja and Fuxa (1992) reported that *Euplectrus* sp. parasitized 3.6 percent of *Spodoptera frugiperda* (Smith) and *Euplectrus platyphypenae* Walker parasitized 1.2 percent of *S. frugiperda*. According to Manisegaran et al. (1997), *Pediobius bruchicida* parasitized 4% of *C. medinalis*.

Eupelmidae (Apocrita: Chalcidoidea)

The majority of Eupelmidae species are principal endoparasitoids of eggs of Blattaria, Hemiptera, Lepidoptera, Mantodea, Neuroptera, Orthoptera, and Phasmidae (Gibson, 1995). According to Potineni and Agarwal (1984), *Neanastatus*

grallarius (Masi) parasitizes 20-85% of its host *O. oryzae*. Kobayashi et al. (1990) reported that *N. grallarius* parasitized over 68.2% of the *O. oryzae* population.

Eurytomidae (Apocrita: Chalcidoidea)

Eurytomidae is a family of ectoparasitoid insects that are usually solitary but can be found in groups; some are endoparasitic on cecidogenic insects and phytophagous (Bouček and Askew, 1968). *Eurytoma setitibia* (Gahan) is recognized as a hyperparasite of *Platygaster oryzae* (Cameron) (Mathur et al., 1989). As a hyperparasitoid, *Eurytoma manilensis* was reared from *Pelopidas mathias* (Narendran, 1994) and *Borbo cinnara* (Gupta and Kalesh, 2012).

Ichneumonidae (Apocrita: Ichneumonoidea)

Ichneumonids parasitize almost all insect orders except Mecoptera, Siphonaptera, and Strepsiptera; they prefer parasitizing insect larvae and pupae. Adults prefer wet environments with lots of ground cover (Matthews, 1974; van Achterberg, 1984). *Ecthromorpha conopleura* (Fabricius) parasitizes 22% of *Spodoptera mauritia* (Boisduval) (Swezey, 1940). The egg stage for *Itoplectis naranyae* (Ashmead) in *C. suppressalis* (Walker) lasted one day. The *Xanthopimpla stemmator* (Thunberg) parasitized *C. suppressalis* at a rate of 37 percent (Rothschild, 1971). Mohyuddin, (1972) recorded *Dentichasmias busseolae* (Heinrichs) as a pupal parasitoid of *Chilo partellus*. The larvae of *C. medinalis* seemed normal and continued to feed until the day before the parasitoid *Nythobia* sp. larvae pupated (Lingappa, 1972). *Itoplectis naranyae* parasitism was found to be 11 percent in *C. medinalis*, while *Trathala flavoorbitalis* (Cameron) (=*Cremastus biguttulus* Munakata) parasitism was 34-54% in *C. medinalis* according to Kobayashi and Wada (1979). Pati and Mathur (1982) noted that *Temelucha philippinensis* (Ashmead) parasitized 21.7 percent of *C. medinalis*. They also discovered that *Xanthopimpla flavolineata* (Cameron) (=*Xanthopimpla immaculata* (Morley)) parasitizes *C. medinalis* to a rate of 7.5%.

Mymaridae (Apocrita: Chalcidoidea)

Mymaridae appeared early in Apocrita's history (Yoshimoto, 1975), particularly as internal parasitoids of insect eggs (Huber, 1986). Larvae typically exhibit solitary behavior and prefer targeting the eggs of Auchenorrhyncha, which are concealed within plant tissues, beneath bark, and within soil layers. Pupation occurs within the confines of the host eggs, marking a crucial stage in their life cycle (Bellows and Fisher, 1999). Biological control efforts have proven successful with some species (Clausen, 1978). According to Otake (1967), *Alaptus* sp. parasitism on *Laodelphax striatellus* (Fallen) was highest in September and early October, reaching up to 93.1 percent. *Anagrus* spp. parasitize 24.03% of *N. lugens*, as per Israel and Prakasa-Rao (1969). According to Storozheva (1990), each *Oulema oryzae* (Kuwayama) egg produced two to four *Anaphes nipponicus* (Kuwayama) individuals. Although parasitism was modest in the spring, it reached 100% by mid-July. Li and He (1991) reported that *Anagrus nilaparvatae* (Pang & Wang) parasitized *S. furcifera* at 40.3–92.6 percent and 20–60% on *N. lugens*. Zhang (1991) reported that *Anagrus* sp. parasitized 50% of the *S. furcifera* eggs. *Anagrus optabilis* (Perkins) male and female developmental periods was 11 and 12 days in *N. lugens*, respectively (Suzuki et al., 1994).

Platygastridae and Scelionidae (Apocrita: Platygastroidea)

Platygastroidea is the third biggest parasitoid hymenopteran superfamily after Ichneumonoidea and Chalcidoidea, represented by over 6048 species under 264 genera in 2 families worldwide viz., Platygastridae and Scelionidae (Johnson et al., 2018). Scelionids are solitary idiobiont endoparasitoids that only consume the eggs of Coleoptera, Diptera, Lepidoptera, Heteroptera, Neuroptera, Mantodea, and Araneomorph spiders (Rajmohana and Patra, 2019). Descamps (1956) found that *Platygaster diplosisae* (Risbec) parasitized *O. oryzae* at a rate of 20%. Parasitization of *Telenomus gifuensis* (Ashmead) on *Scotinophora lurida* (Burmeister) was over 95 percent (Hidaka, 1958). *Scelio* sp. parasitized 100% of tiny egg pods of rice grasshoppers (Irshad, 1977). *Gryon flavipes* (Ashmead) attacked an average of 20, 10, and 0.6 percent of rice pest *L. oratorius* eggs of 1–2,

3, and 4 days old. *Gryon flavipes* parasitized egg masses of *L. oratorius* on rice more frequently than on weeds (Barrion et al., 1981). *Platygaster foersteri* (Gahan) parasitizes *O. oryzae* at a rate of 68.2 percent (Kobayashi et al., 1990). *Platygaster oryzae* (Cameron) parasitism on *O. oryzae* reaches 40–50% in the tillering stage and 80–95% at the end of the season (Kumar et al., 1995). Pandya et al. (1995) found 35–43% *Telenomus dingus* (Gahan) parasitism on *S. incertulas*, whereas Islam and Karim (1995) reported 64% *Telenomus rowani* (Gahan) parasitism on *T. incertulas*. *Telenomus remus* was reported from *Mythimna unipuncta* (Haworth), *Spodoptera litura* (Joshi and Rao, 1980), *Mythimna loreyi* (Duponchel) (Dass and Parshad, 1984), *Spodoptera mauritia* (Gautam, 1987), *Creatonotus gangis* (Bughio et al., 1994).

Pteromalidae (Apocrita: Chalcidoidea)

The Pteromalidae is a large family of chalcidoids, a biologically complex and taxonomically difficult group. Ectoparasitism is the most frequent type of parasitism and can be solitary or gregarious. Holometabolous larvae and pupae primarily inhabit stems, leaf mines, galls, and analogous environments, serving as their principal hosts. Among these, certain species function as parasitoids during the larval-pupal stage, further delineating the intricate relationships within their ecological niche (Bellows and Fisher, 1999). Parasitism is reported in the 50 to 68 percent range in *Orseolia oryzae* (Pathak et al., 1986). The developmental period of *Trichomalopsis apanteloctena* was 13–15 days, with an F: M ratio of 1.11–1.33:1 until mid-October, when it reversed to 1:1.29–1.42. Males were smaller than females, laying up to four eggs on each *Pelopidas mathias*, their host (Rao and Behera, 1986). According to Ahmed and Khatun (1988), *Anisopteromalus calandrae* (Howard) required 12 days to mature and showed 76 percent parasitism in *Lasioderma serricorne* (Fabricius). According to Fowler et al. (1991), *Panstenon* sp. parasitized *N. lugens* at a rate of 18%.

Tachinidae (Cyclorrhapha: Oestroidea)

Tachinids are obligatory parasitoids, and their larvae develop in various stages of insects and other arthropods as endoparasitoids (Stireman et al., 2006;

Tschorsnig, 2017). Although most are polyphagous, others are species-specific and prefer parasitizing lepidopteran larvae (Inclán et al., 2014; O'Hara et al., 2019). *Spodoptera* spp. viz., *S. exempta* (Walker), *S. exigua* (Hübner), and *S. mauritia* were also reported to be parasitized by *E. xanthaspis* in various places around the world (CABI, 2019). *Argyrophylax* sp. (Baranov) was reported from rice skipper larvae (IRRI, 2014).

Trichogrammatidae (Apocrita: Chalcidoidea)

Trichogrammatids are primary egg parasitoids and can be solitary or gregarious endo parasitoids. The family has many hosts, including Holometabola, Hemiptera, and Thysanoptera (Doutt and Viggiani, 1968). According to Yashiro (1979), *Oligosita tachikawai* parasitized *N. lugens* to 10.6%. According to Lin (1983), *T. japonicum* parasitized *Paralimna* sp. at a rate of 20–50%. *Trichogramma dendrolimi* parasitized *Chrysolopus spectabilis* at a rate of 24.7% (Shen et al., 1988). *Oligosita* sp. had a 13.8-day developmental period on *N. lugens* (Gupta and Pawar, 1989). Wada et al. (1991) reported that *Oligosita* sp. parasitizes *N. lugens* in 10 to 70% of cases. The previously reported records of such egg parasitoids in Taiwan are thoroughly reviewed by Triapitsyn et al. (2020). *Pseudoligosita nephotetticum* (Mani) was observed parasitizing the zig-zag leafhopper *Maiestas dorsalis* (Motschulsky), the green rice leafhopper *Nephotettix cincticeps* (Uhler), as well as the delphacids *Laodelphax striatella* (Fallén) and *Nilaparvata lugens* (Stål) (Gurr et al., 2011).

Rice pest-parasitoid associations in the Indian subcontinent

The insect pests are a serious threat to rice production in India. So, considering the detrimental impact of pesticides, studies on biological control of rice pest management have received much attention among the Indian research community. Many researchers have studied the parasitoids reared from the rice pests in the Indian subcontinent. The hymenopterous parasites were reported from the rice stem borers by Subba-Rao and Chawla (1964), and Singh (1999). Fernando (1970) investigated the rice stem borer's chemical and biological control potential. Rao (1970, 1972) published a paper on rice stem borer parasitoids in India, Pakistan, Sri

Lanka, and Malaysia. Balasubrahmanian et al. (1994) and Karthikeyan et al. (2007) tested rice yellow stem borer and leaf folder egg parasitoids, *Trichogramma japonicum* and *T. chilonis*, in the field. Borah (1994) studied the effectiveness of *T. japonicum* parasitism on rice stem borers in Assam. Manas (2003) studied the prevalence and performance of natural enemies of rice yellow stem borer in the coastal saline tract of West Bengal. Catling et al. (1983) studied the egg parasitism of *Scirpophaga incertulas* (Walker) (Pyralidae) in Bangladesh's deepwater rice fields. Chandramohan and Chelliah (1984) researched the yellow stem borer parasioid complex and observed that *Tetrastichus schoenobii* (Ferriere) was effective against the yellow stem borer.

Hymenopterous parasitoids of the rice leaf folder, *Cnaphalocrocis medinalis* (Guenée), were discovered in Kerala by Abraham et al. (1973). Bharati and Kushwaha (1988) published their research on parasitoids of leaf folder pupae from Haryana. The parasitoids were *Xanthopimpla* sp. (Ichneumonidae), *Brachymeria* sp. nr. *lasus* (Walker) (Chalcididae), and *Tetrastichus ayyari* (Rohwer) (Eulophidae). Some rice pests were reported as hosts for some *Brachymeria* spp. in a monograph on Oriental Brachymeria published by Joseph et al. (1973). Chandraker et al. (1989) studied Raipur's naturally occurring rice gall midge parasitoids. According to their findings, the most common parasitoid was *Platygaster oryzae*, active 25–30 days after transplanting and during the second week of September, when host infection was at its lowest (5.5%). Kaur et al. (2000) published a list of the parasitoids of rice insect pests in the districts of Jalandhar and Sangrur in 1998–1999 in Punjab. They claim that egg parasitoids like *Trichogramma* wasps are crucial in lowering the number of rice stem borer populations. In Assam, parasitoids of rice hispa were reported by Bhattacharya et al. (2000). They reared *Bracon hispae* and *Chrysonotomyia* sp. from larvae of *Dicladispa armigera*. Padmakumari and Pasalu (2005) investigated the rice ecosystem for the Paspalidium midge, *Orseolia fluvialis* (Felt), and its parasitoids. Kaur and Brar (2008) experimented with different doses of *Trichogramma* sp. to manage a variety of rice pests. In Karnataka, Manjunath et al. (1978) investigated the natural enemies of *N. lugens* (Stål) and *Nephotettix nigropictus* (Stål). An

Oligosita species parasitized the eggs, and the nymphs and adults of *N. lugens* were parasitized by the dryinids *Ecthrodelphax fairchildii* (Perkins) and *Haplogonatopus* sp. at a rate of 51%. Chandra (1979) investigated the taxonomy and bionomics of rice leafhopper and planthopper insect pests and their roles in biological control. Bentur et al. (1982) investigated the egg and nymphal parasitoids of *N. lugens* and *Sogatella furcifera*. Subba-Rao and Hayat (1986) compiled a list of enemies of some of India's most common planthoppers and leafhoppers. The population dynamics of the rice hopper complex and its natural enemies were studied by Singh et al. (2011). Parasitism was stated by Rao et al. (1983) as a key factor in controlling the rice pest population. Narendran (1984) compiled a key to the Indian genera of the Chalcididae family (Hymenoptera: Chalcidoidea), which included several parasitic hymenopteran species of rice pests. Natural enemies of rice leafhoppers and planthoppers in Andhra Pradesh were studied by Bentur and Kalode (1985). Their study included the trichogrammatid egg parasite *Oligosita tachikawai*, the mymarid egg parasite *Anagrus armatus*, and the dyrinid larval-adult parasites *Gonatopus* spp. appeared to be new records. During the crop season 1981, 16.1% of the eggs of *N. lugens* were parasitized, and the *Oligosita* spp. accounted for 10.6% of the parasitization.

Nalini and Manickavasagam (2011) conducted detailed surveys and discovered five Encyrtidae species associated with Brevenniarehi (Lindinger) in the rice fields of Tamil Nadu. Abraham et al. (1973) reported hymenopterous parasitoids of the rice leaf folder, *Cnaphalocrocis medinalis* (Guenée). They claimed that *Tetrastichus israeli* (Mani & Kurian) is a gregarious pupal endoparasitoid with a wide host range. Beevi et al. (2000) studied hymenopteran diversity in single and double-cropped rice ecosystems in Kerala during the rabi season in 1997 to determine hymenopteran diversity. *Telenomus*, *Fidiobia*, *Tetrastichus*, *Platygaster*, *Trissolcus*, and *Gonatocerus* were the most common parasitoids obtained from all sites. Additional genera, including *Aprostocetus*, *Pteromalus*, *Elasmus*, and *Macroteleia*, exhibited a notable abundance of species. Notably, the parasitoid community within the single-cropped Kole lands displayed greater richness and diversity than those inhabiting the double-cropped typical lowlands. *Telenomus*

oryzae (Hymenoptera: Platygastridae), a rice black bug egg parasitoid from India, is new to science (Rajmohana and Nisha, 2013). Ranjith et al. (2015a) described two new species of Oriental *Microplitis* Foerster (Hymenoptera: Braconidae, Microgastrinae) reared from the larvae of *Psalis pennatula*. In a study by Ranjith et al. (2015a), the host-parasitoid relationship and the prevalence of microgastrine wasps (Hymenoptera: Braconidae) in rice fields across Kerala were investigated. The study identified four species, namely *Microplitis narendrani* Ranjith & Nasser, *Apanteles* sp. 1 parasitizing *Cnaphalocrocis medinalis* Guenée, *Apanteles* sp. 2 parasitizing *Pelopidas mathias* Fabricius, and *M. pennatulae* Ranjith & Rajesh parasitizing *Psalis pennatula* Fabricius. A novel pupal parasitoid, *Tetrastichus paraponyxi* Santhosh (Hymenoptera: Eulophidae, Tetrastichinae) of the rice case worm, *Parapoynx stagnalis* (Zeller) (Lepidoptera: Crambidae), a pest of paddy, was described by Santhosh and Karthikeyan (2017). As a hyperparasitoid, *Eurytoma manilensis* was reared from *Pelopidas mathias* (Narendran, 1994) and *Borbo cinnara* (Gupta and Kalesh, 2012). Previously, the larval parasitoid *Casinaria ajanta* was reported from *Ampittia dioscorides* and *Parnara* sp. in Kerala by Gupta et al. (2016). Menon et al. (2016) studied the diversity and distribution of parasitoid wasps of the Chalcidoidea (Hymenoptera) in the paddy fields of Palakkad district. The district has been reported to contain eleven families, and *Eurytoma* was discovered to be the most prevalent genus. Rajesh et al. (2020) published new distributional data on fairyflies (Hymenoptera: Mymaridae) from Kerala's rice–agroecosystems. For the first time, they reported *Gonatocerus aegyptiacus*, *Gonatocerus shamimi*, and *Anagrus* sp. from Kerala's rice fields. In addition, they reported ten new Mymaridae species with new distributional records in Kerala's rice agroecosystems.

Caterpillar's defense strategy against natural enemies

Even though many caterpillars are susceptible to parasitoids and predators, some caterpillars are shown to be less vulnerable to parasitism and predation. Many researchers investigated the anti-predator defense strategy of caterpillars to figure out why.

Caterpillars exhibit a diverse array of morphological attributes that serve as defensive mechanisms (as discussed in reviews by Edmunds, 1974; DeVries, 1987; Evans and Schmidt, 1991; Gross, 1993; Godfray, 1994; Dyer, 1995; Eisner et al., 2007). These features are commonly classified into two main categories: A) integumental structures found on caterpillars, such as spines or hairs; and B) coloration patterns, encompassing both brightly colored (aposematic) and visually cryptic adaptations. Predation may be influenced by the caterpillar's size or the rate at which it develops (Evans, 1983; Gaston et al., 1991; Montllor and Bernays, 1993). For example, if they are bigger than their enemies (i.e., later instars), their size may enhance their behavioral or physical defenses (Iwao and Wellington, 1970; Schmidt, 1974; Stamp, 1984). Remmel et al. (2011) reviewed this topic. They concluded that a 2-fold increase in the linear size of prey causes an estimated 4.9-fold reduction in arthropod predation rates. Exoskeletons that are tough or thicker may protect caterpillars against some predators (Malicky, 1970; Schmidt, 1974), and this trait may be prevalent among caterpillars that join ant colonies (Malicky, 1970; Schmidt, 1974). For example, the neotropical genus *Menander* (Riodinidae) has a dorso-ventrally flattened, tank-like body structure in some species (DeVries, 1997), which helps some species of caterpillars to push themselves closely against the leaf surface and protect exposed appendages that could otherwise be susceptible to predation. Various integumental structures may also play a role in defense (Epstein et al., 1994; Eisner et al., 2007). Spines and hairs are two integumental features investigated in several systems and are present in species across the lepidopteran phylogeny (Dyer, 1995, 1997; Lindstedt et al., 2008; Murphy et al., 2010). Anyone who has dealt with caterpillars in the field is familiar with urticating or stinging spines and hairs. Even though they are found in at least six Lepidopteran families (Kephart, 1914; Foot, 1922; Bishopp, 1923; Valle et al., 1954; Jones and Miller, 1959; Beard, 1963; Wirtz, 1984; Gibbons et al., 1990; Deml and Dettner, 2003; Bohrer et al., 2007), there are interestingly few studies that have examined their efficacy against predators (Murphy et al., 2010). Hairs' effectiveness is unclear, and generalizations like "hairs are an excellent protection against invertebrate predators" are inevitably inaccurate. The inclination of predators to reject prey based on their defensive mechanisms

varies, with each predator responding uniquely to a range of caterpillar defenses, encompassing both physical attributes and other forms of protection. Although the intricacies of individual caterpillar-predator interactions remain diverse and largely unexplored, studies assessing the effectiveness of various defensive strategies offer foundational insights into these dynamics (Greeney et al., 2012). A study comparing caterpillar predation by ants (Formicidae), wasps (Vespidae), and bugs (Hemiptera) revealed that morphological defenses were successful depending on the predatory group (Dyer, 1997). As an illustration, substantial size proved to be an effective defense mechanism against two solitary predators, namely bugs and wasps, yet it did not deter ants. Ants possess the ability to overcome larger prey by summoning reinforcements, a strategy that allows them to effectively prey upon larger targets (Greeney et al., 2012). The thick hair coverings deter predatory bugs from caterpillars. They prevent the proboscis from being inserted (Dyer, 1997; Bowers, 1993) and are helpful against predators with sucking mouthparts. An interesting alternative function of caterpillar hairs is to warn the caterpillar of an approaching predator or parasitoid before the predator, or parasitoid have a chance to catch the caterpillar (Tautz and Markl, 1978; Castellanos et al., 2011), with some larval species bearing setae modified explicitly for this purpose (Rota and Wagner, 2008).

Hairs are less efficient against other predators, such as birds and wasps, which can destroy them (Bowers, 1993). Caterpillar coloring is classified into three categories as a defense strategy: 1) bright warning colors; 2) cryptic patterning that matches their substrate; and 3) imitation of inedible things or similarities to hazardous species to their predators. Some species show ontogenetic changes between various color schemes (Grant, 2007; Sandre et al., 2007) or may vary which part of their plant they are cryptic (Greeney et al., 2010b, 2010c, 2011), or even seasons (Greeney et al., 2010a, 2010b, 2010c). Wagner (2005) mentions *Papiliotroilus* (Papilionidae), which resembles a bird dropping for several instars before resembling a snake in later instars. Visual predators such as wasps, birds, and mantids may require aposematic (warning) colors to catch the caterpillars, although ants and other chemically orientated animals are unlikely to need them. When predators are repelled by vividly colored prey, it lends credence to the long-

held theory that aposematism is an adaptive explanation for bright colors and distinctive patterns (Cott, 1940; Ruxton and Sherrat, 2006). Brightly colored prey, however, is not a deterrent to many visually oriented predators, including reduviids, pentatomids (Johnson, 1983), and several parasitoids (Dyer, 1997; Gentry and Dyer, 2002). In the animal kingdom, a relationship between taste and coloration is generally accepted (e.g., Cott, 1940; Edmunds, 1974; Harborne, 1988), and coloration has even been utilized as a palatability indicator (Sillén-Tullberg, 1988). However, this relationship is frequently exaggerated as more predation studies are published. Many caterpillar species have patterns that closely resemble the parts of the plant where they eat or rest, helping them blend in and escape predator attention (DeVries, 1987; Greene, 1989; Stamp and Wilkens, 1993). Many caterpillars are "behaviorally cryptic," meaning they adopt resting or feeding positions that resemble a section of the host plant or damage inflicted by the caterpillar itself. In Geometridae, such behavior is highly developed and effective (McFarland, 1988; Wagner, 2005). Caterpillars have two different ways of changing the shape of their bodies: they can freeze and resemble straight twigs or twist and contort (Greeney et al., 2012). For example, hesperiid larvae resting on exposed shelter ceilings were unaffected by ants moving directly below them (Baer and Marquis, 2020).

Hence, further detailed studies on the caterpillar's defense strategy against predators and parasitoids are essential.

Study Area

The whole study was carried out in the selected paddy fields of North Kerala, comprising Kannur, Wayanad, Kozhikode, Malappuram, and Palakkad districts. Study sites were selected based on the agro-ecological zones classified by the Kerala State Planning Board and the National Bureau of Soil Survey and Land Use Planning, Bengaluru (KSHIS, 2019).

Study region: *North Kerala, India* (For the study of host-parasitoid association)

The Kerala state, situated in the southwestern region of India, spans an area of 38,863 km2 (latitude: 8°18'–12°48' N, longitude: 74°52'–77°22' E). Its coastline

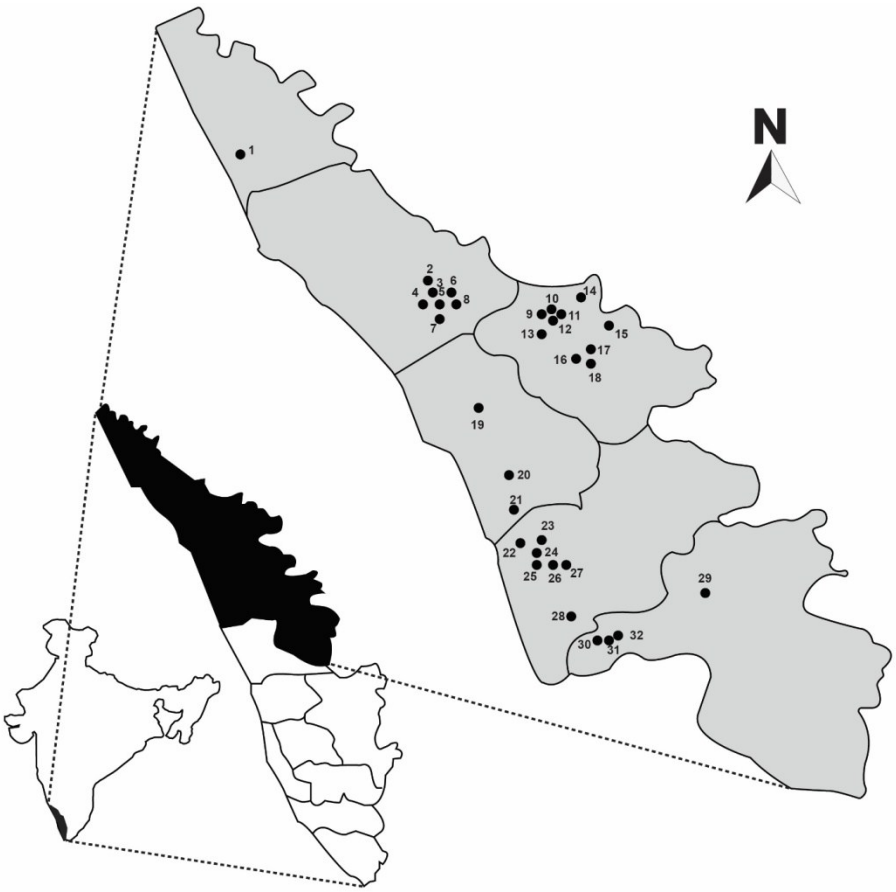
stretches approximately 580 km, ranging from the Arabian Sea in the west to the hilly tropical evergreen forest in the east, extending in a Northwest to southeast direction. Geographically, the state is characterized by lowland, midland, and highland regions (Noble, 2019). Kerala experiences a humid tropical climate, with temperatures averaging between 20 to 37 degrees Celsius. The period from June to December witnesses tropical monsoon rains, brought about by both the southwest and Northeast monsoons, resulting in an annual precipitation of approximately 3225 millimeters (Balasubramanian, 2017; Louis, 2018). North Kerala primarily stretches along the Western Ghats of peninsular India, which extends along the Arabian Sea coastline for 1500 km from the Tapti River (21° 16'N) to peninsular India (Kanyakumari, 8° 19'N) in a North-south direction (WGEEP, 2011). The Western Ghats stretch parallel to the coastline for about 30 km in North Kerala, forming a narrow strip of midland (Chattopadhyay and Kumar, 2013).

The samples selected to study the host-parasitoid associations were collected from 32 localities (Table 1.1) of North Kerala (including Kasaragod, Kannur, Kozhikode, Malappuram, Wayanad and Palakkad districts) (Map 1). The insects were collected randomly, either with or without visible signs of parasitism, from the rice fields during 2016–2020.

Table 1.1 Sites in North Kerala, where the eggs, larvae, and pupae of rice pests were collected (2016 – 2020).

Sl.no.	Field site	Coordinates	Altitude (m asl)
1	Alacherry	11°52'04.5"N 75°40'39.1"E	38
2	Amayur	10°49'53.0"N 76°11'06.4"E	32
3	Arimbra	11°07'41.6"N 75°59'55.3"E	32
4	Chavassery	11°56'50.2"N 75°36'45.7"E	36
5	Erattengal	11°53'31.4"N 75°37'13.8"E	34
6	Kadakkattupara	11°07'16.9"N 75°52'28.8"E	8

7	Kakkoor	11°22'52.8"N 75°49'28.0"E	9
8	Kammanam	11°47'13.0"N 76°01'39.1"E	733
9	Kaniyambetta	11°42'27.8"N 76°05'44.8"E	721
10	Kanjirad	11°55'17.1"N 75°38'59.4"E	49
11	Kanjiravayal	11°53'12.0"N 75°38'23.9"E	25
12	Kannivayal	11°48'10.55"N 76° 2'11.37"E	722
13	Kooriyad	11°03'07.2"N 75°56'22.0"E	4
14	Koyileri	11°47'00.5"N 76°02'50.8"E	715
15	Kurichipatta	11°48'03.7"N 76°07'42.3"E	744
16	Kuttoolangadi	11°11'22.3"N 75°51'33.2"E	3
17	Mathothpoyil	11°44'22.18"N 76° 3'16.32"E	720
18	Muyyorath	11°52'30.8"N 75°38'32.3"E	24
19	Nittaramba	11°52'54.4"N 75°38'25.3"E	21
20	Padannakkad	12°15'29.6"N 75°07'16.9"E	6
21	Palachiramad	10°59'45.9"N 75°58'30.3"E	7
22	Panamaram	11°44'34.7"N 76°04'14.6"E	716
23	Pantharangadi	11°02'17.5"N 75°53'33.4"E	3
24	Pattambi	10°48'51.5"N 76°11'48.5"E	27
25	Ramanattukara	11°11'10.9"N 75°52'33.6"E	5
26	Sreekrishnapuram	10°54'25.9"N 76°25'03.3"E	56
27	Thalappara	11°04'13.0"N 75°54'21.7"E	4
28	Thannikkal	11°47'42.7"N 76°02'29.2"E	715
29	Thodeekkalam	11°51'41.27"N 75°39'33.02"E	49
30	Valancherry	10°53'04.1"N 76°04'40.1"E	10
31	Valiyakunnu	10°52'41.50"N 76° 5'44.25"E	10
32	Valliyurkaav	11°48'09.9"N 76°01'57.3"E	720



Map1. Rice pest- parasitoid collection sites in North Kerala: 1- Padannakkad; **2-** Erattengal; **3-** Kanjiravayal; **4-** Muyyorath; **5-** Nittaramba; **6-** Kanjirad; **7-** Thodeekkalam; **8-** Alacherry; **9-** Kammanam; **10-** Valliyurkaav; **11-** Kannivayal; **12-** Thannikkal; **13-** Koyileri; **14-** Kurichipatta; **15-** Panamaram; **16-** Mathothpoyil site 1; **17-** Mathothpoyil site 2; **18-** Kaniyambetta; **19-** Kakkoor; **20-** Kuttoolangadi; **21-** Ramanattukara; **22-** Kadakkattupara; **23-** Arimbra; **24-** Thalappara; **25-** Palachiramad; **26-** Pantharangadi; **27-** Kooriyad; **28-** Valancherry; **29-** Sreekrishnapuram; **30-** Valiyakunnu; **31-** Amayur; **32-** Pattambi.

Agro-ecological zones of North Kerala (for the study of percentage composition)

The Kerala agro-ecological delineations were carried out under the project organized by the Kerala State Planning Board and the National Bureau of Soil Survey and Land Use Planning, Bengaluru, in 2012. The state was divided into agro-ecological zones and units in 2007–08 based on climate, soil type, and landform. According to the Department of Agriculture, Government of Kerala, high hills are hilly areas that range from south to North, comprising the Western Ghats and plateaus. It forms the highest region at 600 m above mean sea level (AMSL), with several peaks rising above 1800 m, the Western Ghats, and highland plateaus, The Central Sahyadri, the Nilgiris, and South Sahyadri form the Western Ghats. The foothills lie between the midland laterites on the west and the high hills on the east,

with the undulating and rolling lands and low hills. The zone is occupied by 4,60,07,4 ha (11.84 %), and the terrain has very narrow valleys. The midland laterite region stretches from the southern to the state's North end. It involves undulating, rolling land between the coastal plain on the west and foothills and hills on the east, interspersed with narrow valleys. This zone occupies 27.18% of total zones with 10,56,385 ha (KSHIS, 2019).

North Kerala consists of four agro-ecological zones: high hill, foothill, midland laterites, and coastal plains. In our study, we excluded the coastal plain region because it is a separate system to study. The rice fields in the North Kerala coastal areas (Kaipad) are proximal to the sea. A periodical influx of marine water into the fields ensures the uniqueness of rice varieties in this region. Also, indigenous knowledge and local resources are efficiently utilized in this farming system (Chandramohanan et al., 2016).

Our study was carried out in three agro-ecological zones; each of the high hill (Wayanad District), foothill (Kannur District), and midland laterites (Kozhikode and Malappuram District) located in the North region of Kerala (Map 2). We have twelve sampling sites for each zone for long-term monitoring of insect population dynamics and community structure in crop fields (Table 1.2). Each study site's exact location and altitude were recorded using the Global Positioning System and Google Earth engine. Local agriculture in the high hill is dominated by coffee production, banana cultivation, arecanut cultivation, and a large share of subsistence farming, including rice cultivation. The elevation of the Wayanad district ranges from 700 to 2100 meters AMSL. The rice fields selected for the study of the high hill region are located at an altitude of 716–753 m. The foothill region selected is situated in the Kuthuparamba municipality. Agriculture in the foothill region is characterized by rubber and arecanut plantations and banana cultivation, but it also has a small scale of subsistence rice production. The selected rice fields of this community are situated at altitudes between 22 and 34 m. The North midland laterite zone occupies the midland parts of the four districts: Kasaragod, Kannur, Kozhikode, and Malappuram. The selected study region is situated in the municipality of

Ramanattukara (Kozhikode District) and Pantharagadi near Chemmad, the most prominent commercial center of Tirurangadi Taluk, which belongs to the Malappuram district; the altitude ranges from 2m to 4m. At each site, five plots were selected for this study. Individual fields are spaced at a minimum distance of one kilometer in each district. The rice fields situated in North Kerala span altitudes ranging from 2 to 753 meters. The study was undertaken across two distinct rice-growing seasons: Nanja (wet season) and Punja (dry season), encompassing the period from July to March. It's worth noting that the transplantation dates may vary slightly depending on specific zones and climatic conditions. The investigation was carried out over the years 2017, 2018, and 2019. All rice fields were solely managed by their owners using conventional rice cultivation practices and the standard production processes of small-scale landholders.

Map 2. The map of experimental plots in four districts of North Kerala, South India (Classification of agro-ecological zones and map source: KSHIS, 2019)

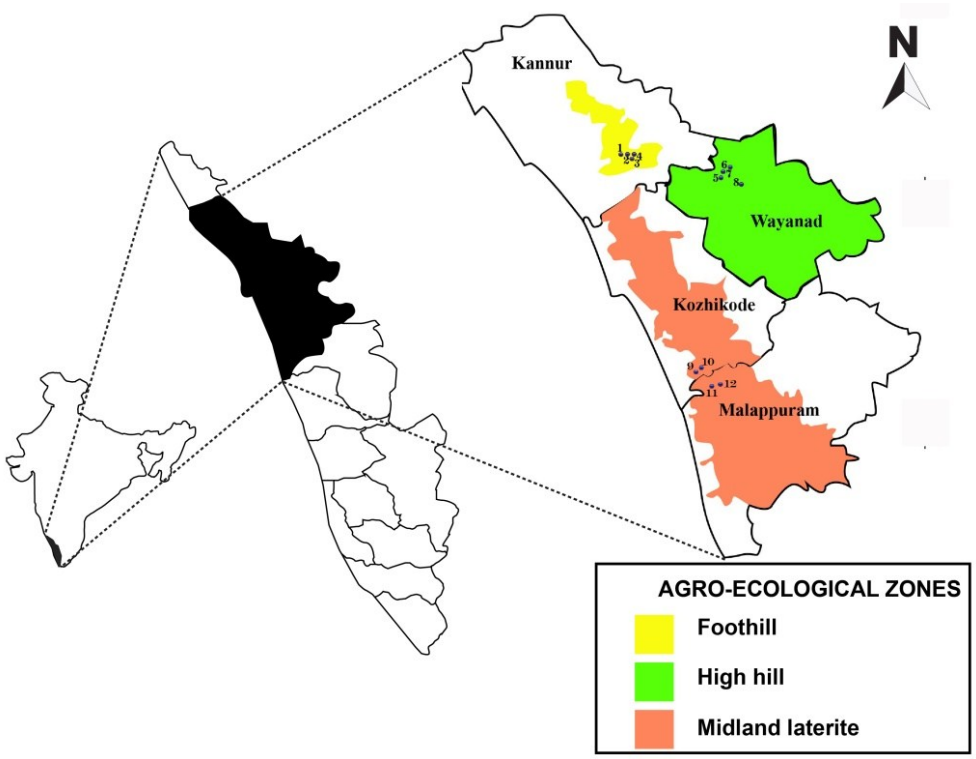


Table 1.2. Details for the distribution and selection of the rice fields in three different ecological zones during 2017–2019 in North Kerala, South India.

Agro-ecological Zone	Districts	Site	Field site	Latitude	Longitude	Altitude (m)
Foothill	Kannur	1	Nittaramba	11°52'54.4"N	75°38'25.3"E	22
		2	Kanjiravayal	11°53'12.08"N	75° 38'23.9"E	26
		3	Muyyorath	11°52'30.8"N	75°38'32.3"E	23
		4	Erattengal	11°53'31.4"N	75°37'13.8"E	34
Highhill	Wayanad	5	Kammanam	11°47'13.0"N	76°01'39.1"E	753
		6	Kannivayal	11°48'10.55"N	76°2'11.37"E	721
		7	Thannikkal	11°47'42.7"N	76°02'29.2"E	716
		8	Mathothpoyil	11°44'22.18"N	76° 3'16.32"E	731
Midland laterite	Kozhikode	9	Kuttoolangadi	11°11'22.3"N	75°51'33.2"E	2
		10	Ramanattukara	11°11'10.9"N	75°52'33.6"E	2
	Malappuram	11	Pantharangadi	11°02'17.8"N	75°53'27.6"E	4
		12	Vengalipadam	11°02'17.6"N	75°53'47.4"E	4

The rice variety Uma, which was observed in this study, comprises open-pollinated landraces meticulously chosen and enhanced through the expertise and efforts of indigenous farmers in the region.

Materials and methods

Methods of collection

Handpicking

A transect measuring 25m x 2m laid on the four sides of the field was covered on foot. Any eggs, larvae, or pupae of rice pests observed in the field were collected and brought to the laboratory and then separately placed in glass containers covered with nylon mesh and reared at 28 ± 2°C with 70–80 % relative humidity until parasitoid emergence or host emergence. Daily observations were made to record the emergence of adult parasitoids or adults of the pest. The emerged parasitoids were counted, preserved in 70% alcohol, and identified up to species level.

Sweep netting

Sweep net sampling was conducted along the sides of the paddy fields, which were divided into transects (25m x 2 m). A rice field has transects set up on each of its four corners. There were five double sweeps in each plot, each with nine full cycles. Instead of the usual round sweep net, a triangular one was used for the sweeping.

Rearing of the parasitoid

Eggs, larvae, and pupae of the pests were collected from the field and brought to the laboratory. The samples were then enclosed in a glass beaker (500

ml) covered with a muslin cloth and observed for parasitoid emergence. Every day, recently emerged wasps were carefully collected into clean glass tubes measuring 2.5cm × 20cm. Subsequently, they were supplied with water and honey (50:50 by volume, placed on a strip of plastic sheeting (Allen et al., 2014).

Mounting and preservation of parasitoids

Wet specimens were refrigerated in cryo boxes in small vials of 70% ethyl alcohol. The preservative was adjusted and refilled regularly to prevent drying. Insect boxes were made explicitly for preservation; card-mounted specimens were placed inside the boxes. Also, to protect the specimen from other insects, naphthalene balls and paradichlorobenzene (PDB) were placed in the inner corners of the boxes. After treating them, the specimens were mounted on a triangular card and labelled.

Taxonomic identification and imaging of parasitoids

Sorting, mounting, and taxonomic characterization was done with the help of the stereoscopic binocular microscope model LEICA M 205A. Initial identifications were carried out with the help of all available traditional taxonomic literature, catalogues, and keys given by several authors like Bouček (1988), Narendran (1994), Jonathan (2006), Rajmohana (2006), and Sureshan (2008). In addition, help was also taken from the identified parasitoid collection at the Department of Zoology, University of Calicut, Malappuram, for confirmation. The description of new species was done with the help of taxonomy experts in the desired area. The generic and species nomenclature for most of the species in the present study was updated by referring to the online tool "Universal Chalcidoidea Database" developed by Noyes (2019). Identified specimens are deposited at the Department of Zoology, Malabar Christian College, Kozhikode; Department of Zoology, Guruvayurappan College, Kozhikode; National Bureau of Agricultural Insect Resources, Bengaluru, Karnataka; Zoological Survey of India, Kolkata; and Department of Zoology, University of Calicut, Malappuram. Mounted specimens were photographed with a Leica DFC 500 camera affixed to a Leica M205A stereozoom trinocular microscope. Leica Automontage Software combined images with different focal levels into a single image with varying magnifications per requirement for closely examining taxonomic characters.

Construction of trophic webs

To gauge the complexity of the insect community, we evaluated two metrics: the count of actual trophic interactions, denoted as L, and the connectance (C), which signifies the proportion of all feasible interactions within the system. Connectance was determined by the equation C=L/HP, where H represents the total number of hosts, P represents the number of parasitoids, and HP signifies the maximum potential number of host-parasitoid associations. Hence, the ratio L/HP quantifies the fraction of realized links within the ecosystem (Valladares et al., 2001; Rocca and Greco, 2015). Parasitoid overlap graphs were constructed to summarize the patterns of shared parasitism. Overlap was computed as the tally of species pairs among herbivores or primary parasitoids that shared a minimum of one primary parasitoid or hyperparasitoid, divided by the total potential number of such connections (Sunderland et al., 2005; Shameer et al., 2018).

Calculation of percentage parasitism

The percentage parasitism was calculated by using the following formula.

$$\text{Percentage parasitism} = \frac{\text{Number of infected egg or larvae}}{\text{Total number of egg or larvae}} \text{X } 100$$

Parasitoids were categorized as idiobionts if they suspended host insect development or as koinobionts if the parasitized host was allowed to continue to develop (before eventual host death) (Askew and Shaw, 1986). Parasitoids were further classified as either endoparasitoids or ectoparasitoids, based on the location where the parasitoid larvae developed in relation to the insect host (Gratton and Welter, 2001).

Morphological measurements of caterpillars

Caterpillars were collected from the field and kept in the refrigerator for a few minutes to reduce movement. Using a Leica EZ4 microscope, photographs of the caterpillar placed on graph paper were taken.

The length of the hairs on the caterpillar was also measured. The average length of each hair was calculated by taking the mean of hairs in the unit area (1cm x 1cm) of 30 individuals of each pest species. Caterpillars' minute hair length was measured using a Stereo zoom microscope, Leica M205A, with a DMC2900

camera. In addition, field observation was made to find the nature of larval shelter and larval exposure; and photographs of pests were to understand larval skin color. The effect of larval skin color, hair length, and larval exposure on the parasitization rate was then analyzed.

Data analysis

Data on larval morphology (skin color, hair length, and larval exposure) and egg characteristics (clutch size and egg covering) were collected to analyze the anti-parasitoid defense strategy. To assess the normal distribution of the data, the Shapiro-Wilk test was employed. Subsequently, the significance of variables was evaluated using the Kruskal-Wallis test. Kendall's Tau (Kendall Rank Correlation Coefficient) test was used for correlation analysis. All analyses were done with PAST ver. 3 software (Hammer et al., 2001).

Results

Rice pests

Out of 54 samplings in three years, in all three agro-ecological zones of North Kerala combined, 118057 individual eggs, 19651 larvae, and 2784 pupae of pests were handpicked. A total of 12028 individuals, including larvae and adults of rice pests, were collected through the sweep netting method during the study period.

Thirty-six species belonging to 4 insect orders (Coleoptera, Hemiptera, Lepidoptera, and Orthoptera) and 15 families were collected, including larval and adult stages, by sweep netting and handpicking. The families are Acrididae (n=2), Alydidae (n=1), Cercopidae (n=1), Chrysomelidae (n=2), Cicadellidae (n=2), Crambidae (n=5), Delphacidae (n=1), Erebidae (n=5), Gryllidae (n=1), Hesperiidae (n=4), Lophophidae (n=1), Noctuidae (n=4), Nymphalidae (n=2), Pentatomidae (n=4), and Tetrigidae (n=1).

Among all insect orders collected in the study, Lepidoptera was more species-rich (n=20) and abundant in all agro-ecological zones, followed by Hemiptera (n=9), Orthoptera (n=4) and Coleoptera (n=2) (Table 1.3). In nearly all cases, it was possible to distinguish the insect pests by their egg and larval morphology, adult morphology, and larval feeding pattern.

Table 1.3. The rice pests collected from the paddy fields of North Kerala.

Order	Family	Species	Common name
Coleoptera	Chrysomelidae	*Dicladispa armigera*	Rice hispa
	Chrysomelidae	*Leptispa pygmaea*	Rice blue beetle
Hemiptera	Alydidae	*Leptocorisa acuta*	Rice ear bug
	Cicadellidae	*Cofana spectra*	White leafhopper
	Cicadellidae	*Nephotettix nigropictus*	Rice green leafhopper
	Cercopidae	*Callitettix versicolor*	Rice spittle bug
	Delphacidae	*Nilaparvata lugens*	Brown planthopper
	Lophopidae	*Pyrilla perpusilla*	Sugarcane planthopper
	Pentatomidae	*Menida versicolor*	Shield bug
	Pentatomidae	*Nezara viridula*	Southern green stink bug
	Pentatomidae	*Pygomenida variepennis*	Stink bug
	Pentatomidae	*Scotinophara bispinosa*	Rice black bug
Orthoptera	Acrididae	*Hieroglyphus banian*	Rice grasshopper
	Acrididae	*Oxya hyla*	Rice grasshopper
	Gryllidae	*Euscyrtus concinnus*	Field cricket
	Tetrigidae	*Tetrix subulata*	Slender Groundhopper
Lepidoptera	Crambidae	*Cnaphalocrocis medinalis*	Rice leaf roller
	Crambidae	*Helcystogramma arotraeum*	Rice leaf roller
	Crambidae	*Parapoynx stagnalis*	Rice caseworm
	Crambidae	*Scirpophaga incertulas*	Yellow stem borer
	Crambidae	*Scirpophaga innotata*	White stem borer
	Erebidae	*Creatonotus gangis*	Hairy caterpillar
	Erebidae	*Euproctis similis*	Yellow tail moth
	Erebidae	*Lyclene* sp.	
	Erebidae	*Mocis frugalis*	Sugarcane looper
	Erebidae	*Psalis pennatula*	Yellow hairy caterpillar
	Hesperiidae	*Ampittia dioscorides*	Common bush hopper
	Hesperiidae	*Pelopidas agna*	Obscure branded swift
	Hesperiidae	*Pelopidas mathias*	Small branded swift
	Hesperiidae	*Parnara* sp.	Grey swift
	Noctuidae	*Mythimna separata*	Rice ear-cutting caterpillar
	Noctuidae	*Naranga aenescence*	Rice green semilooper
	Noctuidae	*Spodoptera litura*	Rice cutworm
	Noctuidae	*Spodoptera mauritia*	Paddy swarming caterpillar
	Nymphalidae	*Melanitis leda ismene*	Common evening brown
	Nymphalidae	*Orsotriaena medus*	Medus brown

Major rice pests in three agro-ecological zones of North Kerala

The rice pests were collected during a three-year study (2017–2019) in dry seasons (DS) and wet seasons (WS). The number of pests was high in the WS compared to the DS. Details are given below:

1. Acrididae

Two hundred and sixty-four individuals of *Hieroglyphus banian* (DS: 45.8%, WS:54.2%) and 195 individuals of *Oxya hyla* (DS: 39.5%, WS: 60.5%) were collected.

2. Alydidae

One thousand four hundred sixty-five individuals of only one species of Alydidae, the rice ear head bug, viz., *Leptocorisa acuta*, with 425 individuals (29.0%), were obtained in the DS and 1040 individuals (71.0%) in the WS via sweep netting from the three zones.

3. Cercopidae

In the WS, the rice spittle bug called *Callitettix versicolor* (n=17) was collected via sweep netting from the foothill region.

4. Chrysomelidae

Five hundred eighteen individuals of *Dicladispa armigera* (DS: 28.6%, WS: 71.4%) and 751 individuals of *Leptispa pygmaea* (DS: 4.3%, WS: 95.7%) were collected using sweep netting (for adults) and handpicking (for arvae) from the three agro-ecological zones.

5. Cicadellidae

One thousand three hundred and fifty nine individuals of two species of Cicadellidae, the white leafhopper, viz., *Cofana spectra*, (DS: 41.4%, WS: 58.6%) and *Nephotettix nigropictus* (DS: 42.2%, WS: 57.8%) were obtained via sweep netting.

6. Crambidae

Five Lepidopteran moth species, viz., *Cnaphalocrocis medinalis* (5335 individuals, DS: 27.0%, WS: 73.4%), *Helcystogramma arotraeum* (1224 individuals, DS: 26.6%, WS: 73.0%), *Parapoynx stagnalis* (4221 individuals, DS: 19.9%, WS: 80.1%), *Scirpophaga incertulas*, (545 individuals, DS: 34.3%, WS: 65.7%), and *Scirpophaga innotata* (20 individuals, DS: 40.0%, WS: 60.0%), were sampled by sweep netting and handpicking from the three agro-ecological zones.

7. Delphacidae

Only one species of Delphacidae, the brown hopper, viz., *Nilaparvata lugens*, with 137 individuals, was obtained via the sweep netting method in the dry season and 218 individuals in the wet season from the rice fields of North Kerala.

8. Erebidae

Five Lepidopteran moth species, viz., *Creatonotus gangis* (78 individuals, DS: 75.6%, WS: 24.4%), *Euproctis similis* (349 individuals, DS: 36.1%, WS: 63.9%), *Lyclene* sp. (7 individuals, DS: 0%, WS: 100%), *Mocis frugalis* (84 individuals, DS: 0%, WS: 100%), and *Psalis pennatula* (579 individuals, DS: 48.1%, WS: 51.9%), were sampled in two crop growth seasons for three years.

9. Gryllidae

Only one species of Gryllidae, the cricket, viz., *Euscyrtus concinnus*, was obtained via the sweep netting method (204 individuals, DS: 42.6%, WS: 57.4%).

10. Hesperiidae

Four Lepidopteran butterfly species, viz., *Ampittia dioscorides*, *Pelopidas agna*, *Pelopidas mathias*, and *Parnara* sp., with 5095 individuals (DS: 18.5%, WS: 81.5%) were sampled. Out of four Hesperiidae species, 1657 individuals of *A. dioscorides* (DS: 11.2%, WS: 88.8%), 1184 individuals of *P. agna* (DS: 25.8%, WS: 74.2%), 129 individuals of *P. mathias* (DS: 44.2%, WS: 55.8%), and 2125 individuals of *Parnara* sp. (DS: 18.7%, WS: 81.3%) were collected.

11. Lophophidae

Only one species of Lophopidae, the sugarcane planthopper, viz., *Pyrilla perpusilla*, was obtained. No *P. perpusilla* was collected in the dry season, and only two individuals were collected in the wet season from all three agro-ecological zones.

12. Noctuidae

Four Lepidopteran moth species, viz., *Mythimna separata*, *Naranga aenescens*, *Spodoptera litura*, and *Spodoptera mauritia*, with 1163 individuals (DS: 18.5%, WS: 81.5%) were sampled. Of the four Noctuidae species, 347 individuals of *M. separata* (DS: 19.3%, WS: 80.7%), 134 individuals of *N. aenescens* (DS: 20.9%, WS: 79.1%), 162 individuals of *S. litura* (DS: 9.8%, WS: 90.2%), and 510 individuals of *S. mauritia* (DS: 20.4%, WS: 79.6%) were collected in the two-rice crop growing season.

13. Nymphalidae

Two species belonging to the family Nymphalidae, viz., *Melanitis leda ismene* (641 individuals, DS: 39.1%, WS: 60.9%), and *Orsotriaena medus* (797 individuals, DS: 24.5%, WS: 75.5%), with an overall sample of 1438 individuals (DS: 31.0%, WS: 69.0%).

14. Pentatomidae

Three Hemipteran species, viz., *Menida versicolor*, *Nezara viridula*, and *Scotinophara bispinosa*, were sampled. Thirty-eight individuals of *M. versicolor* (DS: 7.9%, WS: 92.1%), six individuals of *N. viridula* (DS: 0%, WS: 100%), and 107 individuals of *S. bispinosa* (DS: 38.3%, WS: 61.7%) were collected by the sweep netting method in the dry season. No *M. versicolor* was collected from the foothill and midland laterite regions.

15. Tetrigidae

One hundred and twenty eight individuals of only one species of Tetrigidae, the slender groundhopper species, viz., *Tetrix subulata*, were collected via sweep netting in the DS (DS: 24.2%) from the foothill region. No *T. subulata* was obtained during DS from the high hill and midland laterite regions. Ninety-seven individuals (75.2%) were collected in the WS.

Erebidae was the most species-rich family (n=5) among rice pests, but Hesperiidae dominated in numbers in both the DS and WS. In the three consecutive DS, three rice pest species, viz., *Callitettix versicolor*, *Lyclene* sp., *Nezara viridula*, and *Pyrilla perpusilla* were not observed in all three agro-ecological zones. *Menida versicolor*, *Mocis frugalis*, *Leptispa pygmaea*, *Naranga aenescence*, and *T. subulata* were absent in the midland laterite study site during all three consecutive DS. Whereas, in the DS of the high hill region, *L. pygmaea*, *Scirpophaga innotata*, *Scotinophara bispinosa*, and *T. subulata* were not observed. In foothill region, *M. versicolor*, *S. incertulas*, and *S. innotata* were absent (Table 1.4).

Some pest species were restricted to only one agro-ecological zone during the DS; *L. pygmaea*, and *T. subulata* were present only in the foothill region. *Menida versicolor* was restricted to the high hill region, and *S. innotata* to the midland laterite region. The highest percentage composition was 38.70% by *Cnaphalocrocis medinalis* in the midland laterite region and 31.54% in the foothill region. *Cnaphalocrocis medinalis* dominated both in the foothill and midland laterite region. However, *Parapoynx stagnalis* was the dominant pest species in the high hill region, and the highest percentage composition was 26.57%.

Table 1.4. Percentage species composition of rice pests in the dry season (2017–2019). The bold digits represent significant results.

Sl. No.	Insect pest	High hill	Foothill	Midland laterite
1	*Ampittia dioscorides*	1.78	4.20	2.61
2	*Cnaphalocrocis medinalis*	**20.74**	**21.15**	**31.11**
3	*Cofana spectra*	4.33	4.66	2.86
4	*Creatonotus gangis*	0.87	0.82	0.55
5	*Dicladispa armigera*	1.73	3.52	1.55
6	*Euproctis similis*	2.64	1.55	1.55
7	*Euscyrtus concinnus*	1.17	0.87	2.05
8	*Helcystogramma arotraeum*	4.72	8.95	1.85
9	*Hieroglyphus banian*	2.04	1.64	1.90
10	*Leptispa pygmaea*	0.00	1.46	0.00
11	*Leptocorisa acuta*	6.71	6.12	6.81
12	*Melanitis leda ismene*	2.21	5.03	4.51
13	*Menida versicolor*	0.13	0.00	0.00
14	*Mocis frugalis*	0.65	0.23	0.00
15	*Mythimna separata*	1.56	0.78	0.70
16	*Naranga aenescens*	0.82	0.41	0.00
17	*Nephotettix nigropictus*	2.08	1.32	1.75
18	*Nilaparvata lugens*	2.43	0.73	3.26
19	*Orsotriaena medus*	2.34	3.93	2.76
20	*Oxya hyla*	1.47	0.87	1.15
21	*Parapoynx stagnalis*	**23.60**	**10.51**	**3.31**
22	*Pelopidas agna*	4.24	5.71	4.16
23	*Pelopidas mathias*	0.43	0.91	1.35
24	*Parnara bada*	5.85	7.81	4.91
25	*Psalis pennatula*	2.51	4.34	6.31
26	*Scirpophaga incertulas*	0.48	0.00	8.82
27	*Scirpophaga innotata*	0.00	0.00	0.40
28	*Scotinophara bispinosa*	0.00	0.05	1.85
29	*Spodoptera litura*	0.17	0.14	0.45
30	*Spodoptera mauritia*	2.30	0.87	1.45
31	*Tetrix subulata*	0.00	1.42	0.00
		100	**100**	**100**

In all three consecutive wet seasons, *C. versicolor* was restricted only in the foothill region, and *S. innotata* and *N. viridula* were restricted to midland laterite region. The armyworm, *S. litura* and *N. viridula* were not collected from the foothill region for three consecutive years. In the high hill region, *P. stagnalis* showed the highest percentage composition (26.20%), followed by *C. medinalis* (21.33%). In the foothill region also, the same pattern is seen, and the highest percentage composition of *P. stagnalis* was 23.88%, followed by *C. medinalis* (15.34%). Interestingly, *C. medinalis* dominated in the midland laterite region, and the highest

percentage composition was 43.93%. In the midland laterite region, three rice pest species viz., *C. versicolor*, *Lyclene* sp., and *M. frugalis* were not found in our collection (Table 1.5).

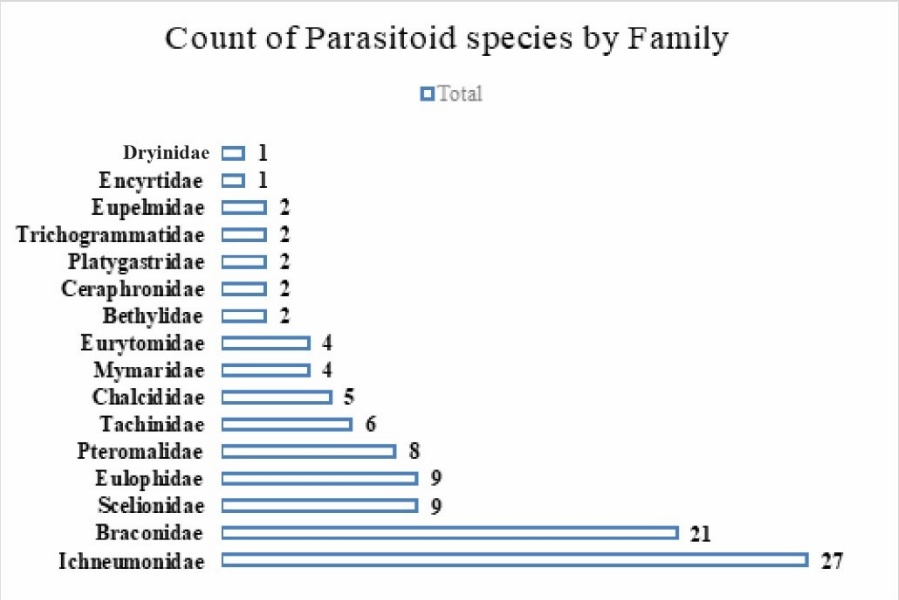
Table 1.5. Percentage species composition of rice pests in the wet season (2017–2019). The bold digits represent significant results.

Sl. No.	Insect pest	High hill	Foothill	Midland laterite
1	*Ampittia dioscorides*	1.82	13.24	3.69
2	*Callitettix versicolor*	**0.00**	**0.18**	**0.00**
3	*Cnaphalocrocis medinalis*	**18.34**	**14.69**	**39.09**
4	*Cofana spectra*	3.40	1.47	1.67
5	*Creatonotus gangis*	0.54	0.03	0.05
6	*Dicladispa armigera*	2.23	2.06	1.74
7	*Euproctis similis*	2.06	0.77	1.31
8	*Euscyrtus concinnus*	0.52	0.47	1.12
9	*Helcystogramma arotraeum*	3.82	6.29	3.07
10	*Hieroglyphus banian*	1.41	0.38	0.99
11	*Leptispa pygmaea*	0.24	5.14	5.45
12	*Leptocorisa acuta*	4.47	1.37	2.45
13	*Lyclene* sp.	**0.00**	**0.08**	**0.00**
14	*Melanitis leda ismene*	1.86	1.68	3.39
15	*Menida versicolor*	0.26	0.24	0.07
16	*Mocis frugalis*	0.33	0.74	0.00
17	*Mythimna separata*	3.01	1.21	0.66
18	*Naranga aenescence*	1.21	0.54	0.00
19	*Nephotettix nigropictus*	1.82	0.56	1.31
20	*Nezara viridula*	**0.04**	**0.00**	**0.09**
21	*Nilaparvata lugens*	2.04	0.46	1.86
22	*Orsotriaena medus*	3.47	3.61	2.47
23	*Oxya hyla*	0.85	0.46	0.82
24	*Parapoynx stagnalis*	24.20	22.46	4.19
25	*Pelopidas agna*	6.59	4.67	3.23
26	*Pelopidas mathias*	0.63	0.06	0.85
27	*Parnara* sp.	5.46	13.53	5.45
28	*Psalis pennatula*	1.50	1.09	2.98
29	*Pyrilla perpusilla*	**0.00**	**0.00**	**0.05**
30	*Scirpophaga incertulas*	0.00	0.11	7.97
31	*Scirpophaga innotata*	0.00	0.00	0.27
32	*Scotinophara bispinosa*	0.33	0.09	0.99
33	*Spodoptera litura*	2.36	0.00	1.31
34	*Spodoptera mauritia*	5.12	1.35	1.26
35	*Tetrix subulata*	0.07	0.95	0.14
		100	**100**	**100**

Parasitoids of rice insect pests

One hundred and five species under 67 genera belonging to 16 families (Bethylidae, Braconidae, Ceraphronidae, Chalcididae, Dryinidae, Encyrtidae, Eulophidae, Eupelmidae, Eurytomidae, Ichneumonidae, Mymaridae, Platygastridae, Pteromalidae, Scelionidae, Tachinidae, and Trichogrammatidae) were recorded from the rice agro-ecosystems. Ichneumonidae was the most species rich family (n=27), followed by Braconidae (n=21) (see Fig. 1.1).

Fig. 1.1 Count of parasitoid species by Family collected from the rice fields of North Kerala.



Species composition of parasitoids in the rice ecosystems of North Kerala

Eleven thousand one hundred sixty-nine parasitoid individuals belonging to 16 families were collected from the high hill, foothill, and midland laterite zones of North Kerala. The species composition of each parasitoid species in the 16 families in two crop seasons (dry and wet) is detailed below:

1. Bethylidae

Sixty-seven individuals (DS: 49.3%, WS: 50.7%) of two parasitoid species, viz., *Goniozus hanoiensis*, and *Goniozus platycephalus* were sampled from the study

site. A total of 38 individuals of *G. hanoiensis* (DS: 55.3%, and WS: 44.7%) and 28 individuals of *G. platycephalus* (DS: 39.3%, and WS: 60.7%) were collected.

2. Braconidae

Twenty braconid wasps, with a total of 3116 individuals (DS: 33.3%, WS: 66.7%), were sampled in the two crop seasons. The parasitoid wasps collected were *Apanteles* sp.1 (941 individuals, DS: 32.3%, WS: 67.7%), *Apanteles* sp.2 (561 individuals, DS: 31.1%, WS: 68.9%), *Aspidobracon noyesi* (121 individuals, DS: 38.8%, WS: 61.2%), *Bracon* sp. (186 individuals, DS: 37.1%,WS: 62.9%), *Cardiochiles philippinensis* (309 individuals, DS: 30.4%, WS: 69.6%), *Chilonus* sp. (20 individuals, DS: 15.0%, WS: 85.0), *Chorebus* sp. (12 individuals, DS: 25.0%,WS: 75.0%), *Cotesia flavipes* (294 individuals, DS: 42.2%, WS: 57.8%), *Cotesia ruficrus* (290 individuals, DS: 37.2%, WS: 62.8%), *Dolichogenidea* sp. (42 individuals, DS: 14.3%, WS: 85.7%), *Glypapanteles* sp. (17 individuals, DS: 17.6%, WS: 82.4%), *Hormius* sp. (17 individuals, DS: 11.8%, WS: 88.2%), *Macrocentrus philippinensis* (14 individuals, DS: 35.7%, WS: 64.3%), *Macrocentrus* sp. (43 individuals, DS: 23.3%, WS:76.7%), *Microplitis* sp. (15 individuals, DS: 40.0%, WS: 60.0%), *Opius* sp. (30 individuals, DS: 36.7%, WS: 63.3%), *Scutibracon* sp. (14 individuals, DS: 14.3, WS: 85.7%), *Spathius* sp. (2 individuals, DS: 0%, WS: 100%), *Tropobracon hayati* (68 individuals, DS: 33.8%, WS: 66.2%), and *Tropobracon luteus* (122 individuals, DS: 36.0%, WS: 63.4%)

3. Ceraphronidae

Two hyperparasitoid species of Ceraphronidae, consisting of 494 individuals (DS: 40.3%, WS: 59.7%), were sampled from the study site. They were *Aphanogmus fijiensis* (471 individuals, DS: 39.3%, WS: 60.7%), and *Ceraphron* sp. (23 individuals, DS: 60.9%, WS: 39.1%)

4. Chalcididae

Five Chalcidid species, comprising 793 individuals (DS: 34.4%, WS: 65.6%) of *Antrocephalus* sp. (62 individuals, DS: 58.1%, WS: 41.9%), *Brachymeria burski* (143, DS: 0.6%, WS: 99.4%), *Brachymeria excarinata* (150 individuals, DS: 34.0%, WS: 66.0%), *Brachymeria jambolana* (76 individuals, DS: 0%, WS: 100%), and *Brachymeria lasus* (362 individuals, DS: 51.1%, WS: 48.9%) were sampled.

5. Encyrtidae

Only one encyrtid parasitoid species, viz., *Ooencyrtus* sp., was collected from the study site. No parasitoid species were found in our collection in the DS. Eight individuals were collected during the WS.

6. Eulophidae

Ten eulophid species, consisting of 608 individuals (DS: 31.9%, WS: 68.1%), were sampled. The parasitoids collected were *Elasmus* sp. (82 individuals, DS: 40.2%, WS: 59.8%), *Elasmus* sp. 1 (94 individuals, DS: 27.7%, WS: 72.3%), *Elasmus* sp. 2 (39 individuals, DS: 17.9%, WS: 82.1%), *Euplectrus* sp. (16 individuals, DS: 18.8%, WS: 81.2%), *Hemiptarsenus oryzae* (11 individuals, DS: 27.2%, WS: 72.8%), *Pediobius* sp. (5 individuals, DS: 0%, WS:100%), *Sympiesis* sp. (101 individuals, DS: 29.7%, WS: 70.3%), *Tetrastichus schoenobii* (141 individuals, DS: 34.0%, WS: 66.0%), *Tetrastichus* sp. 1 (58 individuals, DS: 41.4%, WS: 58.6%), *Tetrastichus vayalicus* (61 individuals, DS: 32.8%, WS: 67.2%).

7. Dryinidae

Only one dryinid parasitoid species, viz., *Gonatopus flavifemur* with 135 individuals (DS: 29.6%, WS: 70.4%), was sampled from the study site.

8. Eupelmidae

Seventy-four Eupelmid wasps were collected (DS: 22.9%, WS: 77.1%), which consist of two species, viz., *Neanastatus* sp. 1 (52 individuals, DS: 21.2%, WS: 78.8%) and *Neanastatus* sp. 2 (22 individuals, DS: 27.3%, WS: 72.7%).

9. Eurytomidae

Three eurytomid species with 299 individuals (DS: 38.5%, WS: 61.5%) consisting of *Eurytoma manilensis* (146 individuals, DS: 34.2%, WS: 65.8%), *Eurytoma* sp. 1 (139 individuals, DS: 38.2%, WS: 61.8%), and *Eurytoma* sp. 2 (14 individuals, DS: 85.7%, WS: 14.3%), were sampled from the study site.

10. Ichneumonidae

One thousand two hundred and fourteen individuals (DS: 27.8%, WS: 72.2%) belonging to 26 species of Ichneumonids were collected. The percentage composition of ichneumonid wasps in the dry and wet seasons is given in Table 1.6.

In North Kerala rice fields, *Mesochorus* sp. (18.10%) had the highest percentage composition during the dry season, whereas *Casinaria ajanta* (14.32%) showed the highest percentage composition during the wet season.

Table 1.6. Percentage composition of Ichneumonid wasps in the dry and wet seasons.

Species	**Dry season (DS)**	**Wet season (WS)**
Barichneumon sp.	1.19	1.35
Casinaria ajanta	0.00	14.32
Charops bicolor	12.17	13.90
Charops plauta	0.00	0.31
Chirotica sp. 1	0.00	0.52
Chirotica sp. 2	1.48	0.21
Chorebus sp.	0.89	0.00
Diadegma sp.	0.00	0.21
Diadegma sp. 1	0.59	1.04
Diadegma sp. 2	0.00	1.14
Dictyonotus sp.	1.78	1.24
Goryphus basilaris	0.30	0.21
Goryphus sp.	1.78	1.45
Ischnojoppa luteator	7.42	5.19
Isotima sp. 1	3.86	5.91
Isotima sp. 2	2.08	5.91
Mesochorus sp.	18.10	12.86
Microcharops sp.	0.00	0.41
Orthocentrus sp.	2.08	0.62
Paraphylax sp. 1	5.64	4.25
Paraphylax sp. 2	1.19	1.66
Temelucha sp.	1.19	1.76
Trathala flavoorbitalis	10.98	9.02
Trichomma sp.	5.93	2.80
Xanthopimpla flavolineata	8.90	5.08
Xanthopimpla punctata	12.46	8.61

11. Mymaridae

Four Mymarid species with 131 individuals (DS: 48.9%, WS: 51.1%) consist of *Anagrus* sp. (42 individuals, DS: 57.1%, WS: 42.9%), *Gonatocerus* sp. 1 (21 individuals, DS: 33.3%, WS: 66.7%), *Gonatocerus* sp. 2 (50 individuals, DS: 54.0%, WS: 46.0%), and *Mymar* sp. (18 individuals, DS: 33.3%, WS: 66.7%), were sampled.

12. Platygastridae

Three hundred and sixty individuals (DS: 33.6%, WS: 66.4%) belonging to two species, namely *Macroteleia* sp. (325 individuals, DS: 34.2%, WS: 65.8%), and *Trissolcus* sp. (35 individuals, DS: 28.6%, WS: 71.4%), were collected.

13. Pteromalidae

Eight parasitoid species with 1433 individuals (DS: 33.0%, WS: 67.0%) consisting of the parasitoids, viz., *Callitula peethapada* (199 individuals, DS: 29.6%, WS: 70.4%), *Callitula rugosa* (49 individuals, DS: 38.8%, WS: 61.2%), *Callitula travancorensis* (275 individuals, DS: 39.6%, WS: 60.4%), *Panstenon* sp. (46 individuals, DS: 34.8%, WS: 65.2%), *Propicroscytus oryzae* (110 individuals, DS: 30.9%, WS: 69.1%), *Trichomalopsis apanteloctena* (278 individuals, DS: 29.9%, WS: 70.1%), *Trichomalopsis ovigastra* (121 individuals, DS: 33.9%, WS: 66.1%), and *Trichomalopsis thekkadiensis* (362 individuals, DS: 32.9%, WS: 67.1%) were sampled.

14. Scelionidae

One thousand seven hundred and fifty-four individuals (DS: 37.5%, WS: 62.5%) belonging to nine species, viz., *Gryon* sp. (321 individuals, DS: 40.5%, WS: 59.5%), *Platyscelio* sp. (203 individuals, DS: 35.5%, WS: 64.5%), *Scelio* sp., (48 individuals, DS: 37.5%, WS: 62.5%), *Telenomus oryzae* (265 individuals, DS: 35.1%, WS: 64.9%), *Telenomus remus* (558 individuals, DS: 38.2%, WS: 61.8%), *Telenomus rowani* (166 individuals, DS: 39.2%, WS: 60.8%), *Telenomus* sp. 1 (23 individuals, DS: 21.7%, WS: 78.3%), *Telenomus* sp. 2 (98 individuals, DS: 31.6%, WS: 68.4%), *Telenomus* sp. 3 (72 individuals, DS: 43.0%, WS: 57.0%) were collected.

15. Tachinidae

Three Tachinid species with 433 individuals (DS: 32.1%, WS: 67.9%) represented by *Argyrophylax* sp. (113 individuals, DS: 41.6%, WS: 58.4%), *Halidaia luteicornis* (235 individuals, DS: 30.6%, WS: 69.4%), and *Thecocarcelia* sp. (85 individuals, DS: 23.5%, WS: 76.5%) were sampled from the study site.

16. Trichogrammatidae

Six hundred and fifty-one individuals (DS: 45.9%, WS: 54.1%) belonging to two species, viz., *Trichogramma chilonis* (229 individuals, DS: 44.9%, WS: 55.1%), and *Trichogramma japonicum* (422 individuals, DS: 46.4%, WS: 53.6%), were collected from North Kerala. Fifteen and sixteen parasitoid families were collected during DS and WS respectively.

Table 1.7. Percentage composition of parasitoids in the three agro-ecological zones of North Kerala (Dry season).

Sl.No.	Parasitoid family	High hill	Foothill	Midland laterite
1	Bethylidae	0.65	1.11	0.64
2	Braconidae	35.18	23.65	18.27
3	Ceraphronidae	4.88	5.40	4.45
4	Chalcididae	5.95	8.57	5.91
5	Dryinidae	0.60	0.56	2.09
6	Eulophidae	3.10	3.25	9.18
7	Eupelmidae	0.36	0.40	0.55
8	Eurytomidae	1.55	4.05	3.45
9	Ichneumonidae	5.71	10.16	10.09
10	Mymaridae	2.20	0.87	0.00
11	Platygastridae	3.93	2.14	3.27
12	Pteromalidae	8.81	13.73	13.64
13	Scelionidae	15.71	16.03	17.55
14	Tachinidae	4.46	2.70	2.73
15	Trichogrammatidae	6.90	7.38	8.18
		100	100	100

In three consecutive DS and WS, the percentage composition of Braconidae was highest in all three agro-ecological zones (DS-35.18%, WS-29.67%), followed by Scelionidae in the DS (17.55%). The respective percentage compositions of the other parasitoid families are given in Table 1.7 and 1.8.

Table 1.8. Percentage species composition of parasitoids in the three agro-ecological zones of North Kerala (Wet season).

Sl.No.	Parasitoid family	High hill	Foothill	Midland laterite
1	Bethylidae	0.82	0.85	0.45
2	Braconidae	29.67	24.29	20.04
3	Ceraphronidae	3.04	3.96	4.47
4	Chalcididae	15.92	12.17	3.67

5	Dryinidae	0.70	0.89	2.91
6	Encyrtidae	0.11	0.16	0.00
7	Eulophidae	2.76	3.92	11.00
8	Eupelmidae	0.45	0.85	1.00
9	Eurytomidae	1.97	2.71	2.36
10	Ichneumonidae	7.71	16.17	10.20
11	Mymaridae	1.41	0.73	0.00
12	Platygastridae	3.09	2.87	2.91
13	Pteromalidae	11.25	12.17	13.01
14	Scelionidae	12.15	12.37	17.98
15	Tachinidae	4.33	3.23	3.01
16	Trichogrammatidae	4.64	2.67	6.98
		100	100	100

Host-parasitoid associations in the rice ecosystem

From the handpicked field collection of parasitized hosts, 66 parasitoid species belonging to 34 Genera and 11 Families (Bethylidae, Braconidae, Ceraphronidae, Chalcididae, Eulophidae, Eurytomidae, Ichneumonidae, Pteromalidae, Scelionidae, Tachinidae, and Trichogrammatidae) were reared as egg, larval, pupal, and hyperparasitoids in the laboratory. Of all reared parasitoids, 47 were primary parasitoids, including 43 Hymenopteran parasitoids, four Dipteran parasitoids, and 20 hymenopteran hyperparasitoids.

The egg parasitoids belong to four families viz., Eulophidae, Platygastridae, Scelionidae, and Trichogrammatidae comprising 11 parasitoid species (Eulophidae=1, Platygastridae=1, Scelionidae=6, and Trichogrammatidae=2). The genus *Telenomus* was the most dominant (n=7), and *T. remus* was the major generalist egg parasitoid of rice pests. It was reared from the eggs of six Lepidopteran species (Table1.9).

Table 1.9. Egg parasitoids reared from the rice pests of North Kerala.

Family	Parasitoid	Hosts
Eulophidae	*Tetrastichus schoenobii*	*Scirpophaga incertulas* *Scirpophaga innotata*
Platygastridae	*Gryon nixoni*	*Leptocorisa oratorious*
Scelionidae	*Telenomus remus*	*Mythimna separata* *Spodoptera mauritia* *Scirpophaga incertulas* *Scirpophaga innotata* *Psalis pennatula* *Pelopidas agna* *Pelopidas mathias*
	Telenomus rowani	*Scirpophaga incertulas*
	Telenomus oryzae	*Scotinophara bispinosa*
	Telenomus sp1.	*Pygomenida varipennis*
	Telenomus sp2.	*Creatonotus gangis*
	Telenomus sp3.	*Melanitis leda ismene*
Trichogrammatidae	*Trichogramma chilonis*	*Pelopidas agna* *Psalis pennatula* *Scirpophaga incertulas* *Scirpophaga innotata*
	Trichogramma japonicum	*Scirpophaga incertulas* *Scirpophaga innotata* *Cnaphalocrocis medinalis* *Pelopidas agna* *Pelopidas mathias*

The connectance value for the herbivore-egg parasitoid trophic web was recorded at 0.15 (Fig. 1.2). Additionally, an extensive proportion of overlap among egg parasitoids associated with herbivores was observed, reaching 0.30 overall. Specifically, nine pairs of herbivore species were interconnected by multiple parasitoids, with the most significant overlap identified between *S. incertulas* and *S. innotata* (n=4) (Table 1.10).

Fig. 1.2 Trophic interactions between herbivores and egg parasitoids in the rice ecosystem of North Kerala. Composite connectance web summarizing egg parasitism within the rice insect community. Insect pests: 1. *Cnaphalocrocis medinalis*, 2. *Creatonotus gangis*, 3. *Leptocorisa acuta*, 4. *Melanitis leda ismene*, 5. *Mythimna separata*, 6. *Pelopidas agna*, 7. *Pelopidas mathias*, 8. *Psalis pennatula*, 9. *Pygomenida variepennis*, 10. *Scirpophaga incertulas*, 11. *Scirpophaga innotata*, 12. *Scotinophara bispinosa*, 13. *Spodoptera mauritia*; Primary parasitoids: 1. *Gryon nixoni*, 2. *Tetrastichus schoenobii*, 3. *Telenomus remus*, 4. *Telenomus rowani*, 5. *Telenomus oryzae*, 6. *Telenomus* sp. 1, 7. *Telenomus* sp. 2, 8. *Telenomus* sp. 3, 9. *Trichogramma chilonis*, 10. *Trichogramma japonicum*.

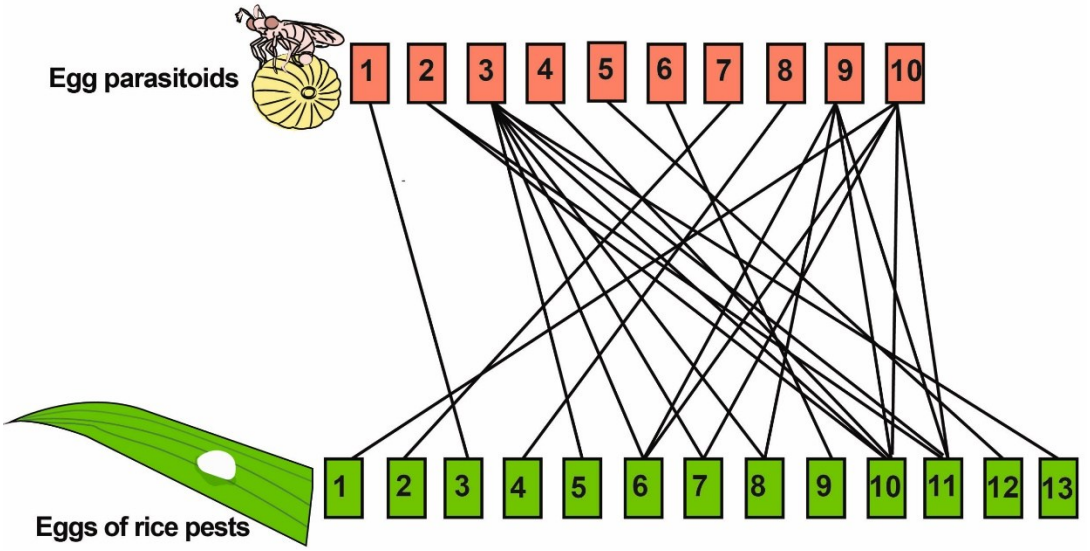


Table 1.10. The extent of egg parasitoid overlap among herbivores is depicted. It illustrates the count of shared egg parasitoid species between each potential pair of herbivore species.

Species	2	3	4	5	6	7	8	9	10	11	12	13
1					1	1			1	1		
2												
3												
4												
5					1	1	1		1	1		1
6						2	2		3	3		1
7							1		2	2		1
8									2	2		1
9												
10										4		
11												1
12												
13												

Hymenopteran and Dipteran larval parasitoids reared from the rice pests belonged to seven families comprising 30 parasitoid species (Hymenoptera=27, Diptera=3). Koinobiont endo parasitism was the most frequent nature of parasitism

reported from Braconidae (n=8), Ichneumonidae (n=9), and Tachinidae (n=3). Idiobiont ectoparasitism was more frequent in Eulophidae (n=5), followed by Bethylidae (n=3) (Table 1.11).

Table 1.11. Larval parasitoids reared from the rice pests of North Kerala

Order	**Family**	**Parasitoid**	**Nature of parasitism**	**Hosts**
Hymenoptera	Bethylidae	*Goniozus hanoiensis*	Idiobiont ecto parasitism	*Cnaphalocrocis medinalis*
		Goniozus platycephalus	Idiobiont ecto parasitism	*Cnaphalocrocis medinalis*
		Goniozus nr. *madrassipattanami*	Idiobiont ecto parasitism	*Cnaphalocrocis medinalis*
	Braconidae	*Apanteles* sp. 1	Koinobiont endo parasitism	*Pelopidas agna, Pelopidas mathias*
		Cotesia flavipes	Koinobiont endo parasitism	*Cnaphalocrocis medinalis*
		Cardiochiles philippinensis	Koinobiont endo parasitism	*Cnaphalocrocis medinalis*
		Apanteles sp. 2	Koinobiont endo parasitism	*Parapoynx stagnalis*
		Cotesia ruficrus	Koinobiont endo parasitism	*Spodoptera mauritia, Mythimna separata*
		Microplitis pennatula	Koinobiont endo parasitism	*Psalis pennatula*
		Microplitis narendrani	Koinobiont endo parasitism	*Psalis pennatula*
		Scutibracon hispa	Koinobiont endo parasitism	*Dicladispa armigera*
	Dryinidae	*Gonatopus flavifemur*	Idiobiont Ectoparasitism	*Nilaparvata lugens*
	Eulophidae	*Elasmus* sp.	Idiobiont ecto parasitism	*Cnaphalocrocis medinalis*

		Euplectrus sp.1	Idiobiont ecto parasitism	*Psalis pennatula*
		Euplectrus sp.2	Idiobiont ecto parasitism	*Orsotriaena medus*
		Hemiptarsenus orizae	Idiobiont ecto parasitism	*Helcystogramma arotraeum*
		Sympiesis sp.	Idiobiont ecto parasitism	*Ampittia dioscorides, Parnara* sp.
	Ichneumonidae	*Casinaria ajanta*	Koinobiont endo parasitism	*Ampittia dioscorides Parnara* sp.
		Charops bicolor	Koinobiont endo parasitism	*Psalis pennatula Pelopidas agna Pelopidas mathias Parnara* sp.
		Xanthopimpla punctata	Koinobiont endo parasitism	*Ampittia dioscorides*
		Diadegma sp. 1	Koinobiont endo parasitism	*Cnaphalocrocis medinalis*
		Diadegma sp. 2	Koinobiont endo parasitism	*Melanitis leda ismene*
		Microcharops sp.	Koinobiont endo parasitism	*Melanitis leda ismene*
		Dictyonotus sp.	Koinobiont endo parasitism	*Cnaphalocrocis medinalis*
		Trathala flavoorbitalis	Koinobiont endo parasitism	*Cnaphalocrocis medinalis*
		Goryphus cinctipes	Koinobiont endo parasitism	*Ampittia dioscorides*
	Pteromalidae	*Trichomalopsis apanteloctena*	Idiobiont ecto parasitism	*Pelopidas agna, Pelopidas mathias*
Diptera	Tachinidae	*Halidaia luteicornis*	Koinobiont endo parasitism	*Parnara* sp. *Pelopidas agna*
		Argyrophylax nigrotibialis	Koinobiont endo parasitism	*Parnara* sp. *Pelopidas agna Pelopidas mathias*
		Thecocarcelia sp.	Koinobiont endo	*Mythimna separata*

parasitism

The connectance value for the herbivore–larval parasitoid trophic web (Fig. 1.3) was determined to be 0.088. Additionally, the proportion of larval parasitoid overlap among the herbivores was calculated to be 0.066. Four pairs of caterpillar species were found to be interconnected by multiple larval parasitoids. Specifically, the highest number of shared parasitoids (n=4) was observed between *P. agna* and *P. mathias* (Table 1.12).

Fig. 1.3 Trophic interactions between herbivores and larval parasitoids in the rice ecosystem of North Kerala. Composite connectance web summarizing larval parasitism within the rice insect community. Insect pests: 1. *Ampittia dioscorides*, 2. *Cnaphalocrocis medinalis*, 3. *Dicladispa armigera*, 4. *Helcystogramma arotraeum*, 5. *Leptispa pygmaea*, 6. *Melanitis leda ismene*, 7. *Mythimna separata*, 8. *Nilaparvata lugens*, 9. *Orsotriaena medus*, 10. *Parapoynx stagnalis*, 11. *Pelopidas agna*, 12. *Pelopidas mathias*, 13. *Parnara* sp., 14. *Psalis pennatula*, 15. *Spodoptera mauritia*; Primary parasitoids: 1. *Apanteles* sp. 1, 2. *Apanteles* sp. 2, 3. *Argyrophylax nigrotibialis*, 4. *Cardiochiles philippinensis*, 5. *Casinaria ajanta*, 6. *Charops bicolor*, 7. *Cotesia flavipes*, 8. *Cotesia ruficrus*, 9. *Diadegma* sp.1., 10. *Diadegma* sp.2, 11. *Dictyonotus* sp., 12. *Elasmus* sp., 13. *Euplectrus* sp. 1, 14. *Euplectrus* sp. 2, 15. *Gonatopus flavifemur*, 16. *Goniozus hanoiensis*, 17. *Goniozus* nr. *madrassipattanami*, 18. *Goniozus platycephalus*, 19. *Goryphus cinctipes*, 20. *Halidaia luteicornis*, 21. *Hemiptarsenus oryzae*, 22. *Microcharops* sp., 23. *Microplitis narendrani*, 24. *Microplitis pennatula*, 25. *Scutibracon hispa*, 26. *Sympiesis* sp., 27. *Trathala flavoorbitalis*, 28. *Trichomalopsis apanteloctena*, 29. *Xanthopimpla flavolineata*, 30. *Xanthopimpla punctata*.

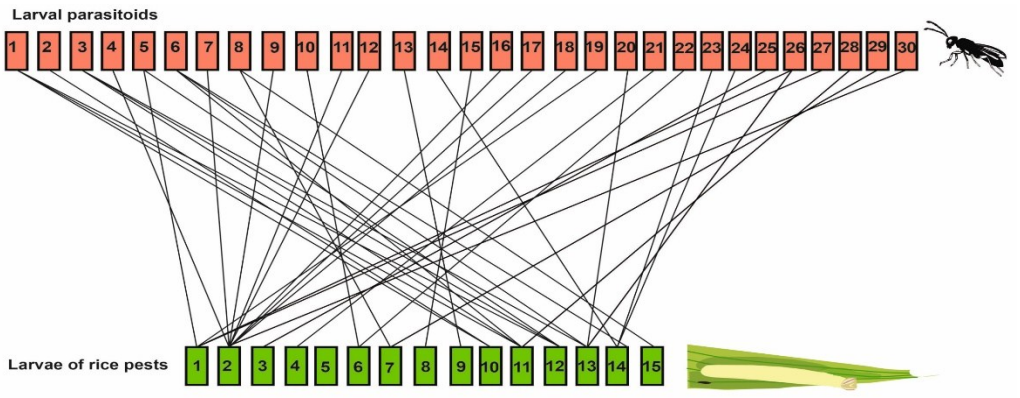
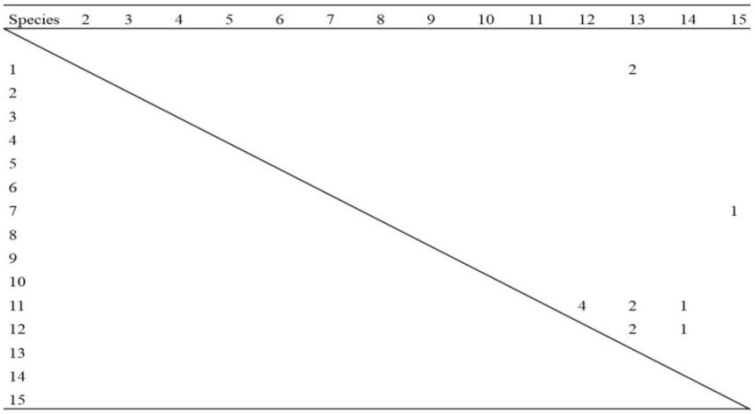


Table 1.12. The extent of larval parasitoid overlap among herbivores is depicted. It illustrates the count of shared larval parasitoid species between each potential pair of herbivore species.



Both Hymenopteran and Dipteran parasitoids emerged from the pupae of rice insects. Emergence of Ichneumonid wasps was the highest (n=4), followed by Tachinidae (n=3). The highest number of pupal parasitoids emerged from *P. agna* (n=7) (Table.1.13).

Table 1.13. Pupal parasitoids reared from the rice pests of North Kerala

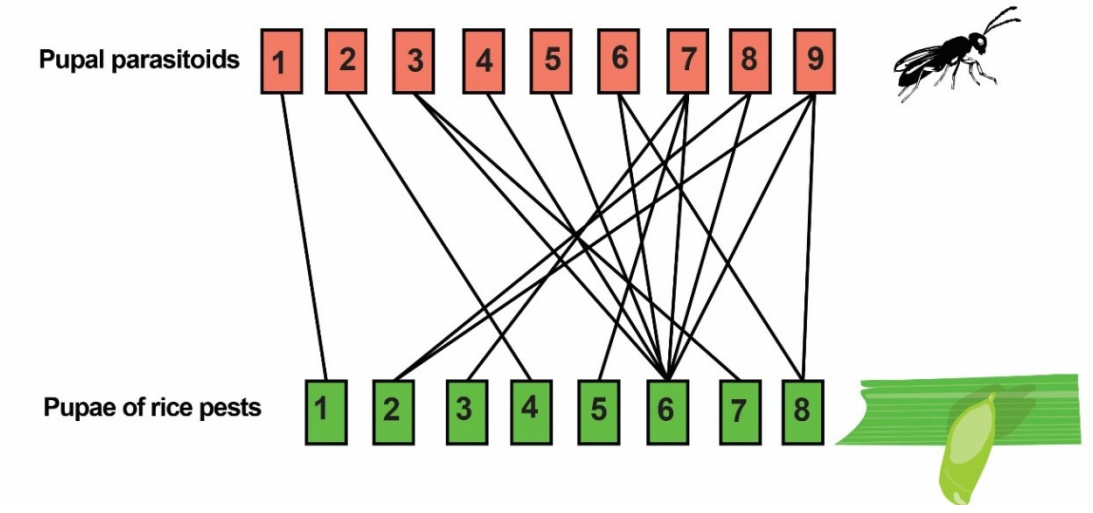
Order	**Family**	**Parasitoid**	**Hosts**
Hymenoptera	Braconidae	*Aspidobracon noyesi*	*Pelopidas agna* *Pelopidas mathias*
	Ichneumonidae	*Goryphus basilaris*	*Pelopidas agna*
		Xanthopimpla flavolineata	*Cnaphalocrocis medinalis,* *Pelopidas agna*
		Xanthopimpla punctata	*Cnaphalocrocis medinalis,* *Pelopidas agna,* *Psalis pennatula*
		Barichneumon sp.	*Pelopidas agna*
		Agrypon sp.	*Ampittia dioscorides*
Diptera	Tachinidae	*Argyrophylax* sp.	*Orsotriaena medus*
		Thecocarcelia sp.	*Parnara* sp. *Melanitis leda ismene* *Pelopidas agna*
		Senometopia sp.	*Psalis pennatula* *Pelopidas agna*

The connectance of the herbivore–pupal parasitoid trophic web (Fig. 1.4) was 0.221. The proportion of pupal parasitoid overlap between the herbivore species was 0.25, and the pupae of two pairs of herbivore species were linked by more than one parasitoid (Table 1.14).

Table 1.14. The extent of pupal parasitoid overlap among herbivores is depicted in the table. It illustrates the count of shared pupal parasitoid species between each potential pair of herbivore species.

Species	2	3	4	5	6	7	8
1							
2					2		1
3				1	1		
4							
5					1		
6						1	2
7							
8							

Fig. 1.4 Trophic interactions between herbivores and parasitoids in the rice ecosystem of North Kerala. Composite connectance web summarizing pupal parasitism and within the rice insect community. Insect pests: 1. *Ampittia dioscorides*, 2. *Cnaphalocrocis medinalis*, 3. *Melanitis leda ismene*, 4. *Orsotriaena medus*, 5. *Parnara* sp., 6. *Pelopidas agna*, 7. *Pelopidas mathias*, 8. *Psalis pennatula*; Primary parasitoids: 1. *Agrypon* sp., 2. *Argyrophylax* sp., 3. *Aspidobracon noyesi*, 4. *Barichneumon* sp., 5. *Goryphus basilaris*, 6. *Senometopia* sp., 7. *Thecocarcelia* sp., 8. *Xanthopimpla flavolineata*, 9. *Xanthopimpla punctata*.

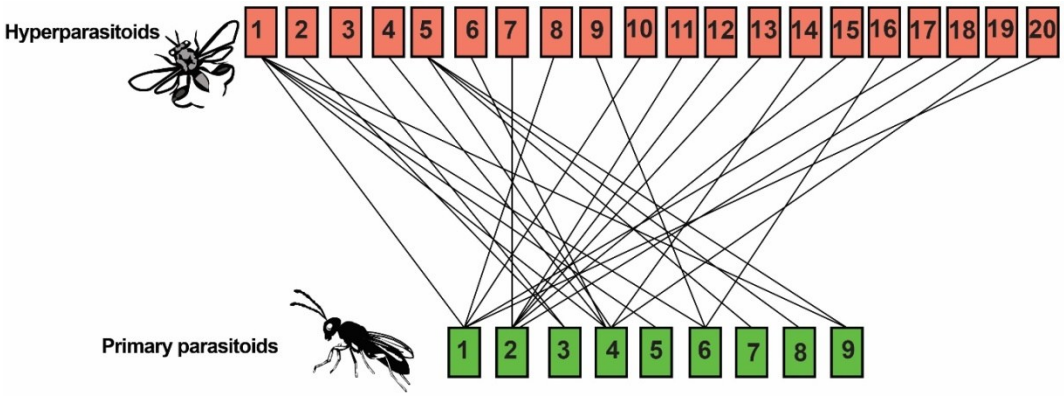


Hyperparasitoids belonging to six families comprising 20 parasitoid species were recorded. Braconidae and Ichneumonidae are more susceptible to attack of hyperparasitoids and the highest number of secondary parasitoids emerged from the pupae of *C. ajanta* (n=8), followed by *Apanteles* sp. 2 (n=6) (Table 1.15).

Table 1.15. Hyperparasitoids emerged from the primary parasitoids of rice pests of North Kerala.

Order	**Family**	**Parasitoid**	**Hosts**
Hymenoptera	Ceraphronidae	*Aphanogmus fijiensis*	*Apanteles* sp. 1, *Casinaria ajanta, Cotesia flavipes, Cotesia ruficrus, Trathala flavoorbitalis*
	Chalcididae	*Brachymeria excarinata*	*Aspidobracon noyesi*
		Brachymeria lasus	*Casinaria ajanta Charops bicolor Diadegma* sp. *Trathala flavoorbitalis*
		Brachymeria burski	*Casinaria ajanta*
		Brachymeria jambolana	*Casinaria ajanta*
	Eulophidae	*Tetrastichus vayalicus*	*Apanteles* sp. 1
		Tetrastichus sp. 1	*Apanteles* sp. 2
		Tetrastichus sp. 2	*Casinaria ajanta*
		Elasmus sp. 1	*Casinaria ajanta*
		Elasmus sp. 2	*Apanteles* sp. 2
	Eurytomidae	*Eurytoma manilensis*	*Apanteles* sp. 1
	Ichneumonidae	*Mesochorus* sp.	*Cotesia ruficrus*
		Paraphylax sp. 1	*Apanteles* sp. 1
		Paraphylax sp. 2	*Apanteles* sp. 2
		Paraphylax sp. 3	*Apanteles* sp. 2
		Paraphylax sp. 4	*Apanteles* sp. 2
	Pteromalidae	*Trichomalopsis apanteloctenus*	*Apanteles* sp. 1
		Pteromalid sp. 1	*Casinaria ajanta*
		Pteromalid sp. 2	*Apanteles* sp. 2
		Pteromalid sp. 3	*Cotesia ruficrus*

Fig. 1.5 Trophic interactions between primary parasitoids and hyperparasitoids in the rice ecosystem of North Kerala. Composite connectance web summarizing hyperparasitism within the rice insect community. Primary parasitoids: 1. *Apanteles* sp.1, 2. *Apanteles* sp. 2, 3. *Aspidobracon noyesi*, 4. *Casinaria ajanta*, 5. *Cotesia flavipes*, 6. *Cotesia ruficrus*, 7. *Charops bicolor*, 8. *Diadegma* sp., 9. *Trathala flavoorbitalis*; Hyperparasitoids: 1. *Aphanogmus fijiensis*, 2. *Brachymeria burski*, 3. *Brachymeria excarinata*, 4. *Brachymeria jambolana*, 5. *Brachymeria lasus*, 6. *Elasmus* sp.1, 7. *Elasmus* sp. 2, 8. *Eurytoma manilensis*, 9. *Mesochorus* sp., 10. *Paraphylax* sp.1, 11. *Paraphylax* sp. 2, 12. *Paraphylax* sp. 3, 13. *Paraphylax* sp. 4, 14. Pteromalid sp.1, 15. Pteromalid sp. 2, 16. Pteromalid sp. 3, 17. *Tetrastichus vayalicus*, 18. *Tetrastichus* sp.1, 19. *Tetrastichus* sp. 2, 20. *Trichomalopsis apanteloctena*.



The connectance value for the primary parasitoid-hyperparasitoid trophic web was recorded at 0.15 (Fig. 1.5). Overall, the hyperparasitoid overlap among the primary parasitoids was 0.416. Only one pair of primary parasitoid species was found to be interconnected by multiple hyperparasitoids (Table 1.16).

Table 1.16. Hyperparasitoid overlap among primary parasitoids.

Species	2	3	4	5	6	7	8	9
1			1	1	1			1
2								
3								
4				1	1	1	1	2
5					1			1
6								1
7							1	1
8								1
9								

Fig. 1.6 Biology of major rice insect pest in the rice ecosystems of North Kerala.
Cnaphalocrocis medinalis: a. Eggs, b. Larva, c. Pupa, d. Adult, e. leaf shelter with visible sign of rice plant damage; *Parapoynx stagnalis*: f. Larva, g. leaf shelter, h. feeding the rice plant, i. Pupa, j. Pupa within the silken cocoon, k. Adult

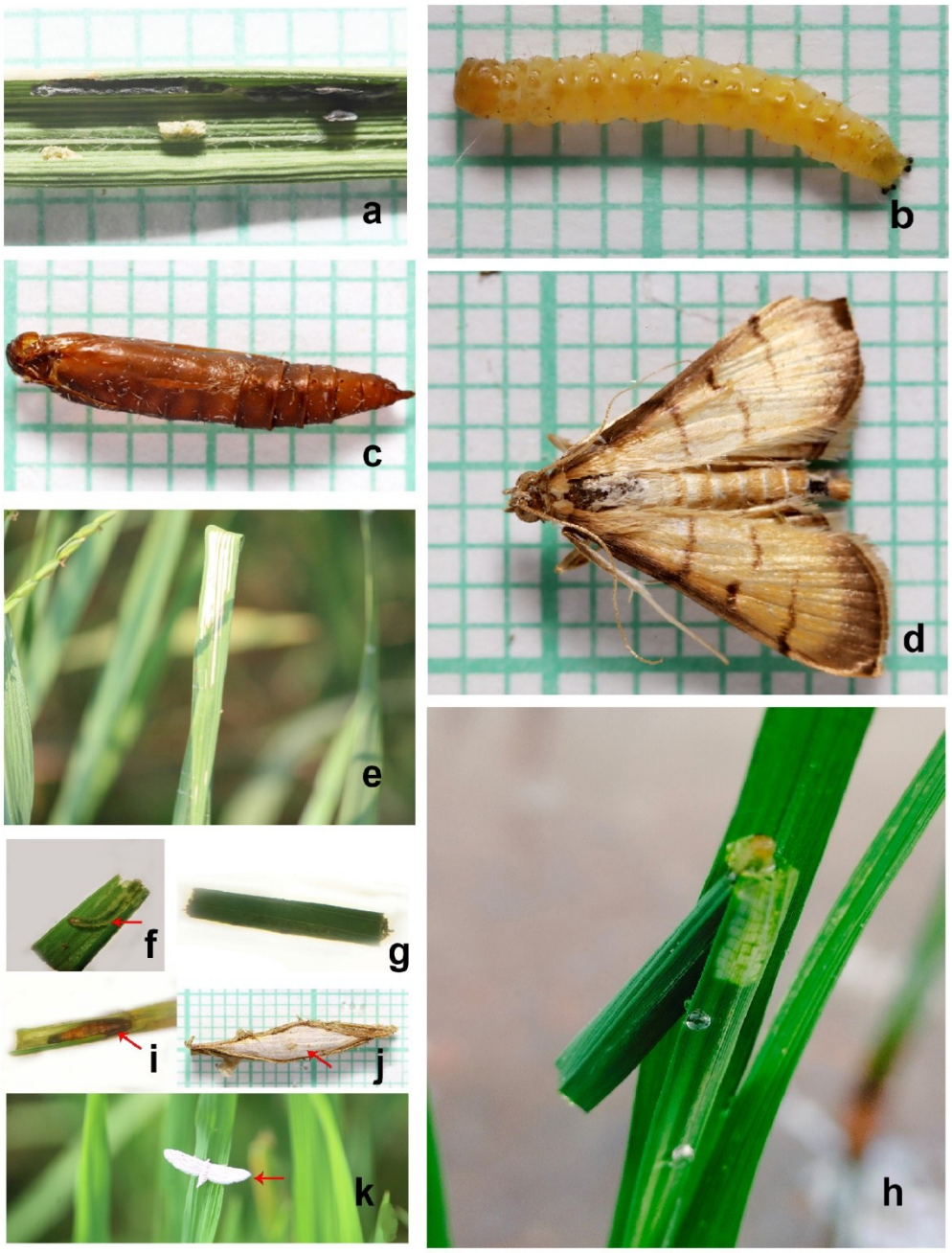
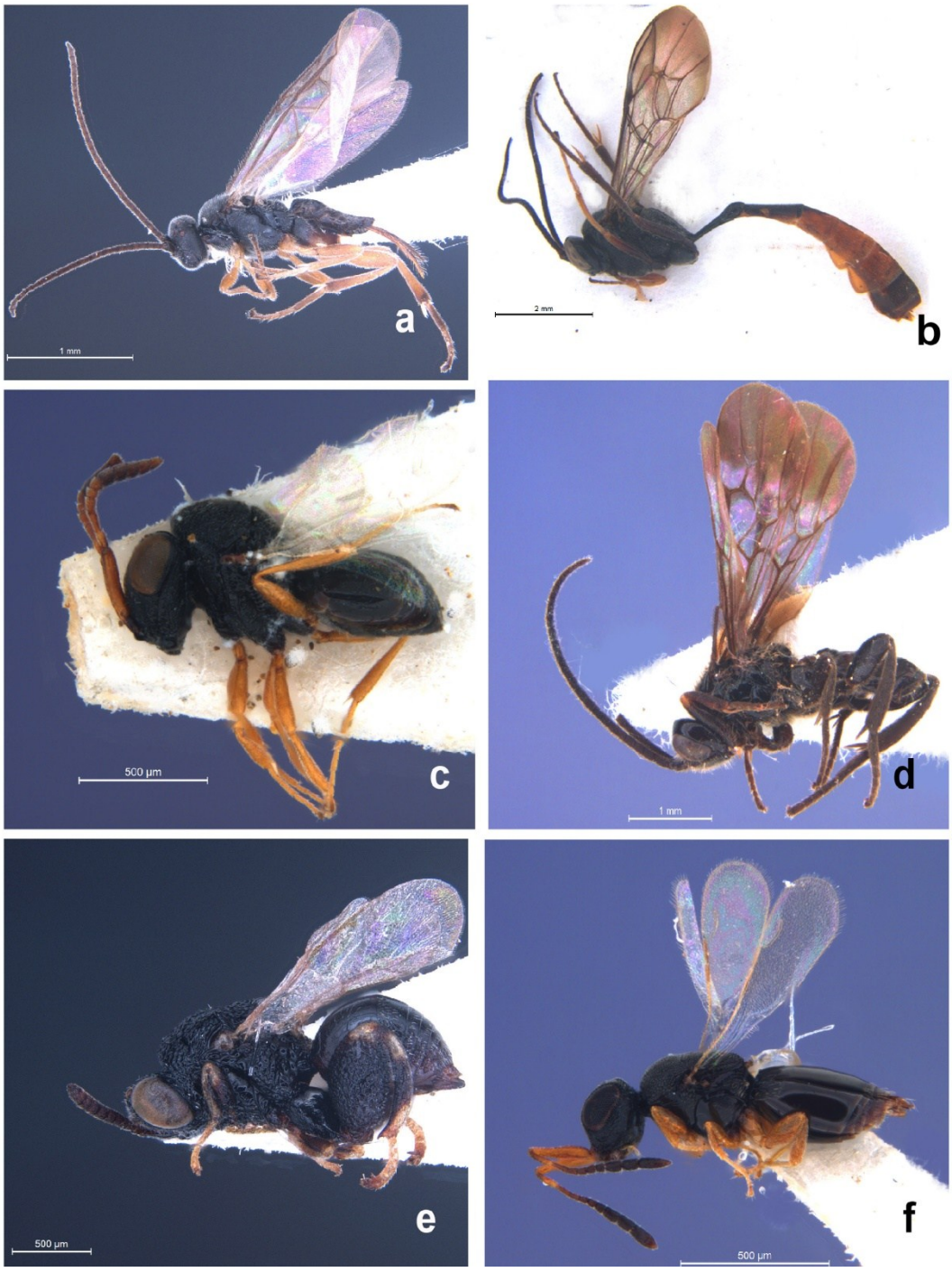


Fig. 1.7 Major parasitoids in the rice ecosystems of North Kerala.
a. *Apanteles* sp. (Larval parasitoid), b. *Casinaria ajanta* (Larval parasitoid), c. *Telenomus* sp. (Egg parasitoid), d. *Cardiochiles philippinensis* (Larval parasitoid), e. *Brachymeria* sp. (Pupal parasitoid), f. *Aphanogmus fijiensis* (Hyperparasitoid).



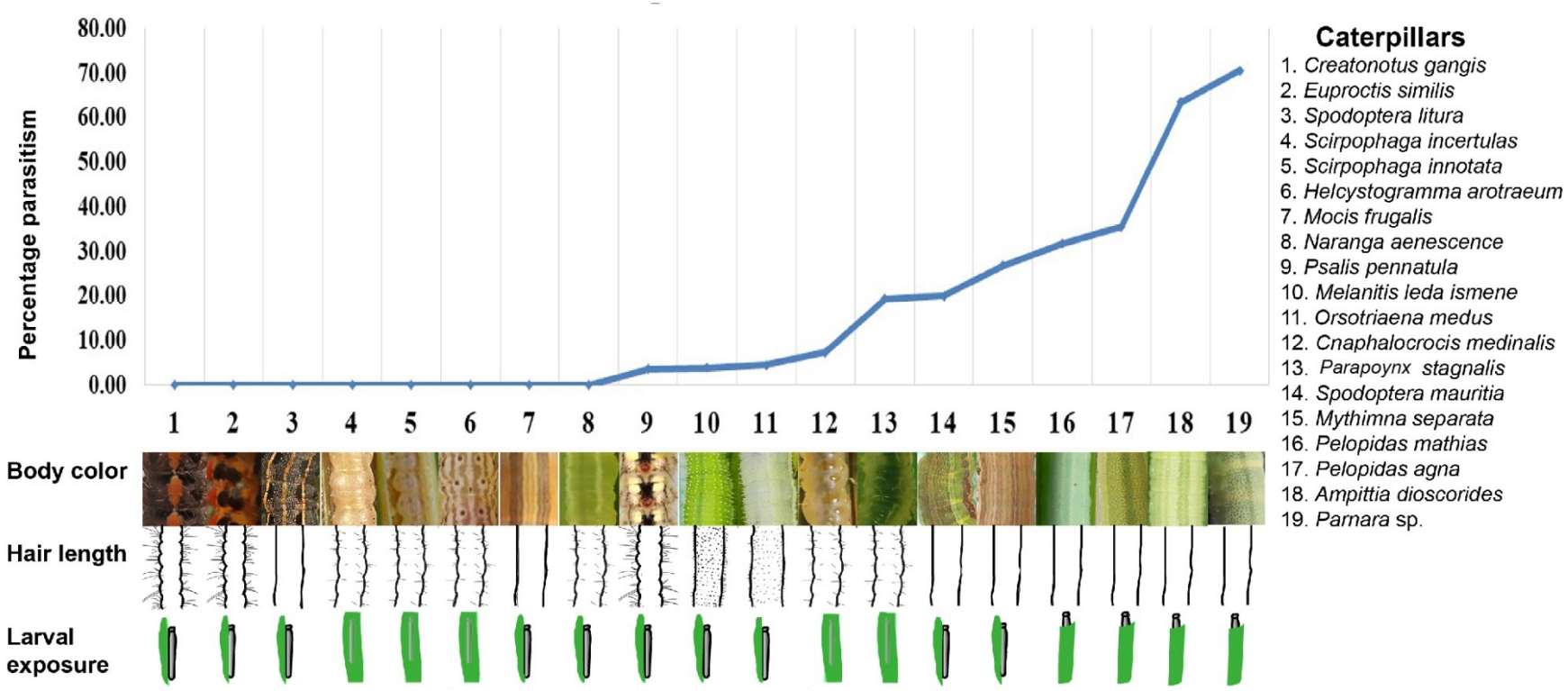
Parasitoid defense strategy in Lepidopteran rice pests

In order to avoid parasitoids, insects exhibit different defense mechanisms. Clutch size and egg covering status (eggs with or without covering) were chosen as variables to determine the factors affecting the rate of egg parasitism. Kruskal-Wallis test and Dunn's post hoc test were used to test the level of significance. A significant difference was observed between egg parasitism with clutch size and eggs without covering ($H = 16.73$, $df = 18$, $p < 0.0002$). In Dunn's post hoc test, clutch size ($p = 0.011$) and eggs without covering ($p = 0.001$) were significant. Kendall's tau correlation coefficient was used to test the correlation between parasitism rate and the two variables. A positive correlation was observed between clutch size ($r = 0.4385$, $p = 0.008$) and egg parasitism. A negative correlation was observed between eggs without covering (naked eggs) and parasitism ($r = -0.3515$, $p = 0.035$).

The significance of larval morphological features, viz., skin color, hair length, and larval exposure against the parasitization rate, was tested (Fig. 1.6) Statistical analysis revealed that both larval hair length and the degree of larval exposure significantly affected parasitism rates. Exposure type refers to how visibly larvae are positioned in their habitat whether fully exposed, partially hidden (semi-exposed), or completely concealed within plant structures. The Kruskal-Wallis test, followed by Dunn's post hoc comparisons, showed significant differences in parasitism rates based on hair length ($p = 0.004$) and exposure type ($p = 0.007$), while larval skin color had no significant effect ($p = 0.773$).

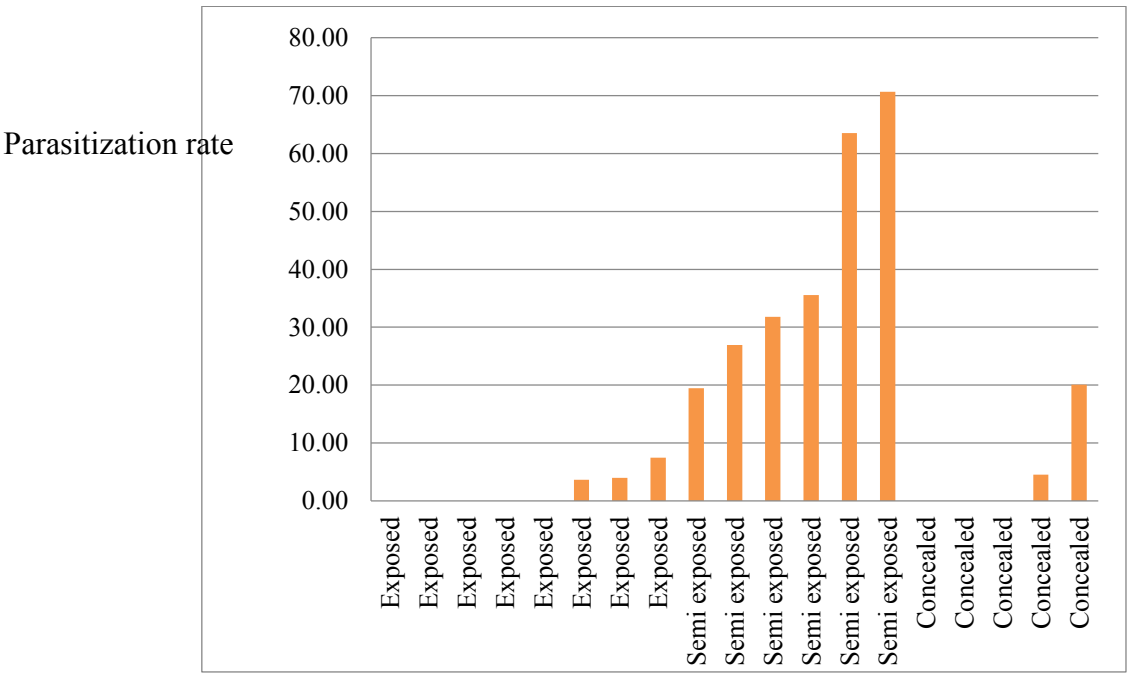
Further analysis using Spearman's rank correlation identified a significant negative relationship between hair length and parasitism ($r = –0.465$, $p = 0.005$), indicating that larvae with longer hair experienced lower parasitism. Although no significant monotonic trend was found when treating larval exposure as an ordered variable ($r = –0.121$, $p = 0.467$), further analysis using binary comparisons revealed a more detailed pattern. Spearman's rank correlation showed a strong positive association between parasitism and semi-exposed larvae ($r = 0.816$, $p < 0.001$), indicating that parasitism rates were substantially higher in this group.

Fig. 1.8 Anti parasitoid defense strategy of herbivores in rice ecosystem. Morphological features such as larval body color, hair length, and larval exposure (based on the nature of larval shelters) summarize its effect on the parasitization rate in the rice ecosystem. The graph is placed in the increasing order of parasitization rate and the combination of defense strategy of caterpillars shown above.



In contrast, fully exposed larvae showed a moderate negative correlation with parasitism ($r = –0.536$, $p = 0.018$), suggesting reduced vulnerability, while concealed larvae exhibited a weak, non-significant negative correlation ($r = –0.261$, $p = 0.281$).

Fig. 1.9 The relation between larval exposure and larval parasitism in rice pests.



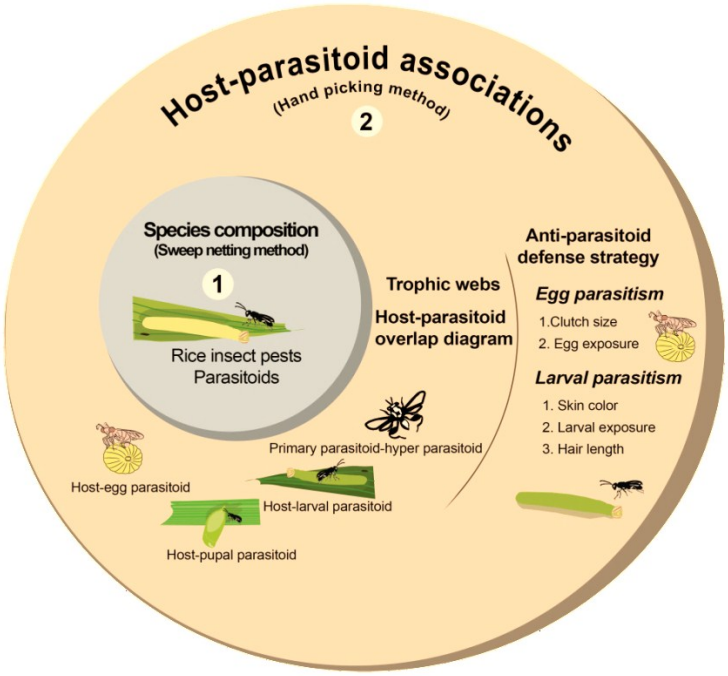
In this study, semi-concealment emerged as a key morphological trait associated with increased susceptibility to parasitism in lepidopteran rice pests. *Parapoynx stagnalis*, which constructs partially enclosed tubular shelters from folded rice leaves (Fig. 1.6g), recorded a parasitism rate of 20.09%, noticeably higher than that observed in fully concealed species. This pattern supports the overall trend in the dataset, where semi-concealed larvae consistently experienced the highest levels of parasitism compared to both exposed and fully concealed larvae. Additional observations revealed that parasitized *P. stagnalis* larvae often modified their shelters after attack by *Apanteles* sp, the primary parasitoid. Specifically, they sealed both ends of their leaf-case with silk and attached it more securely to the plant surface. This structural change, likely influenced by parasitoid development within the host, appeared to restrict movement and reduce the chances of further parasitoid entry. As a result, hyperparasitism rates by *Elasmus* sp. and *Paraphylax* sp. in these

modified shelters remained very low (0.6% -1%) despite high primary parasitism rates.

Discussion

This study is the first systematic report of the trophic interaction of the rice pest parasitoid complex and the morphological anti-parasitoid defense strategy of lepidopteran pests in association with the species makeup of rice insect pests and parasitoids in North Kerala (Fig. 1.8). The findings of the study provide insight into several aspects related to the species composition of insect pests and their associated parasitoids in agricultural ecosystems, focusing on their distribution and potential implications for pest management strategies. The results revealed several key insights into the intricate relationships between pest species and their parasitoids, shedding light on the complex dynamics within these ecological communities.

Fig. 1.10 The two aspects of the study carried out. Species composition (1) and host-parasitoid associations (2) of rice insects.



Species composition of rice insect pests and parasitoids

The results revealed a diverse spectrum of insect species belonging to four distinct orders and 15 families, with Lepidoptera exhibiting the highest species

richness among the collected insects. This dominance of Lepidoptera in both species richness and abundance across all agro-ecological zones underscores its significance as a crucial component in the local rice pest community. It may be attributed to their host plant preferences, adaptability to agricultural landscapes, feeding habits, life cycle characteristics, reduced predation pressure (Bito et al., 2011), and potential tolerance to pesticides commonly used in rice cultivation. Conversely, while Coleoptera exhibited lower species richness, specific species like *Dicladispa armigera* and *Leptispa pygmaea* were observed to have significant population fluctuations across dry and wet seasons, potentially impacting rice crops. It may be because *D. armigera* and *L. pygmaea* prefer specific habitats or food sources that fluctuate between dry and wet seasons. Environmental conditions during different seasons can influence the availability of suitable breeding sites or food resources, affecting their population sizes accordingly. Among Lepidopterans, Erebidae had the highest species richness in the rice fields of North Kerala. Some species within the Erebidae family are known pests of various crops (Kitching et al., 1998), including rice. Higher numbers of these pest species can escalate pest pressure in rice fields, leading to increased crop damage and yield losses. The study site was home to four Hesperiid species: *Ampittia dioscorides*, *Pelopidas agna, P. mathias*, and *Parnara* species. They are common in rice fields. Skippers, notably the Hesperiidae family, strongly prefer grassy habitats, finding rice fields an ideal environment due to the structural and nutritional attributes of rice plants (Grist and Lever, 1969), contributing to their prevalence in rice fields. However, the dominance of Hesperiidae in rice fields may vary based on geographic regions, farming practices, climate, and natural enemy diversity.

A noticeable seasonal variation in insect abundance was evident, with wet seasons displaying higher insect populations than dry seasons. This pattern may align with the increased availability of resources such as water (Pathak, 1968) and vegetation during wet seasons, facilitating favorable conditions for insect breeding and population growth. Moreover, the increased nutrient influx and abundant water supply may have improved crop growth, which would have increased the pest population. More tiller growth may have resulted from the rice transplanting

method, the abundant water supply during the rainy season, the nitrogen availability (Evers et al., 2006), and the organic nutrients washed into the rice fields from the adjacent home gardens and forests. Farmers in North Kerala claimed that amid heavy rains, a significant amount of alluvial soil was deposited in paddy fields, which may have also aided crop growth (Nambudiri, 2018). For instance, the prevalence of various Lepidopteran species, including *Cnaphalocrocis medinalis* and *Parapoynx stagnalis* (e.g., Pathak, 1968), was notably higher during wet seasons, suggesting a correlation between their population dynamics and suitable habitat conditions.

Dry seasons often create conditions that are less favorable for the proliferation of insect pests. Reduced humidity and moisture levels can limit the survival and reproduction of certain pests that thrive in humid environments. Additionally, extreme temperatures or prolonged dry conditions may negatively impact the development and survival of insect populations (e.g., Hu et al., 2016). Furthermore, the seasonal variations in pest management practices, such as pesticide applications or cultural control methods, could influence the population dynamics of these insects.

Additionally, the study highlighted zone-specific preferences among certain insect species. For instance, while some pests like *Cofana spectra* exhibited comparable population distributions across all zones, others, such as *Pyrilla perpusilla*, were more predominant in specific zones (midland laterite), indicating potential ecological niche preferences. Moreover, the emergence of particular species like *C. medinalis* as a dominant pest in the midland laterite region during the dry season necessitates targeted pest management strategies specific to each zone and season. The observations on the prevalence of *C. medinalis* in the dry season across the foothill and midland laterite areas and the dominance of *P. stagnalis* in the high hill zone suggest a strong correlation between insect species distribution and specific ecological conditions. This pattern may be influenced by the climate suitability for these species in different zones, as supported by previous studies associating *C. medinalis* dominance with drier climates (Ali et al., 2019) and *P.*

stagnalis prevalence with humid, high-rainfall regions (Heinrichs and Viajante, 1987; Pathak and Khan, 1994). The findings of Kawazu et al. (2005), Park et al. (2010a), and Park et al. (2010b) further support this observation, emphasizing the influence of geographical regions on the outbreak of *C. medinalis* populations.

Conversely, the midland laterite region consistently supported a higher composition of *C. medinalis* across both dry and wet seasons, possibly due to distinct agro-climatic features favoring this species' prevalence. Moreover, the scarcity of certain pest species like *C. versicolor*, *Lyclene* sp., and *M. frugalis* in the midland laterite zone during the wet season could be attributed to specific biotic and abiotic factors operating within the rice agro-ecosystem. Biotic factors are likely to include limited availability of preferred host plants, increased interspecific competition, or greater pressure from natural enemies such as parasitoids and predators. Abiotic influences, such as the poor water-holding capacity of laterite soils, fluctuations in temperature and humidity, and inconsistent moisture availability due to rainfall variability, possibly constrain the establishment and proliferation of these species in the midland laterite zone. These observations underscore the complex interplay of environmental factors, geographic nuances, and pest species adaptability, emphasizing the need for region-specific pest management strategies tailored to the ecological characteristics of each zone.

The study identified a diverse array of insect pests across various rice ecosystems, with distinct compositions observed in different geographical regions. This variation in species richness and abundance underscores the importance of local environmental factors in shaping the pest community structure. Moreover, the presence of multiple pest species within the same agro-ecosystem highlights the need for multifaceted pest management approaches to mitigate crop damage effectively.

Conversely, the study revealed an equally diverse community of parasitoids associated with the insect pests. The diversity of parasitoid species reflects the intricate nature of biological control mechanisms operating in these ecosystems. The

prevalence and distribution of specific parasitoid species suggest their potential role in regulating pest populations, thereby influencing pest outbreaks and crop damage.

The findings of the present study highlight the prevalence and dominance of parasitic wasps, particularly from the families Ichneumonidae and Braconidae, in the rice fields of North Kerala. The data revealed the occurrence of 27 species of Ichneumonidae and 20 species of Braconidae, suggesting the prominence of these families in the local rice agro-ecosystem. Ichneumonidae is recognized for its vast species diversity globally, and their prevalence in rice fields further emphasizes their ecological significance within this specific agro-ecosystem (e.g., Wahl, 1993). Numerous species within the Ichneumonidae family in rice fields suggest a complex and diverse community of parasitoids, indicating their adaptation to this environment and potential specialization in preying upon or parasitizing various pest species found within the rice ecosystem. Understanding the species richness of Ichneumonidae parasitoids in rice fields is crucial for comprehending their ecological impact, relationships with other organisms, and their potential contributions to sustainable pest management practices in agriculture.

The study conducted in North Kerala during consecutive dry and wet seasons provided insights into the varying prevalence of parasitoid wasp families across different agricultural zones. Braconidae emerged as the most prevalent family, accounting for 35.18% during the dry season and 29.67% during the wet season. Within Braconidae, microgastrine wasps, particularly *Apanteles* sp., were notably abundant, consistent with previous findings identifying *Apanteles* as the predominant genus in Kerala's rice fields (Ranjith et al., 2015b). The abundance of Ichneumonidae followed by Braconidae, with *Casinaria ajanta* being prominent in the foothill region, contributes significantly to the species composition. The diverse species observed across different altitudes and ecological zones indicate how biotic and abiotic environmental factors can influence the structure of these parasitoid wasp communities (e.g., Shmida and Wilson, 1985). Additionally, Chalcididae exhibited substantial representation in the high hill region during the wet season, potentially due to favorable climatic conditions. Furthermore, Scelionidae showed

significant presence across various zones, particularly in the midland laterite during both dry and wet seasons, with *Telenomus remus*, a generalist egg parasitoid, being notably prevalent, possibly due to favorable conditions for host availability.

The study also highlights a discrepancy in the occurrence of two parasitoid families across different zones. Specifically, Mymaridae were absent in the collected samples in the midland laterite zone throughout both dry and wet seasons, while Encyrtid species were absent in all zones during the dry season. The absence or presence of certain parasitoids, such as Encyrtids and Mymarids, in specific zones during different seasons might be due to the influence of a combination of ecological factors, host availability, and the intricacies of their life cycles.

Host-parasitoid associations

Host-parasitoid associations refer to ecological relationships between a host organism and a parasitic species living in or on the host, deriving its nourishment from the host's body while typically causing death to the host (Schmidt et al., 2008). These associations are integral to natural ecosystems and can significantly impact population dynamics, biodiversity, and ecological balance. Studying these interactions helps elucidate the complex ecological networks and aids in conserving host and parasitoid diversity, vital for maintaining ecosystem health and resilience.

The study highlights *Telenomus* as the dominant genus of egg parasitoids, encompassing seven species, particularly emphasizing *T. remus* as a major generalist egg parasitoid for controlling rice pests. This species exhibited effectiveness against eggs from six distinct lepidopteran species: *Mythimna separata*, *Spodoptera mauritia*, *Scirpophaga incertulas*, *Scirpophaga innotata*, *Psalis pennatula*, *Pelopidas agna*, and *Pelopidas mathias*. *Telenomus remus* (Hymenoptera: Scelionidae) is a promising biological control candidate as noted by Tang et al. (2010) and Kenis et al. (2019). The present study indicates that when there is a higher availability or abundance of host eggs in a specific area or habitat, there is an increased likelihood or frequency of those eggs being parasitized by parasitoids (e.g., Kemp and Simmons, 1978). However, it is important to note

that while this relationship generally holds in many ecological scenarios, it may not be universal (Yu and Byers, 1994)

Koinobiont endo parasitism was the most frequent type of larval parasitism in the study region and was reported from Braconidae (n=8), Ichneumoniidae (n=9), and Tachinidae (n=3). This type of parasitism was common in semi-exposed, soft-bodied larvae. Idiobiont ecto-parasitism was more frequent in Eulophidae (n=5), followed by Bethylidae (n=3).

The study highlights two main parasitic strategies adopted by parasitoid wasps, known as koinobionts and idiobionts, which differ in their host specificity. Idiobiont ectoparasitism, notably seen in hairy caterpillars and concealed lepidopteran larvae in the study region in align with Quicke (2015). The study identified Eulophidae genera, such as *Euplectrus* and *Sympiesis*, exhibiting this parasitic behavior. *Euplectrus* sp. preferred tubercle-covered or tufty-haired exposed caterpillars for oviposition, while *Sympiesis* preferred semi-exposed shelter-building caterpillars. This demonstrates how different parasitoid families and genera exhibit varying parasitic strategies, targeting specific host characteristics or behaviors for their parasitization due to their evolutionary adaptations to optimize their reproductive success within their specific ecological niches. These variations may arise from the diverse selection pressures imposed by the hosts' characteristics and behaviors. These variations may arise from the diverse selection pressures imposed by the hosts' characteristics and behaviors.

The study found that ichneumonid species were the primary parasitoids attacking pupae of rice pests, followed by Tachinidae. This discovery was consistent with the findings of Aubert (1969), who noted that Ichneumonidae commonly target larvae or pupae of various insects belonging to the Lepidoptera, Coleoptera, and Hymenoptera orders. The prevalence of *Pelopidas agna*, a butterfly species, was notably high at the study sites. The higher parasitization of *P. agna* pupae by ichneumonids could be linked to its increased abundance, as parasitism rates generally correlate with the host's abundance.

In this study, it was noted that Braconidae and Ichneumonidae showed greater susceptibility to hyperparasitoids. The primary parasitoids, such as *Casinaria ajanta* (Ichneumonidae) and *Apanteles* sp. 2 (Braconidae) were highly vulnerable to hyperparasitism. This vulnerability might be associated with their higher abundance in the rice environment, as previously identified by Ranjith et al. (2015b). For instance, *C. ajanta*, a solitary larval endo-parasitoid, a potential parasitoid of hespriid defoliators, was abundant in the foothill region. On the other hand, *Apanteles* sp. was abundant in all zones in the studied region. This pattern might suggest that varying environmental conditions across these zones could influence the distribution and abundance of these primary parasitoids, which in turn leads to increased hyperparasitism.

The herbivore-parasitoid and primary parasitoid-hyperparasitoid trophic webs constructed in our study provided comprehensive insights into the trophic interactions within the pest-parasitoid networks of the sites observed. The connectance estimates between trophic levels revealed distinct connectivity patterns: the herbivore-egg parasitoid trophic webs exhibited a connectance of 0.15, the herbivore–larval parasitoid trophic web showed 0.088, the herbivore–pupal parasitoid trophic web displayed 0.221, and the primary parasitoid–hyperparasitoid trophic web revealed a connectance of 0.15. Comparisons with previous studies showcased variations in connectance values across different ecosystems. The values obtained in our study were higher than those reported in coconut intercrops (Shameer et al., 2018) and natural communities of herbivores and parasitoids but lower than values from cropping systems with a limited number of species (Rocca and Greco, 2015). Moreover, our connectance estimates surpass certain values documented for natural communities of herbivores and parasitoids (0.06–0.10, across 45 hosts and 31 parasitoids, as reported by Maunsell et al., 2015). The cross-study comparisons between connectance estimates must be made with care because the connectance values are sensitive to sample limitations, which would increase mechanistically in large webs and may explain the lower estimates among webs including more species (Blüthgen, 2010; Poulin, 2010). The observed trophic connectance could be influenced by factors such as biotic, abiotic, and cultural

elements that affect pest and parasitoid populations, thus influencing trophic interactions.

Moreover, higher overlap among parasitoids targeting pests from the same genera was evident, emphasizing the tendency for species within the same genera to share common parasitoids. For instance, *Scirpophaga incertulas* and *S. innotata* exhibited higher overlap in egg parasitoids due to their genus similarity. *Pelopidas agna* was noted for sharing a substantial number of parasitoids with other pests during its larval and pupal stages, reinforcing the tendency of certain pests to share common parasitoids across different developmental stages.

Anti-parasitoid defense strategy in Lepidopteran pests

This study investigates how the rates of parasitism among different pest species during their immature stages are influenced by their defense mechanisms against parasitoids. The study delves into comparing the parasitism rates and physical traits of both the egg and larval stages of these pests. The findings reveal significant connections between egg parasitism, clutch size, and egg exposure. A positive correlation is observed between clutch size and egg parasitism, indicating that higher clutch sizes coincide with increased parasitism rates. Unexpectedly, a negative correlation emerges between egg exposure and parasitism, implying that eggs lacking protective covers are less prone to attack by parasitoids. Interestingly, individuals with protective egg masses and larger clutch sizes show higher parasitism rates. The presence or absence of egg coverings and the clutch size can have multiple functions. These features not only act as a means of defense against parasitoids but also provide signals about the quality and availability of the host. The parasitoids use these signals to locate and select their hosts. Larger egg masses that are more conspicuous may attract more parasitoids than smaller and less visible ones (Thomas et al., 1998). This may explain the observed negative correlation between egg exposure and parasitism in the present study, which is influenced by the trade-off between protection and detection. In line with the findings of Thomas et al. (1998), the variation in egg coverings and clutch sizes may reflect the different levels of predation and parasitism pressures across various habitats and seasons. In

environments where predation risk is higher, such as open grasslands, egg coverings may provide greater benefits, while in habitats where parasitism risk is high, such as forests, clutch sizes may play a more critical role. The timing of these features may also be significant, with egg coverings being more effective in early spring when parasitoids are less active, while clutch sizes may be more relevant in late spring when parasitoids are more abundant.

The study also explores how the morphological features of caterpillars influence parasitism or predation rates. While the effectiveness of lepidopteran larval hairs against parasitism remains unclear, the research highlights that larval hair length and larval exposure significantly influence larval parasitism compared to larval skin color. Intriguingly, brightly colored caterpillars do not necessarily deter parasitism, as certain parasitoids are not repelled by vibrant hues (Dyer, 1997; Gentry and Dyer, 2002).

Higher parasitism rates are found in semi-exposed larvae. Studies comparing free-feeding and shelter-building caterpillars has demonstrated that shelter-building enhances parasitism. This is likely because shelter-building caterpillars experience reduced predation by predators reliant on visual cues to locate prey. Notable studies supporting this include those by Gentry and Dyer (2002), Diniz et al. (2012), Hrcek et al. (2013), and Baer and Marquis (2020). Consequently, these caterpillars may provide a safer environment for parasitoids by avoiding predators that would consume them. This suggests that shelter-building caterpillars might create an enemy-free space for parasitoids, free from predatory threats (Jeffries and Lawton, 1984; Murphy et al., 2014; Stireman et al., 2006).

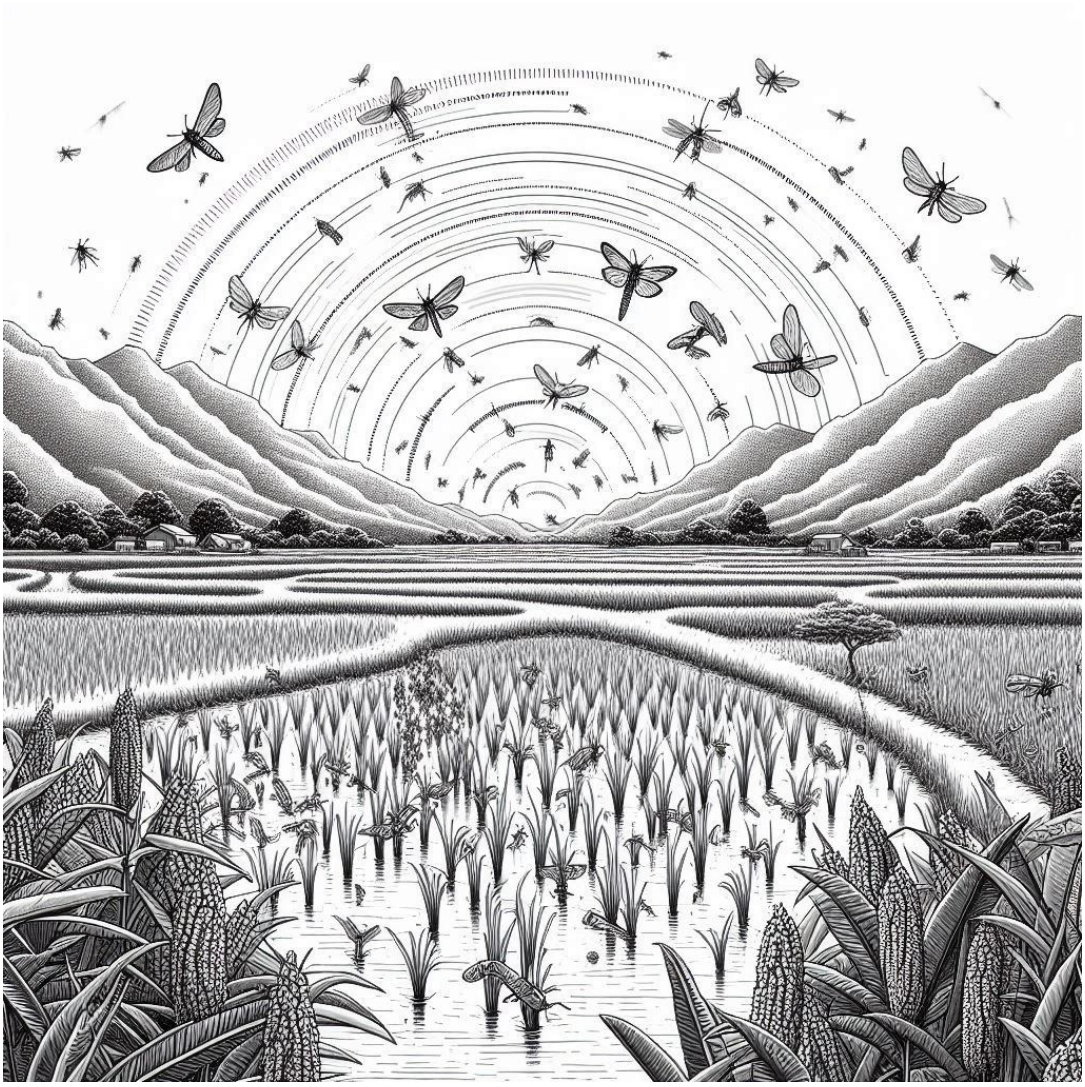
The findings from *Parapoynx stagnalis* provide valuable insight into the limitations of semi-concealment as a morphological defense against parasitoids in lepidopteran rice pests. Despite residing within folded plant material, *P. stagnalis* experienced a relatively high parasitism rate (20.09%), comparable to other semi-concealed species analyzed in this study. This supports the broader pattern that partial concealment offers limited protection compared to full enclosure. Semi-concealed shelters may slow parasitoid access but do not effectively prevent

detection or oviposition, leaving larvae vulnerable during their development. Interestingly, parasitized individuals of *P. stagnalis* were observed to reinforce their shelters post-attack by sealing both ends with silk and anchoring the case to the plant substrate. This behavior significantly reduced hyperparasitism, with secondary parasitoid incidence dropping to 0.6–1% even in cases where primary parasitism reached up to 40% (Kallyadan and Nasser, 2024). While this post-parasitism shelter modification may benefit the parasitoid by protecting its developing brood from competitors, it highlights the limited role of reactive defense in preventing initial parasitic entry. These observations are consistent with previous findings that emphasize the importance of structural concealment as a primary anti-parasitoid trait (Gross, 1993; Cornell et al., 1987). Larvae that feed or reside within concealed spaces such as leaf rolls, stems, or silk-sealed cases tend to exhibit lower parasitism rates due to reduced exposure. In contrast, intermediate forms like *P. stagnalis*, though partially sheltered, appear to occupy a vulnerable middle ground, where incomplete concealment offers neither the mobility of exposed larvae nor the full protection of concealed environments.

Overall, the study sheds light on how different defenses, such as protective covers for eggs and shelter-building behavior in larvae, influence the susceptibility of pests to parasitism, providing valuable insights into host-parasitoid interactions and parasitoid avoidance strategies. The findings from this study underscore the variation in parasitism rates among diverse pest species during their immature life stages, potentially influenced by their anti-parasitoid defense mechanisms. These insights highlight the multifaceted strategies of egg parasitoids in selecting hosts based on certain characteristics and the nuanced interactions between larval traits and parasitism. The findings emphasize the need for further exploration into the complexities of host-parasitoid interactions and the diverse defensive mechanisms of pests, providing valuable insights into pest management strategies and ecological dynamics.Moreover, this study provides a foundation for further investigations into host-parasitoid interactions and encourages the exploration of new avenues in pest management techniques, leveraging biological control mechanisms tailored to the specific challenges posed by rice pests.

CHAPTER 2

SPATIO-TEMPORAL VARIATION OF PESTS AND PARASITOIDS IN THE RICE ECOSYSTEM OF NORTH KERALA



Introduction

Rice pests infest all plant parts at all phases of their development. Since various species have variable preferences for plants at different growth stages, their numbers increase when rice plants of diverse ages are available. Leaf folders, for example, may attack crops at any growth stage and in any field. Black bugs have been observed to harm rice plants at all phases of development, from seedling to maturity (Pathak and Khan, 1994). So, studying the relationship between crop development phases and insect diversity, such as pests and parasitoids, is necessary.

In addition, the study assessed the overall impact of farming practices by collecting data on the frequency of pesticide application from the farmers on insect populations in rice fields to provide solutions for the sustainable management of critical rice pests. Intensive farming in India is typified by small-area farms mainly belonging to separate owners with autonomous agricultural practices. Under the current agricultural scenario, field-based management is a reasonable method. Still, its efficacy remains an open topic, especially when chemicals might be dispersed throughout fields during pest control activities. Hence, this current investigation scrutinized the diversity of pests and parasitoids across rice fields managed by farmers, distinguishing between those treated with pesticides and those left untreated.

Changes in species diversity have long been recognized as substantially influencing the ecology (Ricklefs, 1987; Tilman and Downing, 1994) and phylogeny (Darwin, 1859) of interacting species. Spatial and seasonal variations in community species composition may affect distribution patterns, life cycle traits, population trends, and evolutionary responses of species in a community (Whitham et al., 2003; Thompson, 2005; Johnson and Stinchcombe, 2007; Rowntree et al., 2011). As a result, knowing community structure over time and space can reveal knowledge about species' ecological and coevolutionary processes (Gaston, 2000). Seasonality, especially in tropical areas with well-defined rain and dry seasons, may be observed as a natural process that affects the makeup of animals and shapes the number of species in their habitats (Aranda et al., 2021). Seasonality plays a crucial role in the

life cycles of many organisms, mainly insects, and it needs to be figured out how changes in climate and temperature impact organisms' activities (Wolda, 1980; Fedorka et al., 2013). In the tropics, where temperature changes are modest and seasons are defined by rain and drought, seasonal characteristics and consequences are astonishingly diverse (Wolda, 1988; Anu et al., 2009; Vasconcellos et al., 2010; Silva et al., 2011). Several diversity indices are used to calculate the diversity of species and their relative abundance in a community. Consequently, diversity indices offer a more comprehensive insight into community composition beyond mere species count, considering the relative abundance of different species. These indices provide valuable insights into the prevalence of rare and common species within a community. For biologists striving to understand community organization, the ability to estimate diversity in this way is essential (Pal et al., 2017). This study delved into the species diversity patterns within a host-parasitoid system across diverse geographical regions and seasonal variations. Through metrics such as species diversity (H and eH′), it aimed to explore the correlation between community resemblance and the geographic distribution of rice insect pests and parasitoid communities in North Kerala.

Climate change is the most significant dynamic and worldwide environmental challenge (Kunkel et al., 1999a; Easterling et al., 2000). The repercussions of climate change, from rising temperatures, frequent droughts, unpredictable rainfall, etc., are already visible. Global climatic changes substantially influence agriculture and agricultural pests (Porter et al., 1991). Insects and plants are affected by climate change and harsh weather conditions. The direct consequence of anthropogenic climate change has been recorded on every continent and in most major taxonomic groupings (Cornell and Hawkins, 1995). Insects are presumably very vulnerable to changes in environmental circumstances (Guedes et al., 2000). The present study investigated the impact of climatic conditions on pests and parasitic hymenopterans in rice within three agro-ecological zones of North Kerala, viz., the high hill, foothill, and midland laterite zones. The study explores the effect of climatic factors on the parasitic hymenopterans that play a critical role in regulating the abundance of numerous rice pests.

The development of agriculture has deteriorated the complexity of agricultural landscapes because of the increase of arable fields and the loss of natural habitats (Zhao et al., 2014). These landscape changes, which greatly influence natural enemies (e.g., parasitoids) and biological control services (Brewer et al., 2008; Zhao et al., 2013), have lately gained considerable attention. This study performed field research on pests and parasitoids to examine if the complexity of agricultural landscape layout affects insect diversity associated with rice. Also, it evaluated the influence of structural diversity at different geographical scales.

The pest is likely to disperse to other major rice-growing regions of the country as climatic conditions change, posing substantial dangers to rice production (Huang et al., 2010; Karuppaiah and Sujayanad, 2012; Kwon et al., 2012; Arora and Dhawan, 2013; Ali et al., 2014). In this context, the current study uses the maximum entropy (MaxEnt) modeling approach to investigate the impact of climate change on the proliferation and spatial and temporal distribution of potential pests and parasitoids in India by delineating the bioclimatic variables governing their geographical spread and abundance. The findings of this study might help rice farmers be better prepared for the anticipated spread of rice pests by implementing efficient pest control measures ahead of time.

Earlier studies in Bogor Regency found that the nature of agricultural landscapes substantially influences the abundance of parasitoids and their functional diversity (Ulina et al., 2019). While natural habitats might enhance species richness and diversity, especially of parasitoids, their presence does not always improve the biological management of pests in the agricultural landscape (Karp et al., 2018). As an outcome, integrating food web interactions (Miranda et al., 2013) may explain the link between a resource, consumer, and within-guild competition (Dormann et al., 2017), which is necessary for understanding the agricultural landscape composition impacts on biodiversity. In agricultural contexts, research on food webs has been conducted to investigate the influence of habitat loss and fragmentation on food web interactions (Hagen et al., 2012) and the relationship between biodiversity and food web structure (Rooney and McCann, 2012). This study used quantitative

food-web statistics to investigate the structure of rice pest-parasitoid food webs in the three agro-ecological zones of North Kerala.

Hence, this chapter addressed the following questions:

1. What is the community structure of rice pests and parasitoids in the rice ecosystem?
2. Spatio-temporal variation of rice pests and parasitoids?
3. What are the factors affecting pest and parasitoid diversity across spatial scales?

Review of Literature

Studies on the community structure of rice pests and parasitoids

Each insect presence in the rice field has a distinct role that may be distinguished by guild structure categorization based on their function, including pest, predator, and parasitoid (Bambaradeniya and Edirisinghe, 2008). A few studies have been conducted in rice fields to determine the species makeup of terrestrial insect pests and their natural enemies. Heong et al. (1991) and Schoenly et al. (1996) conducted studies in irrigated rice fields in the Philippines, providing insight into arthropod communities and guild structure. In Sri Lanka, studies on arthropod communities in rice fields are limited to surveys documenting the distribution of major rice pests and their natural enemies (Otake et al., 1976; Rajendran and Devarajah, 1990; Kobayashi et al., 1990; Kobayashi et al., 1995), while no steps have been taken in India to record the structure and diversity of both pests and parasitoid communities in a single study.

Studies on spatio-temporal variations of pests and parasitoids

Spatial variation of rice insects

Insect abundance and diversity are also influenced by the latitude and altitude of their environment (Gauld, 1987; Lawton et al., 1987; Price, 1991; Martin-Pierra and Lobo, 1993). Knowing community structure's temporal and geographical fluctuations can reveal ecological and coevolutionary processes of interacting species. Ecologists are tasked with documenting biogeographic patterns of community diversity and discovering the variables that drive them (Gaston, 2000). Except for bees (Michener, 1979) and certain parasitic Hymenoptera, it has become evident that insect groups have many more species at lower altitudes than at higher altitudes (Gauld, 1987). In Papua New Guinea, Hebert (1980) finds a progressive drop in moth species richness between 2200 and 2800 m and refers to additional evidence for a similar decrease between 2000 and 3400 m. He adds that preliminary studies demonstrate that the diversity of moth populations in Papua New Guinea shows no additional growth at lower altitudes. The loss of species richness with altitude may only begin at higher elevations. Claridge and Singhrao (1978) discovered that the species richness of grasshoppers did not vary much between 300 and 1800 meters on the French Mont Ventoux. Günthart (1984) found a decline in Homopteran species richness as elevation increased between 2200 and 3060 m in Switzerland, but there is no comparable data at lower altitudes.

Numerous investigations have explored the diversity of parasitic wasps within rice ecosystems across three distinct rice-growing regions in Tamil Nadu, namely the western zone, the Cauvery delta zone, and the high rainfall zone. The study examined Ceraphronoidea, Figitidae, Evanoidea, Diapriidae, Platygastridae, Ichneumonidae, and Braconidae, which were the most abundant families in all three zones (Daniel et al., 2019e; Daniel and Ramaraju, 2019a; Daniel and Ramaraju, 2019b). The high rainfall zone was the most diverse, and the Cauvery Delta zone was the least varied but with greater evenness in the case of Mymaridae (Daniel et al., 2019a). Surveys done to explore the parasitic aculeate fauna in the rice ecosystems of Tamil Nadu in 2015–2016 found the high rainfall zone as the most

diverse zone, with the Cauvery delta zone being the least diverse (Daniel and Ramaraju, 2020a). A study conducted between 2015 and 2016 aimed to explore the Platygastroidea fauna across three distinct rice-growing zones in Tamil Nadu. The findings revealed *Gryon* sp. nr. *clavigralla* as the dominant platygastroid within the rice ecosystem, accounting for a relative abundance of 15.2 percent (Daniel and Ramaraju, 2020b). Additionally, surveys were conducted to investigate the Ichneumonid fauna in Tamil Nadu's rice ecosystems during the same period, highlighting the western zone as the most diverse region, while the Cauvery delta zone exhibited the lowest level of diversity. *Leptobatopsis indica* was the main Ichneumonid species in the rice environment, with a relative abundance of 8.1 percent (Daniel et al., 2020). The study of the diversity of Eupelmidae and Eurytomidae in three distinct rice environments of Tamil Nadu discovered that *Neobepharata* sp. (Eurytomidae) and *Mesocomys* sp. (Eupelmidae) were the most numerous faunae among all the species seen, with a relative abundance of 24.0 percent and 50.6 percent, respectively (Alfred et al., 2019).

A few studies have been conducted on the diversity of rice pests and parasitoids on different spatial scales. Because of this, the present study addressed the species diversity of several rice insects in the different agro-ecological zones of the North region of Kerala, India.

Seasonal variation of rice insects

Seasonality, particularly in tropical regions with well-defined wet and dry seasons, may be seen as a natural process that affects the makeup of animals and shapes the abundance of species in their habitats (Aranda et al., 2021). Seasonality plays a crucial role in the life cycles of many organisms, mainly insects. According to Daniel et al. (2019b), leaf folder and rice horned caterpillar larval parasitization were highest in the second fortnight of December (64.3%) and the first fortnight of January (71.88%), respectively; egg parasitism in rice ear head bug was highest in the second fortnight of December (62.95%). Some species are only active for a short period each year. In the tropics, where temperature changes are modest and seasons are defined by rain and drought, seasonal characteristics and consequences are

astonishingly diverse (Wolda, 1988; Anu et al., 2009; Vasconcellos et al., 2010; Silva et al., 2011). Because various elements, such as humidity, food availability, and interactions with other organisms, are directly or indirectly connected with this phenomenon, it is predicted that seasonality would alter insect abundance throughout the year (Wolda, 1978; Novotny and Basset, 1998; Southwood et al., 2004). Only a few studies on the effect of seasonality on the population of rice pests and parasitoids have been conducted in India. The peak activity of the rice gall midge occurs between the 36th and 43rd weeks, spanning from September to October, as determined by field observations of pest incidence. The parasitoids *Platygaster oryzae* (Cameron), *Neanastatus grallarius* (Masi), and one predator, *Paederus fuscipes* Curtis, were active in the 40th to 47th weeks, i.e., October through November, according to the findings (Shrivastava et al., 1987). *Tetrastichus schoenobii* and *Trichogramma chilonis*, two parasitoids of the rice yellow stem borer, *S. incertulas*, were active virtually all year, whereas *T. rowani* was active from late August until the middle of October (Chakraborty, 2012). Over time, species compositions within a community can undergo alterations, holding notable consequences for the interactions among these species (e.g., Bertrand et al., 2016; Sgolastra et al., 2016; Salmah et al., 2017). Seasonal variations in community composition may also be helpful in agricultural contexts since they can give management instructions for biological control (Bertrand et al., 2016). As a result, we investigated the diversity of rice pests and parasitoids in three agro-ecological zones of Kerala throughout the dry and wet seasons.

Variation of the rice insect population in relation to crop growth stages

It is well known that the composition of arthropod populations changes as the rice crop grows (Heong et al., 1991). During its life cycle, the rice plant goes through ten stages: (1) germination and emergence; (2) seedling; (3) tillering; (4) stem elongation; (5) panicle initiation; (6) panicle development; (7) flowering; (8) milk grain; (9) dough grain; and (10) mature grain stages (Reissig et al., 1986). We looked at three phases of rice crop development: vegetative (seedling), booting (tillering), and ripening (panicle development). The pests infest all parts of the plant

at all stages of development. Since different species have varying preferences for plants at various stages of development, they multiply when rice plants of all ages are accessible. So far, not much research has looked into how different pests and their parasitoids vary across the stages of rice plant growth. The leaf folders may attack the crop at any stage of development in any field. Black bugs have been found to damage rice plants at different phases of development, from seedling through maturity (Pathak and Khan, 1994). An egg peak characterized leaf folder population patterns during maximal tillering and a broad larval peak around the booting stage. The peak density of larvae per hill varied from 0.2 to 2.0 (de Kraker et al., 1999). In a no-choice situation, *C. medinalis* moths emerging after flowering did not oviposit in the same crop but emigrated (Wada et al., 1980; Wada and Kobayashi, 1982). Rice leaf folders may accomplish two to three generations on a single rice crop, considering their generation time of laying most eggs in the tillering crop (Fukamachi, 1980, 1983). Wada (1979), Cheng (1987), and Heong (1990) suggest that oviposition preference is connected to the quality of the host plant since rice plants in the ripening stage are less suitable for the growth and survival of leaf folder larvae. *Marasmia patnalis* and *M. exigua* both seem to avoid oviposition on a crop after blooming since just a few eggs of each leaf folder species were observed at the ripening stage (de Kraker et al., 1999). Until now, few studies have been carried out on the influence of rice plant growth stages on rice pests (e.g., Bakar and Khan, 2016). So, this study examined how plant growth stages affected the pests in the rice ecosystem.

Effect of farming practices on rice insect populations

Tillage, irrigation, crop establishment, and pesticide application are common farming practices affecting rice fields. Similarly, the surrounding environment and habitat characteristics may impact insect populations and offer alternate locations for prey and predators (Sharma et al., 2019). Different species respond to organic farming in different ways (Hole et al., 2005; Rahmann, 2011), which might be related to variations in movement or other biological features. Rice (*Oryza sativa* L.) is one of the most important food crops in warm climates, with plenty of

precipitation, mainly in Asia. Previous research has generally focused on the implications for local generalist predator groups (e.g., carabid beetles, spiders, bats, and frogs), and the effects of organic farming compared to conventional farming on biodiversity levels are seldom explored in rice fields (Katayama et al., 2019). Previous research has looked at a few expansions of different predatory, phytophagous, or neutral/other assemblages (e.g., insect communities in organic and nonorganic rice habitats in Indonesia) (Ohwaki, 2015; Toffoli and Rughetti, 2017), in addition to generalist predators (Ovawanda et al., 2016). Several investigations of organic systems have shown increased natural enemy abundance (Fuller et al., 2008). Sharma et al. (2020) compared the numbers of natural enemies in organically and conventionally cultivated aromatic rice in farmers' fields. Three egg parasitoids (*Tetrastichus* sp., *T. japonicum*, and *Telenomus* sp.), three larval parasitoids (*Stenobracon nicevillei*, *Bracon* sp., and *Cotesia* sp.), and three pupal parasitoids (*Tetrastichus* sp., *Brachymeria* sp., and *Xanthopimpla* sp.) were reported. On the other hand, organic rice has considerably more natural parasitism by parasitoids and predators than conventional rice. In Southwest England, Macfadyen et al. (2011) found that the greater the number of species within functional groups in an organic system, the greater the temporal stability of parasitism rates. Gnanakumar et al. (2012) wanted to see whether changes in management approaches impacted the diversity of hymenopteran egg parasitoids. In total, they identified 40 distinct egg parasitoids within organic and conventional paddy ecosystems, with 29 out of the 40 species belonging to 16 taxa within the Platygastridae family. On the other hand, the egg parasitoid populations in both environments showed fewer taxonomic similarities.

It is important to study the effect of agricultural practices on the insect population diversity in the rice ecosystem, and hence, this study addressed this aspect.

Studies on factors affecting pest and parasitoid diversity across spatial scales

Effect of climatic factors on pest-parasitoid population

Agriculture and agricultural pests are both affected by global climate change. Climate change impacts crop plants and pests in both direct and indirect ways. Global warming forecasts obscure regional realities, with more frequent heatwaves, droughts, and severe precipitation events predicted (Kunkel et al., 1999b; Easterling et al., 2000). Most organisms, including insects, will struggle more due to these harsh weather conditions (Godfray et al., 1994). Growing-season temperatures will almost certainly exceed the previous century by 2050, significantly reducing agricultural yields (Battisti and Naylor, 2009; Porter et al., 2014; Rosenzweig et al., 2014). Pest species' reactions to global warming are anticipated to change in the future, affecting the relative responses of pests spatially and across crops (Zvereva and Kozlov, 2006; Deutsch et al., 2008). Species distributions, life cycles, community structure, and ecosystem function are all affected by global climate change (Easterling et al., 2000; Bale et al., 2002). According to a study of over 1700 species, climate change has already impacted 50% of these wild species (Parmesan and Yohe, 2003). Climate and weather variations might significantly impact population genetic composition and the dynamics and status of crop insect pests. These changes arise due to indirect effects on the pests' host plants, competition, physiology, and direct effects on the distribution and abundance of pest population dynamics (Porter et al., 1991).

According to Cornell and Hawkins (1995), climatic conditions may impact insect pest populations directly via effects on reproductive and mortality ratios and indirectly through parasitoids. Seasonal climatic variations, such as rainfall and temperature maxima and minima, might lead to drastic shifts in parasite hymenopteran abundance, particularly in temperate habitats. Weather conditions impact food availability, parasitoids, and herbivorous populations, according to Guedes et al. (2000), and hence, might be key drivers of insect-pest population fluctuations. The food availability of an insect pest, in particular, is determined by climatic factors, which impact parasitoid population growth. Insect population

dynamics are influenced by climatic factors such as faster developmental rates with increasing temperature and lower survival with heavy rain, extreme temperatures, and low moisture (Hespenheide, 1991; Nestel et al., 1994), as well as by negatively affecting individual reproductive behavior (Sæthre and Hofsvang, 2002). Similarly, weather conditions may impact the mortality rate produced by parasitic hymenopterans (Weisser et al., 1997; Stireman et al., 2005). Most parts of the world will see changes in development rates, voltinism, and survival rates due to global warming (IPCC, 2001). Changes in climate and insects, which in turn influence the size, density, and abundance of populations, might significantly impact the genetic makeup of populations and the dynamics and status of insect pests on crops. These might include the level at which the host plant is exploited (Bale et al., 2002). Climate change is expected to boost the frequency of abiotic disturbances, which is detrimental to species that cannot tolerate even small abiotic disturbances. Temperatures alter local to regional frost resistance dynamics, which may cause diapauses or expand the extent of the disturbance (Bale et al., 2002). The magnitude of the disturbance will substantially influence the local to regional dynamics of insect populations and species composition. Insects find optimal growth conditions within a specified temperature range, restricted by species-specific lower and higher developmental thresholds. These adjustments and slow changes may impact the population dynamics of parameters such as development, reproduction, diapause, winter mortality, and flight and dispersion (Warren et al., 2001). According to Lomelí-Flores et al. (2010), understanding the effects of local meteorological factors on insect population dynamics is critical for the long-term viability of any agro-ecosystem. The current research explores the effect of climatic factors on the population of hymenopteran parasitoids and rice pests.

Effect of landscape complexity on rice insect pests

Modern intensive agriculture has substantially altered the organization of arable lands and non-crop ecosystems, resulting in insect outbreaks (Wu et al., 2008; Gagic et al., 2011; Cobbold and MacMahon, 2012). A relationship between landscape complexity and local biodiversity in arable lands has been demonstrated in various organisms (Finke and Snyder, 2010; Holzschuh et al., 2010). Many

natural enemies need alternate hosts and food in non-crop environments, and pest species dominate insect groups due to landscape simplification in modern agriculture (Toledo and Burlingame, 2006; Géneau et al., 2012). Insect parasitoids are a broad group of species that can control pest populations (Menalled et al., 1999; Bianchi et al., 2006; Tscharntke et al., 2012). Due to many non-crop habitats in these landscapes, such as hedgerows, forests, streams, fallows, and grassland, structurally complex landscapes may sustain numerous ecosystem services besides biological pest management (Wratten et al., 2012). These non-crop habitats may increase species diversity or the abundance of natural enemies in arable lands, successfully suppressing insect populations (Clough et al., 2007). As has been demonstrated in several studies (e.g., Risch et al., 1983), increasing structural diversity in agro-ecosystems results in a wider variety of pests and beneficial insects and reduced pest damage, as has been demonstrated in several studies (Risch et al., 1983). This is true both within fields due to intercropping (Perrin, 1977; Altieri et al., 1978; Risch, 1980; Theunissen and Den Ouden, 1980; Tukahirwa and Coaker, 1982; Ryan et al., 1980; McKinlay, 1985) and outside fields (due to promoting a weedy background (Root, 1973; Smith, 1976a,b; Altieri et al., 1981); interactions between species, such as parasitism by insect parasitoids) may be influenced by the complexity of the landscape (Brewer et al., 2008; Zhao et al., 2013). Because of the availability of food, shelter, good microclimates, alternate hosts, or a combination of these factors, parasitoids in agricultural landscapes may benefit from additional crop field habitats (Landis et al., 2000; Gagic et al., 2011). As a result, various non-crop habitats in structurally complex landscapes may significantly boost parasitoids' activity and abundance (Schmidt and Tscharntke, 2005).

Primary parasitism and hyperparasitism have been linked to increased landscape complexity (Schmidt et al., 2008; Gagic et al., 2011; Segoli and Rosenheim, 2012). Most research has concentrated on the link between primary parasitoids and the complexity of the terrain (Roschewitz et al., 2005; Gagic et al., 2011; Macfadyen et al., 2011). Furthermore, the impact of landscape complexity on hyperparasitoids and biological pest management is unclear (Gagic et al., 2011). Because of the combined impacts of hyperparasitoids and landscape composition on primary parasitoids, little is known about the interactions between pests, primary parasitoids, hyperparasitoids, and landscape complexity (e.g., Costamagna et al.,

2004; Gagic et al., 2011). However, Zhao et al. (2014) showed that landscape complexity might enhance the activity or diverse range of primary parasitoids and hyperparasitoids. Several studies have demonstrated that increased landscape complexity might boost natural enemy biodiversity, assisting management approaches such as biological control in such ecosystems (Bianchi et al., 2006; Schmidt et al., 2008; Thies et al., 2008). Natural enemies, for example, insect predators, might be influenced by the surrounding landscape (Ali et al., 2020). Expanding the scope to encompass urban and rural agricultural landscapes through manual or automated classification of aerial or satellite images offers a promising avenue to mitigate methodological biases that might overlook specific production areas like home gardens. Despite its potential, this approach has seen limited application in mapping extant urban and rural agricultural sites (Taylor et al., 2012).

Most applications have been exploratory and focused on identifying agricultural areas—typically farms—in open spaces in peri-urban and urban landscapes in developing countries (Appeaning-Addo, 2010). As objects, agro-ecosystems exhibit high levels of internal heterogeneity, complicating classification efforts. They are composed of patches within patches, or sub-objects, at very fine scales, and the density and size of sub-objects may change as crops develop and senesce (Forster et al., 2009). Participatory GIS (participatory geographical information systems, PGIS) techniques combine community participation using digital geospatial techniques and enable the farmers to identify the landscape surrounding the agricultural fields through a map. In practical application, Participatory GIS solutions exhibit variability contingent upon the specific objectives of the application, the requisite level of information, and the participants' expertise. PGIS methodologies are commonly employed in urban planning and natural resource allocation contexts (e.g., Kingston et al., 2000; Craig et al., 2002; Voss et al., 2004; Fagerholm and Käyhkö, 2009). For landscape mapping and patch analysis, participatory GIS techniques offer a valuable approach (e.g., Fagerholm and Käyhkö, 2009). The process of participatory mapping of landscape values encompasses both individual and group data collection perspectives (e.g., McIntyre et al., 2004; Gunderson and Watson, 2007; Fagerholm and Käyhkö, 2009). Methods, such as sticker dots, point markers, and polygon delineations on the maps, have been applied (McIntyre et al., 2004; Black and Liljeblad, 2006; Tyrväinen et al., 2007),

and in some cases, data has been collected via map interfaces through the Internet (Kyttä and Kahila, 2006).

Studies on food webs

Food webs have been extensively studied in recent decades to learn more about the trophic relationships between different species within an ecosystem (Winemiller and Polis, 1996; Shurin et al., 2006; Ings et al., 2009), and are defined by the presence of feeding links and the strength of interactions among species (Lohaus et al., 2013). Individual food webs provide information on probable direct and indirect interactions between organisms in a community. Groups of food webs give information on the organization of natural communities (Rott and Godfray, 2000). The development of a database of food webs known as Eco Web (Cohen, 1989) was the first step in the study of food webs, with research revealing a range of invariant traits common to a large fraction of webs (e.g., Cohen, 1978; Pimm et al., 1991; Schoenly et al., 1991). These feeding interactions may be crucial for the effective functioning of ecological systems, such as biological control (Tylianakis et al., 2010). Parasitoids are often considered the most important components in controlling phytophagous insect population dynamics (Waage and Hassell, 1982). Plant, herbivorous insect, and parasitoid food webs are a subgroup of the food web that focuses on feeding interactions between plants, herbivorous insects, and parasitoids (Memmott et al., 1994; Valladares and Salvo, 1999). The number of parasitoid species may alter the rate of parasitism (Balvanera et al., 2006) and the food web structure into which they are absorbed, as predicted in the diversity–function relationship (Montoya et al., 2003; Gagic et al., 2012). The structure of parasitoids is important for various reasons, and shared parasitism may significantly impact the structure of the whole insect community (Holt, 1977; Lawton, 1986; Holt and Lawton, 1993). The parasitoid food web is also used to investigate some aspects of agriculture systems (e.g., Valladares and Salvo, 1999; Tylianakis et al., 2007; Jonsson et al., 2009; Macfadyen et al., 2009; Gagic et al., 2011; Lohaus et al., 2013), such as host overlap, parasitoid species richness on hosts, parasitoid host range, and

apparent competition (Memmott and Godfray, 1994). In terrestrial food webs, quantitative information on shared parasitism is limited. Our understanding of population dynamics is based on models involving one or a few pairs of hosts and parasitoids (Hassell, 1986). To comprehend the parasitoid community's population dynamics, one must first grasp how trophic relationships work and the strength and dispersion of these interactions in nature (Memmott and Godfray, 1994).

Study area

The survey was conducted in rice-growing fields in the high hill, foothill, and midland laterite regions of North Kerala, India, (Refer Chapter 1: Table 1.2, Map 2) during the dry and wet seasons (2017–2019) to investigate the incidence of rice pests and parasitoids and the factors affecting their population.

Materials and methods

Sweeping and handpicking

Parasitoid sampling was conducted using sweep netting along the peripheries of the paddy fields, with each field divided into transects measuring 25 meters by 2 meters (25 m × 2 m). Transects were laid along the four sides of each rice field. A triangular sweep net was used to collect samples, and parasitoids were retrieved using an aspirator and then preserved in 70% alcohol for identification. In addition to sweep netting, handpicking was employed to collect lepidopteran caterpillars and other pest species. The number of pests collected was recorded, and selected caterpillars were reared under laboratory conditions until adult emergence to accurately identify the host species. Special attention was given to caterpillars exhibiting signs of parasitism; these were also reared separately to allow the emergence of parasitoids, thereby enabling identification of the parasitoid species and determination of host-parasitoid associations.

Community Structure of Pests and Parasitoids

Relative Abundance:

The relative abundance of each species was computed using the following formula: Relative abundance (%)=(Number of individuals of one species / Total number of individuals of all species) × 100 (e.g., Daniel and Ramaraju, 2019a)

Relative Density:

The relative density of each species was determined using the formula: Relative density (%)=(Number of individuals of one species / Number of individuals of all species) × 100 (e.g., Daniel and Ramaraju, 2019a)

Relative Frequency:

Species frequency was calculated using the formula: Frequency=(Number of occurrences of one species / Total number of sites). Relative frequency of each species was then calculated as follows: Relative frequency (%)=(Frequency of one species / Sum of the frequency of all species) × 100 (Daniel and Ramaraju, 2019a)

Quantitative food web analysis

From combining yearly data (2017–2019) for three agro-ecological zones, we constructed summary quantitative host-parasitoid food webs and estimated the following metrics: Number of higher trophic (hyperparasitoids); Number of lower trophic (caterpillars), Connectance: the realized proportion of possible links; Linkage Density: the mean number of connections per species; Vulnerability is characterized as the average number of consumers (parasitoids) per host (caterpillar), while generality denotes the average number of hosts per consumer (Graham, 2021). Interaction evenness assesses the uniformity of energy flows across various pathways. Additionally, graphical representations of cumulative food webs were generated using the Food Web Designer 3.0 software, pooling data from all three-year samples for each zone to offer a comprehensive overview encompassing all identified interactions.

The Food Web Designer serves as a quantitative visualization tool for trophic and other bipartite and tripartite interaction networks. It allows the

connection of up to three trophic levels, illustrating top-down and bottom-up connections with cascading links between taxa within each level. This tool facilitates the quantification of link width/strength and taxa abundance, enabling the creation of quantitative networks. Utilizing the Food Web Designer, pest-parasitoid and hyper-parasitoid food webs were constructed to visually depict interaction networks, offering insights into pest control and other ecological interactions within managed and natural ecosystems from an ecological network perspective (Sint and Traugott, 2016).

Measurement of diversity

Alpha diversity

The alpha diversity of the three distinct agro-ecological zones—high hill, foothill, and midland laterite—was evaluated using the Shannon-Wiener index (H'), Margalef Index (α), and Pielou's Evenness Index (E1).

Shannon-Wiener index

The Shannon-Wiener index (H') is expressed as follows: $H' = -\Sigma Pi \ln (Pi)$, where $Pi = S/N$; S denotes the number of individuals of a particular species, N represents the total number of all individuals in the sample, and ln signifies the natural logarithm (Shannon and Wiener, 1949). A higher H' value indicates greater diversity (Daniel and Ramaraju, 2019a).

Margalef index

Species richness was calculated for the three zones using the Margalef index, which is given as Margalef Index $=\alpha=(S-1)/\ln (N)$; S=the total number of species, N=the total number of individuals in the sample (Margalef, 1958).

Pielou's1 evenness index

Species evenness was determined using Pielou's Evenness Index (E1), calculated as $E1 = H' / \ln(S)$, where H' represents the Shannon-Wiener diversity index, and S denotes the total number of species in the sample (Pielou, 1966). As both species richness and evenness rise, diversity correspondingly increases (Magurran, 1988).

Spatial variation of pests and parasitoids

The spatial distribution of pests and parasitoids was studied using nonmetric multidimensional scaling (NMDS) (Shepard, 1974). Pests and parasitoids were analyzed for both the dry and wet seasons. Parasitoids were divided into three main categories: egg, larval, and hyperparasitoids, and they were tested in both seasons. All plots' NMDS stress values showed good fitness, with values ranging from 0.05 to 0.1. One-way ANOSIM, was used to assess the spatial dissimilarity across zones. To compare the mean of ranked dissimilarities between groups with the mean of ranked dissimilarities within a group, ANOSIM was employed. An R-value approaching 1.0 signifies significant group dissimilarity, while a value near 0 suggests an equitable distribution of high and low ranks both within and between groups. In the case of pests, an R-value near 1.0 indicates strong dissimilarity in both the dry and wet seasons.

Climatic data set

Climatic data, including rainfall and temperature records, from the preceding three years (2017–2019), were sourced from the Prediction of Worldwide Energy Resources web portal, facilitated by the National Aeronautics and Space Administration (NASA POWER website) (e.g., Allen et al., 2014). Household data and historical meteorological records were used in descriptive statistics to show farmers' perceptions of climate variability and change. The synthetic database was sourced from the gridded weather stations (GridWS) within the NASA/POWER system. records of minimum, maximum, and average air temperature (T_{min}, T_{max}, and T_{avg}) and relative humidity (RH) from the database were evaluated (Stackhouse et al., 2011).

The CRU TS (Climatic Research Unit gridded Time Series) dataset is widely utilized (Harris et al., 2020). The CRU TS version 4 (CRU) dataset is developed by the Climatic Research Unit (CRU) at the University of East Anglia, England. Station anomalies based on 1961–1990 means are spatially interpolated into 0.5° x 0.5° grid boxes, covering the global land surface except Antarctica, and merged with an existing climatology to derive absolute monthly values (Zhu et al., 2015). More

details about data interpolation and quality assessment were reported by Harris et al. (2014). The latest version, CRU TS version 4.05 (available at https://crudata.uea.ac.uk/cru/data/hrg/), uses a revised interpolation function, superseding versions v4.04 and v3.26 (Harris et al., 2020). We collected weather records of precipitation and diurnal temperature for analysis.

The Global Positioning System (GPS), overseen by the United States Department of Defense, serves the purpose of assisting ground-based units in determining their precise real-time location through latitude and longitude coordinates. GPS is used for agricultural applications for machine guidance and and data collection during harvesting operations, soil sampling, and field scouting (Ess and Morgan, 2003). GPS from Google Maps was used to find the location coordinates and find the altitude from Google Earth software.

Additionally, to capture the stress induced by the combined effects of high temperature and high humidity, we calculated apparent heat using the Heat Index (Rothfusz, 1990), where:

HI=c1+c2T+c3R+ c4TR+ c5T2+ c6R2+ c7T2R+ c8TR2+ c9T2R2

The heat index was calculated using the coefficients below when the temperature is provided in degrees Celsius, where

HI=heat index (in degrees Celsius)

T=ambient dry-bulb temperature (in degrees Celsius)

R=relative humidity (percentage value between 0 and 100)

c1=-8.78469475556, c2=1.61139411, c3=2.33854883889, c4=-0.14611605, c5=-0.012308094, c6=-0.0164248277778, c7=0.002211732, c8=0.00072546, and c9=-0.000003582

Cultural dataset

Water depth, plant spacing, frequency of pesticide application, weed cover in the bunds, and distance from the home garden to the field were the selected

variables for the study. We measured the water depth in each quadrate using a ruler scale and calculated the average value. Then, at random, we measured the distance between each rice hill in the quadrate and took an average value (Fig. 2.1b)—details about the pesticide application rate were obtained from the rice farmers. Weed cover present in each bund was assessed independently by visual observation (Fig. 2.1c) using the Braun-Blanquet scale (+=<1%, 1=1–10%, 2=11–25%, 3=26–50%, 4=51–75%, and 5=76–100%) (Braun-Blanquet, 1979). Furthermore, Google Earth software measured the distance between each field and the adjacent home garden.

Fig. 2.1 Measuring of cultural data sets: a) water depth, and b) plant spacing.



Mapping of the land use characteristics

This study analyzed the effects of different types of land use and land cover change in the landscape surrounding the rice ecosystem of North Kerala on the population of pests and parasitoids. We monitored the vegetation characteristics and operational land-use types covering the study area.

The landscape mapping of the rice agro-ecosystem relied on openly accessible global geospatial datasets and satellite imagery, integrated with participatory reference data collection methods and the utilization of Google Earth and Google Earth Engine (Fig. 2.2) (e.g., Koskinen et al., 2019). The study used two strategies to characterize patches surrounding the rice agro-ecosystems in North Kerala: (1) the visual analysis of aerial images of the landscape and (2) the

participatory mapping of complex sites by using high-resolution aerial images in Google Earth.

We generated a collection of reference images depicting rice agricultural landscapes at the study sites within the three distinct agro-ecological zones—high hill, foothill, and midland laterite zones—using aerial images from Google Earth in North Kerala. The reference images of the surrounding landscape of the study sites included the patches of areca nut plantations, banana plantations, built-up areas, coconut plantations, fallow land, homesteads, paddy fields, pineapple plantations, ponds, rivers, rubber plantations, shrubs, streams, vegetable gardens, and wetland area. The sites were visited from July to December 2019 for ground-truthing.

We organized the spatial collection of the geographical data through a participatory mapping campaign in North Kerala from May to September 2021 (Fig. 2.2).

This PGIS campaign used digitally geo-referenced aerial photographs obtained from Google Earth Software. Aerial photographs have been helpful in PGIS campaigns since they are visually attractive without landscape abstraction (Corbett et al., 2006). Aerial photographs were tested in earlier PGIS campaigns and found valuable and reliable for location-specific tasks given to the community members (Makandi, 2008). Aerial pictures of study sites were marked with a 500m radius circle using Google Earth software, with rectangular grids to identify vegetation patches, and printed on a laminated paper sheet for data collection. Then we interviewed seventy-two farmer communities associated with the study site from all three agro-ecological zones of North Kerala by showing the printed (Fig. 2.2) and mobile images of the study sites and associated landscapes.

Fig. 2.2 Participatory mapping campaign, a-d.



Mapping of vegetation characteristic

The National Aeronautics and Space Administration of the USA (NASA) uses 7-band data for feature extraction, called a LANDSAT image (Hu et al., 2008). NDVI is a commonly used index (Bhandari et al., 2012). It is an important vegetation index, widely applied in research on global environmental and climatic change (Bhandari et al., 2012). NDVI (Normalized Difference Vegetation Index) is calculated as a ratio difference between measured canopy reflectance in the red and near-infrared bands, respectively (Nageswara-Rao et al., 2005).

NDVI serves as a metric for quantifying vegetation greenness, aiding in the evaluation of vegetation density and the assessment of changes in plant health. It is determined by the ratio between the near-infrared (NIR) and red (R) values, calculated using the traditional formula: NDVI=(NIR -R) / (NIR + R) (Zeng et al., 2024)

Landsat 8 satellite images were employed and used spectral bands such as Band 4 and Band 5. NIR is represented by Band 5, and R is represented by Band 4.

NDVI=(Band 5 – Band 4) / (Band 5 + Band 4).

The NDVI procedure involves segmenting each band to identify the vegetation index from the multispectral remote sensing image embedded within the satellite image. Once the bands are segregated, the NDVI technique is employed based on its attributes, such as distinguishing vegetation at different NDVI threshold values. Diverse NDVI threshold values are employed to obtain optimal results from the satellite imagery of the study sites (e.g., Alex et al., 2017). The resultant NDVI class values obtained from the NDVI analysis are given below (Table 2.1).

Table 2.1 The ranges of normalized difference vegetation index (NDVI) identified for the various landcover classes (e.g., Akbar et al., 2019).

NDVI Class	**Range**
Emergent aquatic vegetation	-0.28-0.015
Fallow land	0.015-0.18
Crop/Grass	0.18-0.27
Sparse vegetation	0.27-0.36
Agro-forestry	0.36-0.74

Species distribution model

We compiled the site-specific geographic data from the research literature, surveys, and monitoring of rice pests (i.e., latitude and longitude) on the incidence of rice pests and parasitoids. During the rice pest survey, the latitude and longitude for the selected points were referenced using previously reported information and the global positioning system (GPS). A total of 50 records were used in this analysis to predict the spatial distribution of major pests over the Indian subcontinent. The WorldClim database served as the source for obtaining information on the prevailing climate conditions, encompassing 19 "bioclimatic" variables, which include temperatures (minimum, maximum, monthly average, quarterly average, and annual average) as well as rainfall data (Hijmans et al., 2005).

All 19 bioclimatic variables were compared pairwise, and Pearson's correlation was used to exclude highly correlated variables. The MaxEnt model

maps pests' potential invasion risk and geographic distribution (Phillips et al., 2006). To develop the probability distribution function for species occurrence, it was decided that MaxEnt should be used because 'presence only' data were required and could be successful with a small number of data points (Pearson et al., 2007; Kumar and Stohlgren, 2009). It creates the environmental conditions for random locations based on maximal species entropy distribution (Phillips et al., 2006). After testing with various parameters, we found that the default settings in MaxEnt provided the best model for pest distribution in India. According to Peterson et al. (2011), the model's efficiency was evaluated using the area under the curve (AUC) of the Receiver Operating Characteristic (ROC) (Swets, 1988) and the Akaike Information Criterion (AIC). Response curves represented the interrelationship between bioclimatic variables and the likelihood of observing pests. Tenfold cross-validation was done in this software to reduce modeling errors caused by the random splitting of data into testing and training subsets. The final MaxEnt model output was projected onto a spatial map for the chosen climate scenarios (RCP2.6 and RCP8.5) to visualize existing habitat suitability for lepidopteran pests. Spatial mapping was carried out in DIVA-GIS to generate suitability maps under current climatic conditions.

For predicting the potential distribution of species occurrence data of the species collected from the field, other presence points were used by the global biodiversity information facility (GBIF). Presence points were collected only for Peninsular India. Nineteen bioclimatic variables from Worldclim data were used as background. The variables include BIO1=Annual Mean Temperature, BIO2=Mean Diurnal Range (average of monthly max temp -min temp), BIO3=Isothermality (BIO2/BIO7) (multiplied by 100), BIO4=Temperature Seasonality (standard deviation multiplied by 100), BIO5=Max Temperature of Warmest Month, BIO6=Min Temperature of Coldest Month, BIO7=Temperature Annual Range (BIO5-BIO6), BIO8=Mean Temperature of Wettest Quarter, BIO9=Mean Temperature of Driest Quarter, BIO10=Mean Temperature of Warmest Quarter, BIO11=Mean Temperature of Coldest Quarter, BIO12=Annual Precipitation. BIO13=Precipitation of Wettest Month, BIO14=Precipitation of Driest Month, BIO15=Precipitation Seasonality (Coefficient of Variation), BIO16=Precipitation of

Wettest Quarter, BIO17=Precipitation of Driest Quarter, BIO18=Precipitation of Warmest Quarter, and BIO19=Precipitation of Coldest Quarter (Hijmans et al., 2005; Koch and General, 2019). A Receiver Operating Characteristic (ROC) curve is used for testing model fitness in Maxent models. The Area Under Curve (AUC) for the training data is close to 1, indicating good model fitness. The percent contribution of environment variables gives the contribution or influence in the potential distribution of the species.

Data analysis

The Shapiro-Wilk test was done for the normality test. The Kruskal-Wallis test was used to determine the significance of the abundance of parasitoids in three zones. Dunn's post hoc test was done to test the pairwise significance of zones' contributions to parasitoid abundance. The Mann-Whitney U test was used to determine the significant difference between pest and parasitoid abundance in the dry and wet seasons. A Shannon t-test was used to assess the significance of seasons in pest and parasitoid diversity. The Wilcoxon rank test was carried out to test the significance of crop age class for pest and parasitoid abundance. A Shannon t-test was used to assess the significance of crop age for pest and parasitoid diversity. A Mann-Whitney U test was done to determine the significant difference between pests and parasitoid abundance with reference to farming practices. The one-way ANOVA test was employed, as there is one categorical independent variable ("Zone") influencing a continuous dependent variable (pesticide application rates).

A Shannon t-test was used to assess the significance of farming practices for pest and parasitoid diversity. One-way ANOSIM was used to assess the spatial dissimilarity across zones. The spatial distribution of pests and parasitoids was studied using nonmetric multidimensional scaling (NMDS). A correlation/regression analysis was performed to examine the impact of climatic variables (mean temperature (Tmean), maximum temperature (Tmax), diurnal temperature (DT), relative humidity (RH), the heat index (HI), precipitation (Pre.), and altitude (Alt)) on the pest and parasitoid population. Regression models were formulated using multiple regression equations to estimate pest populations using climatic parameters. Multiple linear regression analyses of pest populations' abundance as a dependent variable (Y) and climatic factors, viz., maximum (Tmax) and mean temperatures

(Tmean), diurnal temperature (DT), the heat index (HI), and relative humidity (RH) as independent variables A correlation/regression analysis was performed to examine the effect of agricultural factors such as water depth (WD), plant spacing (PS), frequency of pesticide application (Freq. P), bund weed coverage (BWC), and home garden (HG) on the pest and parasitoid population. Multiple linear regression analyses of pest populations' abundance as a dependent variable (Y) and agricultural factors, viz., water depth (WD), plant spacing (PS), frequency of pesticide application (Freq. P), bund weed coverage (BWC), home garden (HG), and parasitoids (p) as independent variables. The Kruskal-Wallis test assessed the significance of vegetation types for pest and parasitoid diversity. The effect of different vegetation types on pest and parasitoid populations was tested using Dunn's post hoc test. The MANOVA test was used to assess the significance of patch richness in the abundance of pests and parasitoids. The jackknife method was employed to assess the significance of environmental variables that notably influenced the distribution of rice pests, namely *Ampittia dioscorides*, *Cnaphalocrocis medinalis*, *Parapoynx stagnalis*, *Parnara bada*, and *Pelopidas agna*. The community structure, diversity, seasonal variation, spatial variation, climatic variation, the effect of agricultural factors, vegetation types, and land use types of pests and parasitoids were analyzed using PAST 3.0 software. The structure of the host-parasitoid food web was analyzed using Food Web Designer 3.0 software (Sint and Traugott, 2016). The MaxEnt software was used to map major rice pests' present and potential distribution (Phillips et al., 2006). The NDVI value was extracted with the help of ArcGIS 10 software to map the vegetation characteristics of the sampling sites (Esri, 2011).

The potentially suitable distribution areas of major rice pests as predicted by the maximum entropy model were divided into four grades: the unsuitable region (0–0.1069); the low-suitability region (0.1069–0.4046); the moderately suitable region (0.4046–0.7023); and the highly suitable region (0.7023–1) (Liu et al., 2005).

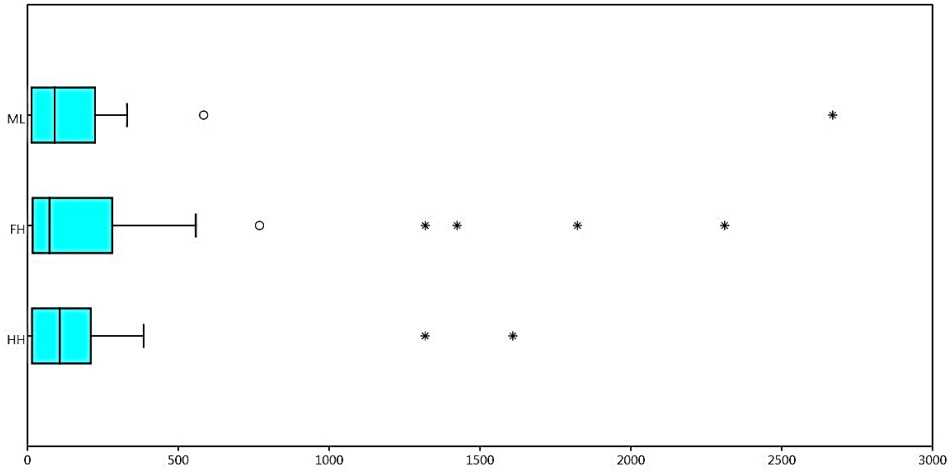
Results

Community Structure of Pests and Parasitoids

a) Pest

In total, 25,010 pest specimens from 35 species were collected across three zones. The foothill region had the highest pest count, with 32 species and a total of 11,470 specimens. The midland and high hill regions yielded similar numbers of species (33 each), with specimen counts of 6,802 and 6,748 respectively.

Fig. 2.3. Agro-ecological zone wise distribution of rice pests: HH-high hill, FH-foothill, and ML-midland laterite region.



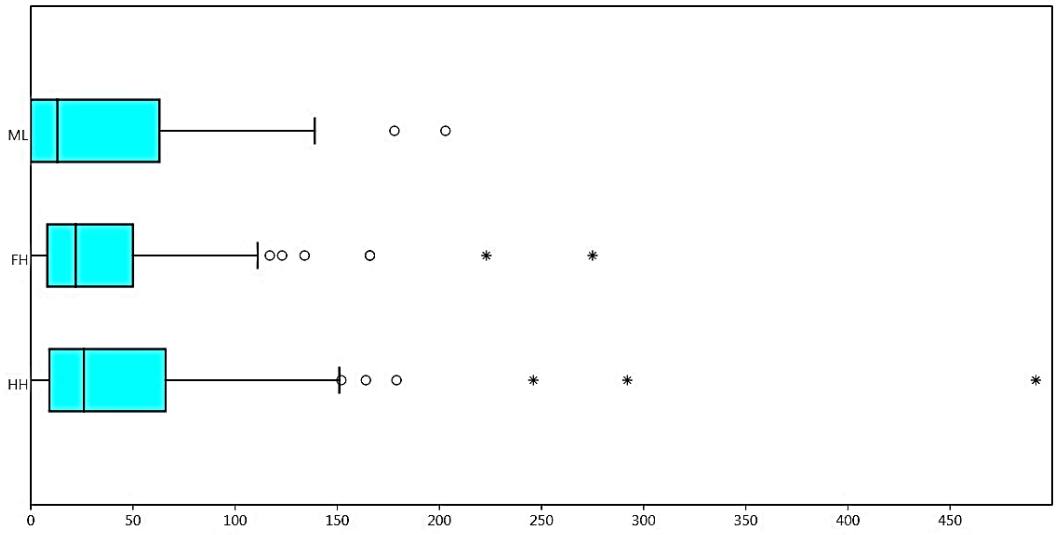
Species like *Cnaphalocrocis medinalis* (HH-1318, FH-1823, ML-2669) and *Parapoynx stagnalis* (HH-1609, FH-2311, ML-273) are more abundant than other pests, which contribute skewness to the data (Fig. 2.3). There was no significant difference between pests collected from the three zones (Kruskal-Wallis test, H (102)=0.359, p=0.835).

a) Parasitoids

A total of 12,028 parasitoid specimens, comprising 100 species, were gathered from three zones. The high hill region yielded the most parasitoids (83 species, N=4,890), followed by the foothills (91 species, N=3,910), and the midland laterite (61 species, N=3,228) (Fig. 2.4). When comparing the abundance of

parasitoids in three zones, a significant difference observed (Kruskal-Wallis test, H (2972)=8.65, p=0.012). Dunn's post hoc test was done to test the pairwise significance of zones' contributions to the parasitoid abundance. High hill and foothill showed no significance (p=0.667), but high hill and midland (p=0.006) and foothill and midland showed (0.020) significant difference in the parasitoid abundance.

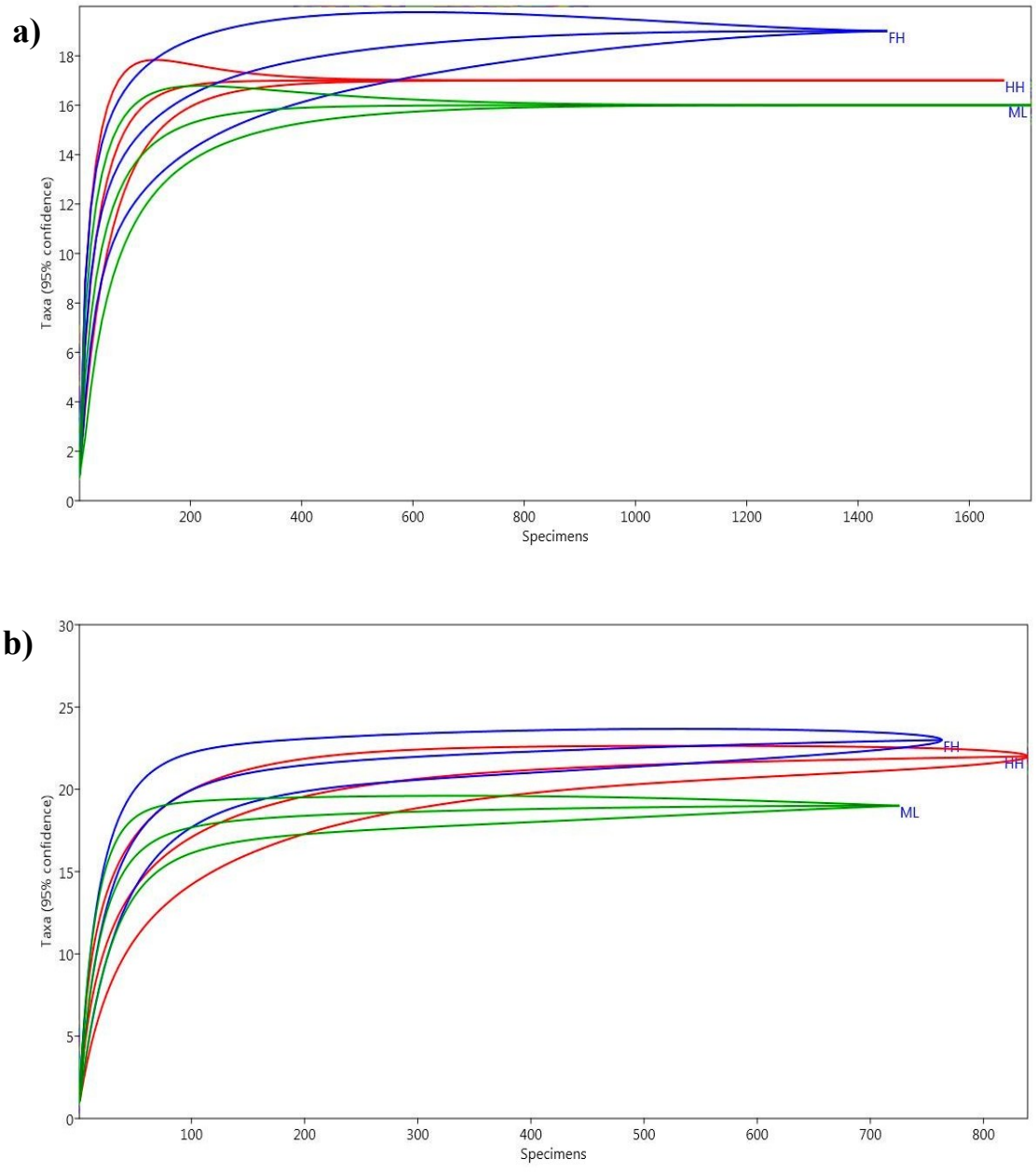
Fig. 2.4. Agro-ecological zone wise distribution of parasitoids: HH-high hill, FH-foothill, and ML-midland laterite region.



Species Accumulation Curve

The Species Accumulation Curve (SAC) gives the number of observed species as a function of sampling effort. Pest data was analyzed for both handpicked and sweep net collected samples. Both the dry and wet seasons are analyzed separately. SAC shows that sweep net collection yields more species than the handpicking method.

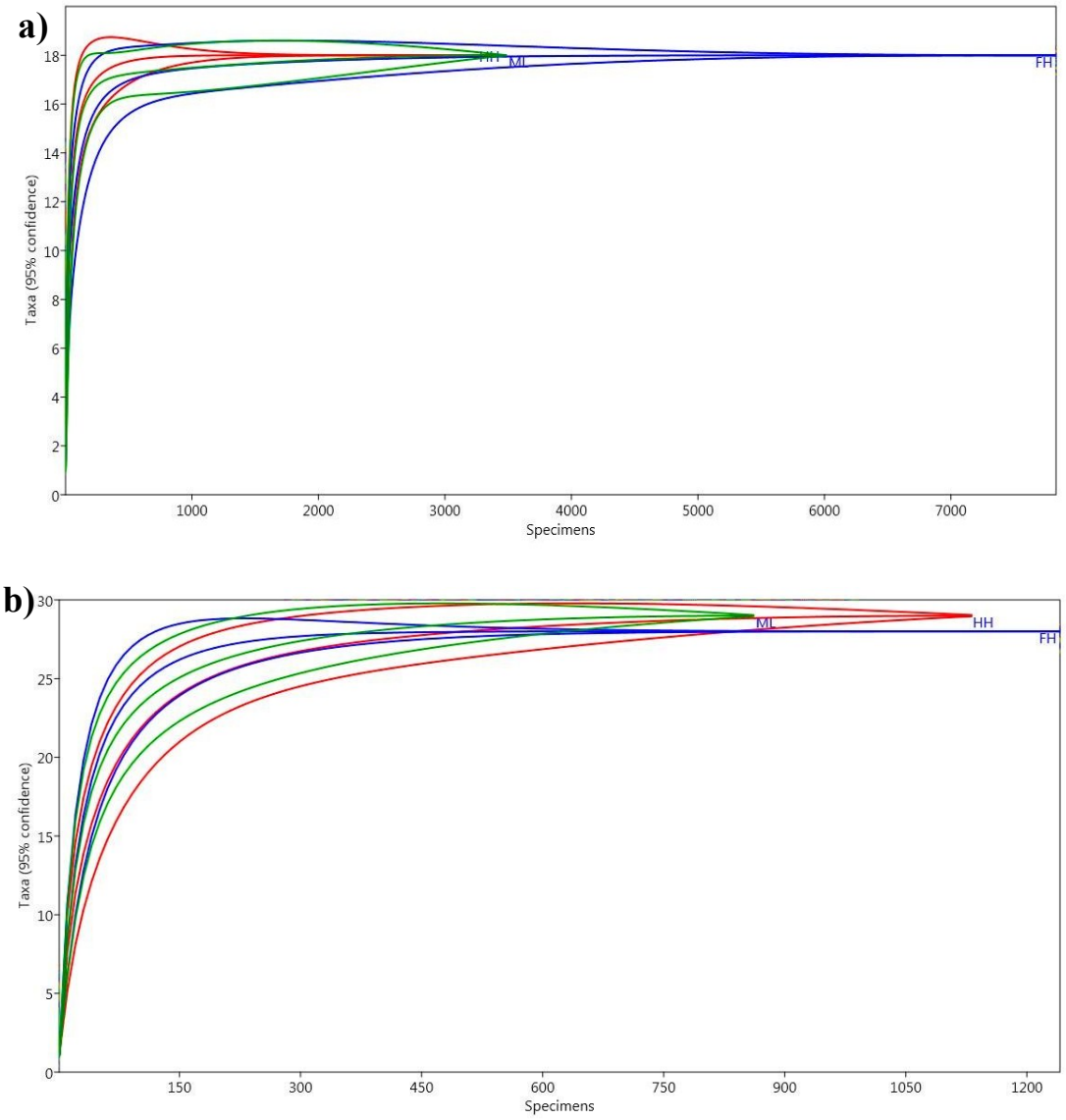
Fig. 2.5. Species accumulation curve for handpicking (a) and sweep netting (b) to collect pests in the dry season of the three agro-ecological zones: HH-high hill, FH-foothill, and ML-midland laterite regions.



There is overlap in all zones for both sampling methods in all seasons, indicating no significant difference in the species accumulation in the three zones. The sampling effort to get the maximum species in the sweep net method was less than the handpicking method, even though the species composition might differ. It is also evident that, in the handpicking method, more sampling effort is needed to yield

the same number of species when compared with the sweep net method (Fig. 2.5a & b).

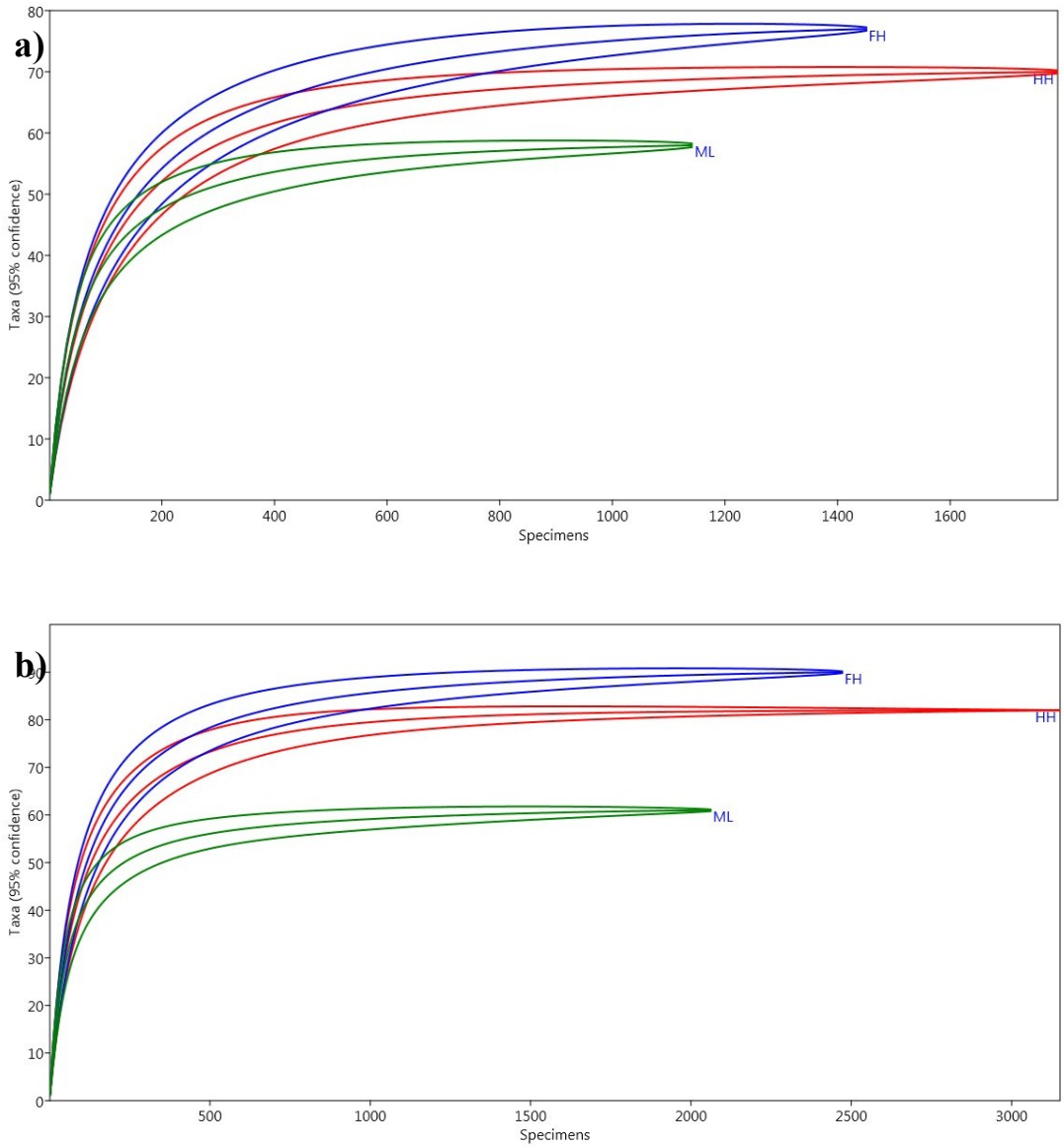
Fig. 2.6. Species accumulation curve for handpicking (a) and sweep netting (b) to collect pests in the wet season of the three agro-ecological zones: HH-high hill, FH-foothill, and ML-midland laterite regions.



For parasitoids, the accumulation curve illustrates that the abundance of parasitoids collected from high hills and foothills was higher than in the midlands. The overlapping confidence intervals in the high hills and foothills indicate that the curve did not differ significantly for these areas. Both the dry and wet seasons have

similar SAC, though the latter requires more sampling effort to yield the same number of species (Fig. 2.6).

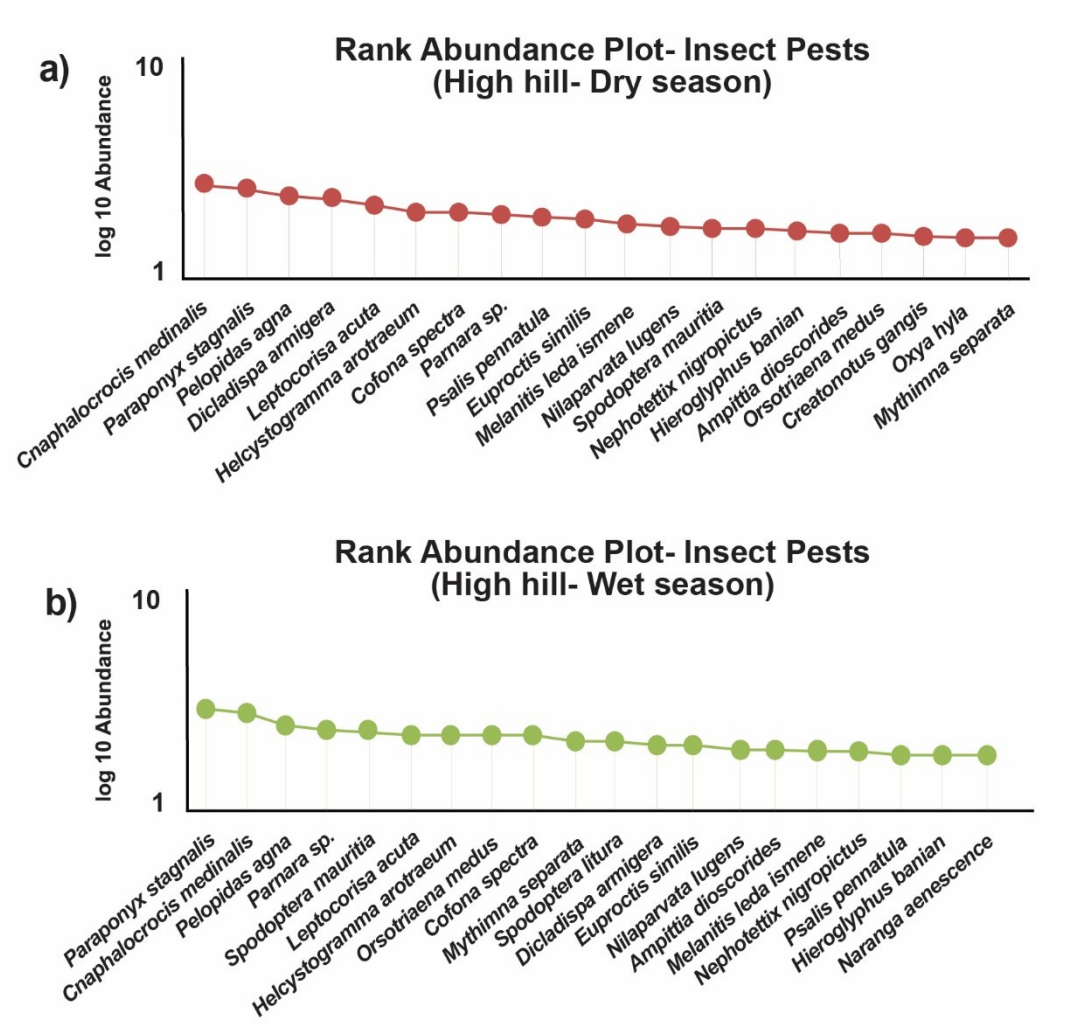
Fig. 2.7. Species accumulation curve of sweep netting to collect parasitoids in the dry (a) and wet (b) seasons of the three agro-ecological zones of North Kerala: HH-high hill, FH-foothill, and ML-midland laterite regions.



Species abundance plot (Pests)

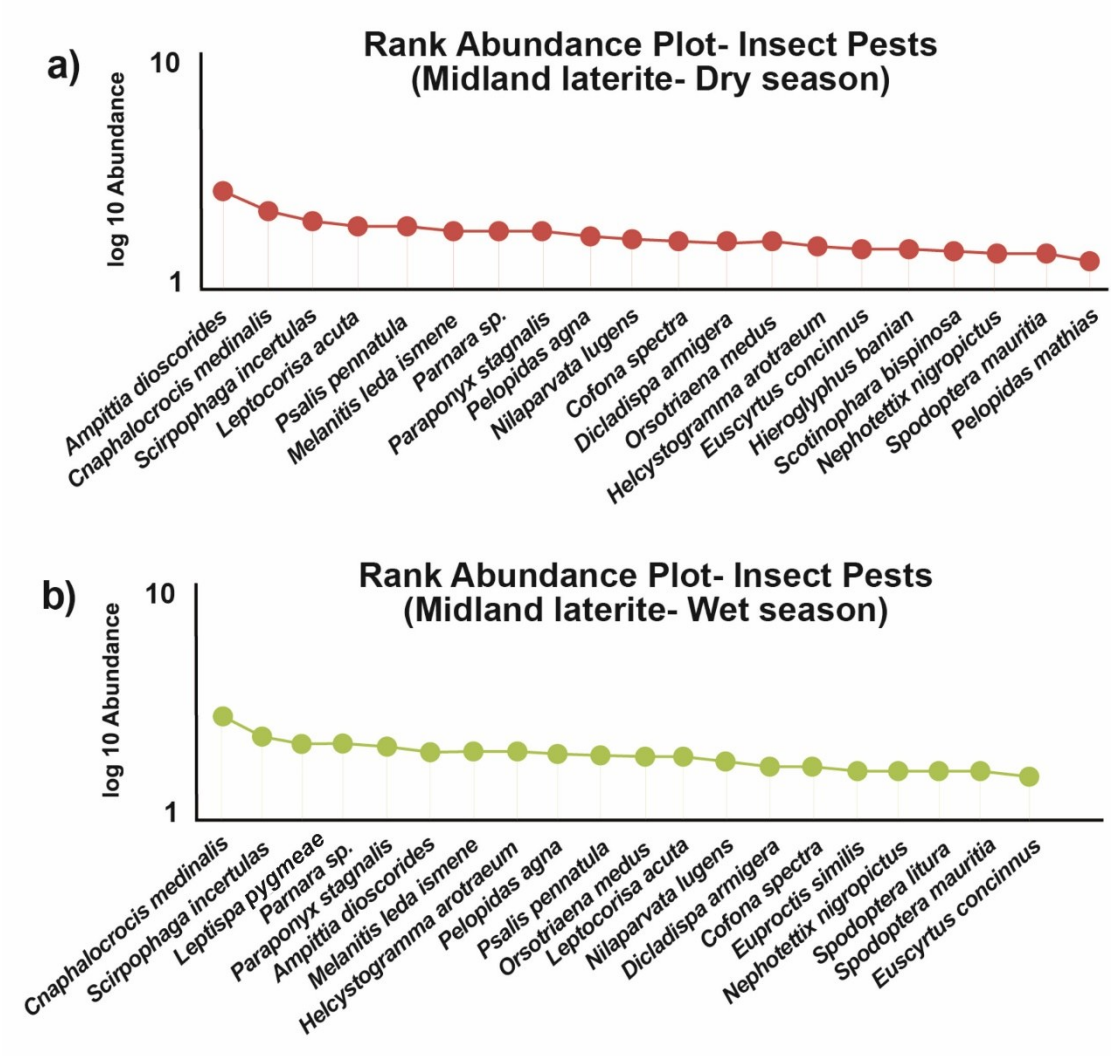
Species abundance plots were made for each zone using three-year data (2017–2019) to analyze the pest community structure

Fig. 2.8. The rank abundance plot illustrates the relative abundance of pest species concerning their rank in the high hill region during both the dry (a) and wet seasons (b).



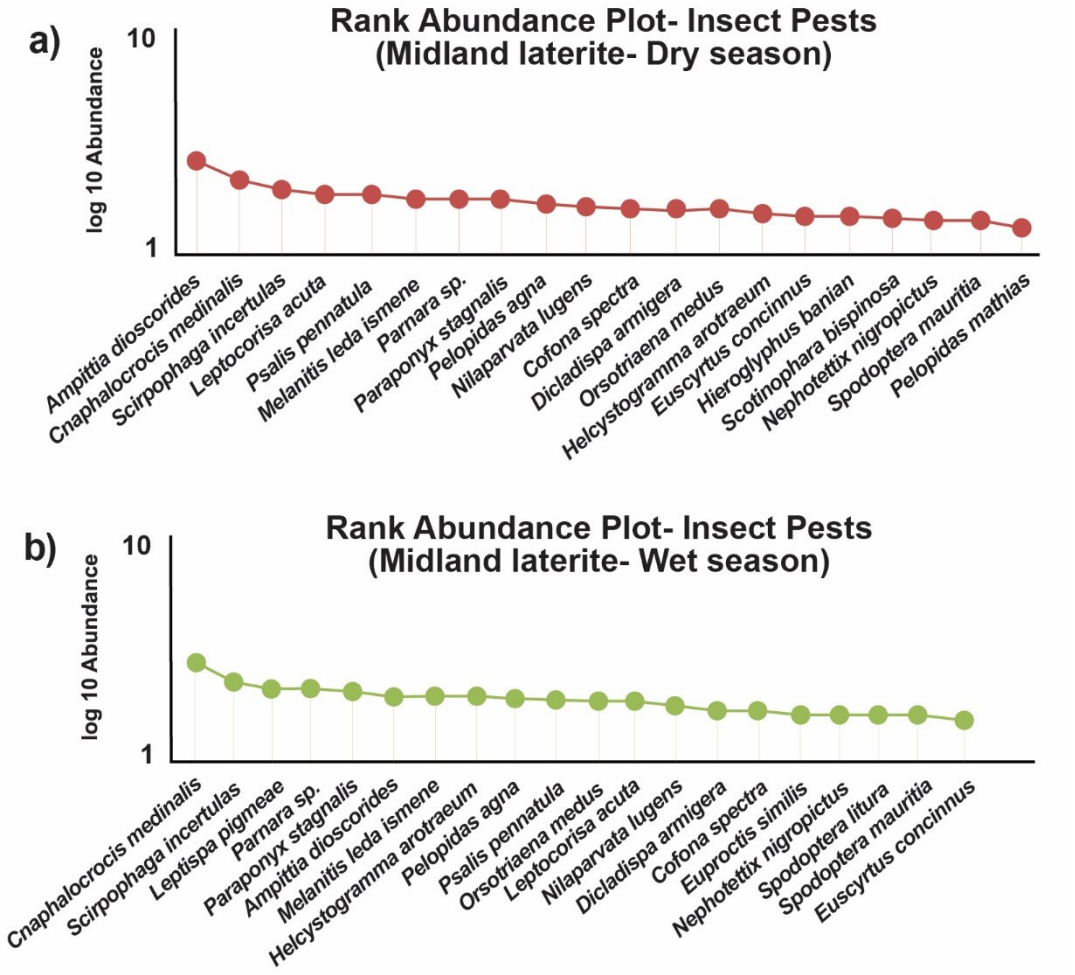
In both dry and wet seasons, all agro-ecological zones had the same pest species in their highest rank of abundance, viz. *C. medinalis*. *Cnaphalocrocis medinalis* ranked first in both the dry (Fig. 2.8a) and *P. stagnalis* ranked first in the wet (Fig. 2.8b) seasons of the high hill region.

Fig. 2.9. The rank abundance plot illustrates the relative abundance of pest species concerning their rank in the foothill region during both the dry (a) and wet seasons (b).



In the foothill region, *C. medinalis* was most abundant in the dry season, followed by *P. stagnalis*, while in the wet season, *P. stagnalis* was the most common, followed by *C. medinalis*. *Helcystogramma arotraeum* and *Parnara* sp. occupied the first five rank of abundance in foothills. The top five abundance rankings in the high hill and foothill regions were almost the same, but the most abundant species in the midland laterite zone were different.

Fig. 2.10 The rank abundance plot illustrates the relative abundance of pest species concerning their rank in the midland laterite region during both the dry (a) and wet seasons. (b).



In the midland laterite region, *Ampittia dioscorides* was the most abundant in the dry season, followed by *C. medinalis* (Fig. 2.10a), while in the wet season, *C. medinalis* was the most common, followed by *Scirpophaga incertulas* (Fig. 2.10b).

Relative density and Relative frequency of rice pests

The relative density (RD) and relative frequency (RF) of the rice pests are given in annexures 1–9. The RD of *Cnaphalocrocis medinalis* and *Parapoynx stagnalis* was high in the high hill and the foothill zones and both the seasons (dry and wet seasons) during 2017–2019 (Table 2.2 & 2.3). *Cnaphalocrocis medinalis* and *Scirpophaga incertulas* showed the highest RD in the midland laterite region in

2017 and 2018 whereas in 2019, *P. stagnalis* and *Parnara* sp. showed the highest RD (Table.2.4).

In all the zones, the pests such as *C. medinalis*, *P. stagnalis*, *Cofana spectra*, *Pelopidas agna*, *Helcystogramma arotraeum*, *Spodoptera litura*, and *Ampittia dioscorides* were the major pests with the highest RD in different agro-ecological zones and seasons (Table 2.2, 2.3 & 2.4).

Table 2.2. The relative density and frequency of major rice pests in the high hill region (2017–2019).

Dry season			**Wet season**		
Species	**Relative density (%)**	**Relative frequency (%)**	**Species**	**Relative density (%)**	**Relative frequency (%)**
High hill 2017					
Cnaphalocrocis medinalis	22.44	6.84	*Cnaphalocrocis medinalis*	21.36	5.15
Parapoynx stagnalis	22.92	6.85	*Parapoynx stagnalis*	22.52	5.15
Cofana spectra	4.70	5.48	*Pelopidas agna*	5.81	5.15
High hill 2018					
Parapoynx stagnalis	21.93	5.59	*Parapoynx stagnalis*	26.20	5.78
Cnaphalocrocis medinalis	18.22	5.24	*Cnaphalocrocis medinalis*	19.27	5.78
Helcystogramma arotraeum	7.06	1.75	*Spodoptera litura*	5.78	5.20
High hill 2019					
Parapoynx stagnalis	26.41	5.43	*Parapoynx stagnalis*	24.30	6.37
Cnaphalocrocis medinalis	21.22	9.05	*Cnaphalocrocis medinalis*	14.58	6.37
Parnara sp.	8.16	9.05	*Parnara* sp.	7.58	6.37

Table 2.3. The relative density and frequency of major rice pests in the foothill region (2017–2019).

Dry season			Wet season		
Species	**Relative density (%)**	**Relative frequency (%)**	**Species**	**Relative density (%)**	**Relative frequency (%)**
Foothill 2017					
Cnaphalocrocis medinalis	14.31	5.79	*Cnaphalocrocis medinalis*	15.11	5.51
Parapoynx stagnalis	9.59	3.31	*Parapoynx stagnalis*	21.90	5.51
Helcystogramma arotraeum	7.73	2.07	*Ampittia dioscorides*	13.30	5.51
Foothill 2018					
Cnaphalocrocis medinalis	18.64	8.10	*Parapoynx stagnalis*	24.35	6.80
Parapoynx stagnalis	11.23	5.26	*Parnara* sp.	16.48	6.80
Helcystogramma arotraeum	11.95	2.83	*Cnaphalocrocis medinalis*	13.92	6.80
Foothill 2019					
Cnaphalocrocis medinalis	31.62	9.62	*Parapoynx stagnalis*	21.97	5.26
Parapoynx stagnalis	10.15	7.21	*Cnaphalocrocis medinalis*	15.33	5.26
Helcystogramma arotraeum	7.79	2.88	*Ampittia dioscorides*	14.10	5.26

Table 2.4. The relative density and frequency of major rice pests in the midland laterite region (2017–2019).

Dry season			Wet season		
Species	**Relative density (%)**	**Relative frequency (%)**	**Species**	**Relative density (%)**	**Relative frequency (%)**
Midland laterite 2017					
Cnaphalocrocis medinalis	40.00	8.20	*Cnaphalocrocis medinalis*	34.32	6.25
Scirpophaga incertulas	13.18	6.15	*Scirpophaga incertulas*	11.93	6.25
Psalis pennatula	6.24	8.20	*Leptocorisa acuta*	8.45	2.50
Midland laterite 2018					
Cnaphalocrocis medinalis	38.57	8.70	*Cnaphalocrocis medinalis*	40.65	5.70
Scirpophaga	8.85	6.09	*Scirpophaga*	7.19	4.84

incertulas			*incertulas*		
Leptocorisa acuta	6.76	8.26	*Parnara* sp.	6.05	5.70
Midland laterite 2019					
Cnaphalocrocis medinalis	38.63	8.62	*Cnaphalocrocis medinalis*	43.38	6.58
Parapoynx stagnalis	7.67	5.60	*Parnara* sp.	6.97	6.58
Scirpophaga incertulas	6.85	5.60	*Parapoynx stagnalis*	5.57	4.61

Species abundance plot (Parasitoids)

Species abundance plots were created for each zone to analyze the parasitoid community structure. The parasitoid species with the greatest abundance rank, *Apanteles* sp. 1, is found in all plots. In both the dry and wet seasons, *Apanteles* sp. 1showed the highest abundance in the high hill region, followed by *Apanteles* sp. 2 and *Telenomus remus* (Fig. 2.11)

In the foothill regions, the *Apanteles* sp. 1, *Apanteles* sp. 2 and *T. remus* occupied the first three ranks in abundance, except for the wet season. In the foothill wet season, *Casinaria ajanta* showed third rank in abundance, and was not present in the dry seasons (Fig. 2.12). In the dry season of both regions, *Brachymeria lasus* was present within the first five ranks in abundance.

In the midland laterite region, similar to the other two agro-ecological zones, *Apanteles* sp. 1 tops first rank of abundance, followed by *T. remus* in the dry and wet seasons (Fig. 2.13).

Fig. 2.11 The rank abundance plot illustrates the relative abundance of parasitoid species concerning their rank in the high hill region during both the dry (a) and wet seasons (b).

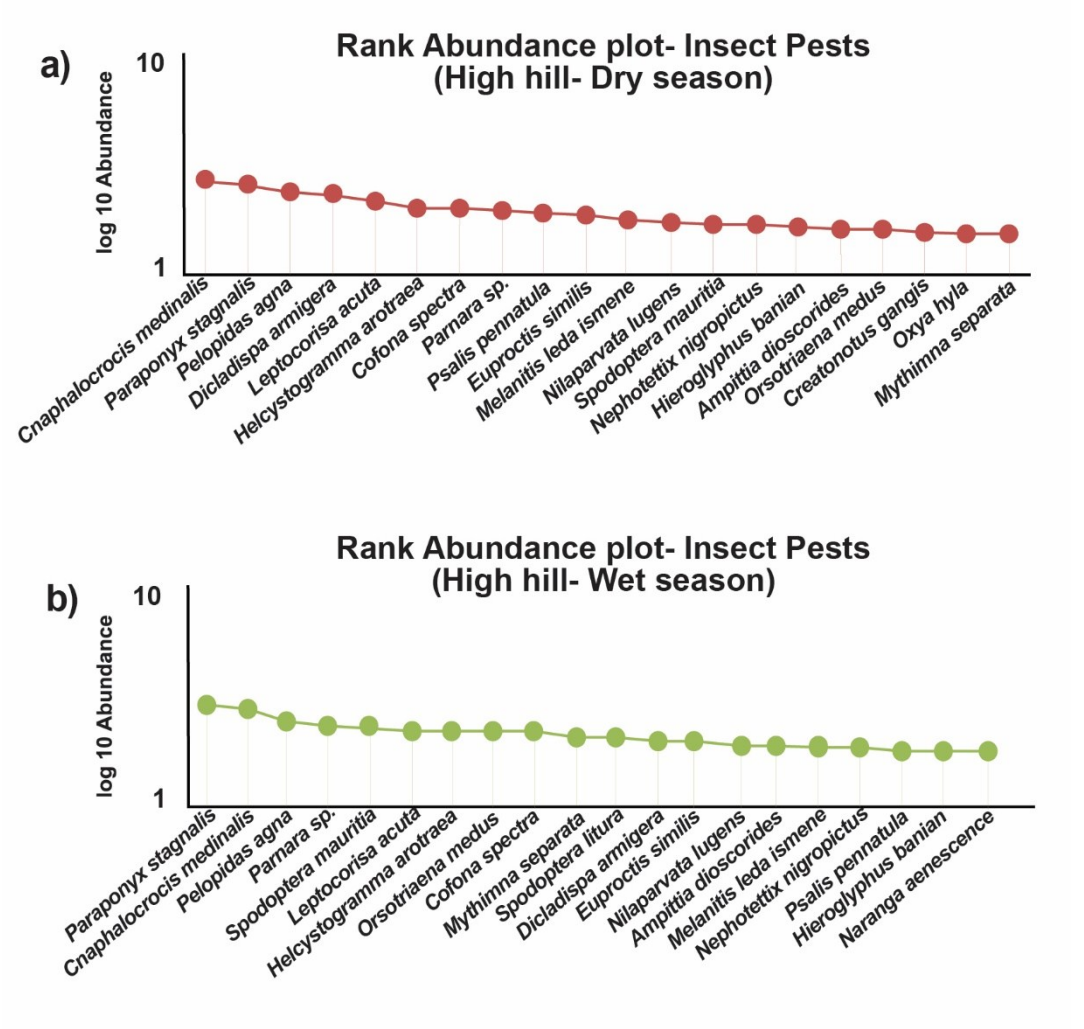


Fig. 2.12 The rank abundance plot illustrates the relative abundance of parasitoid species concerning their rank in the foothill region during both the dry (a) and wet seasons (b).

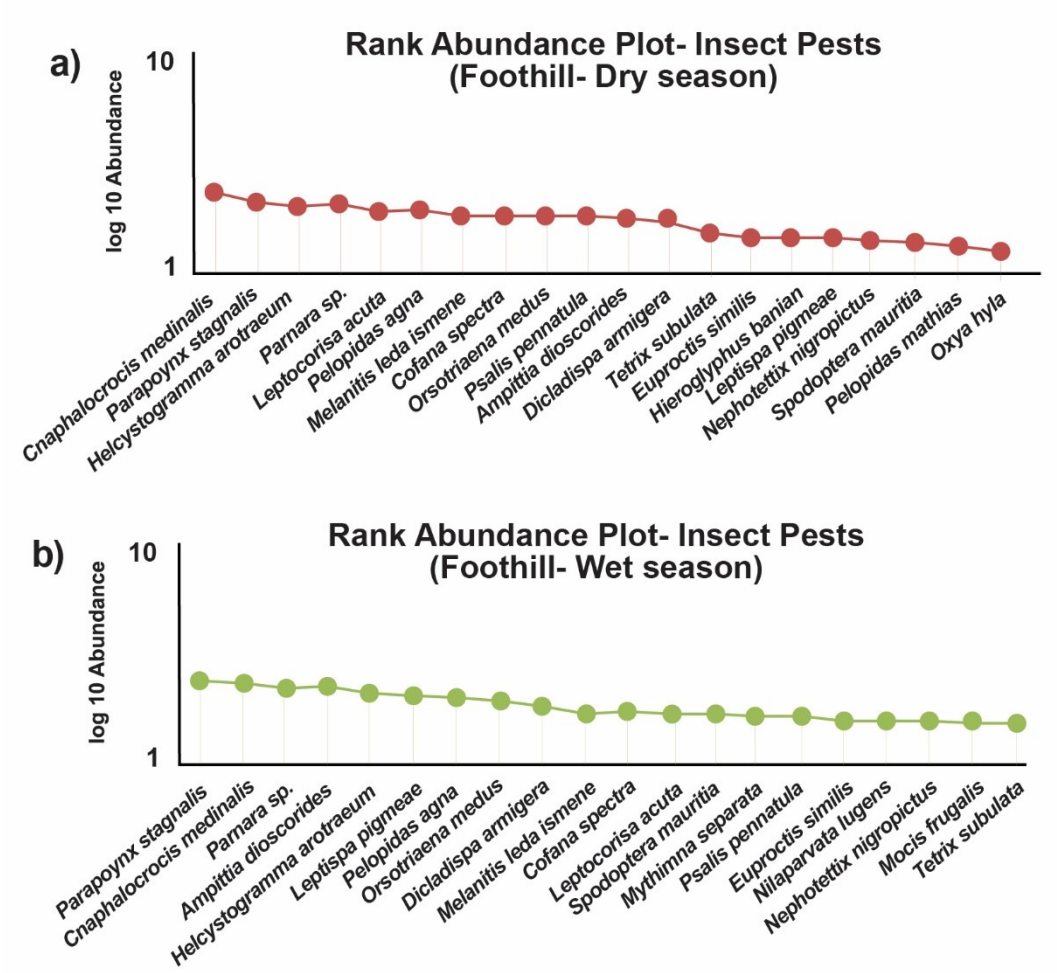
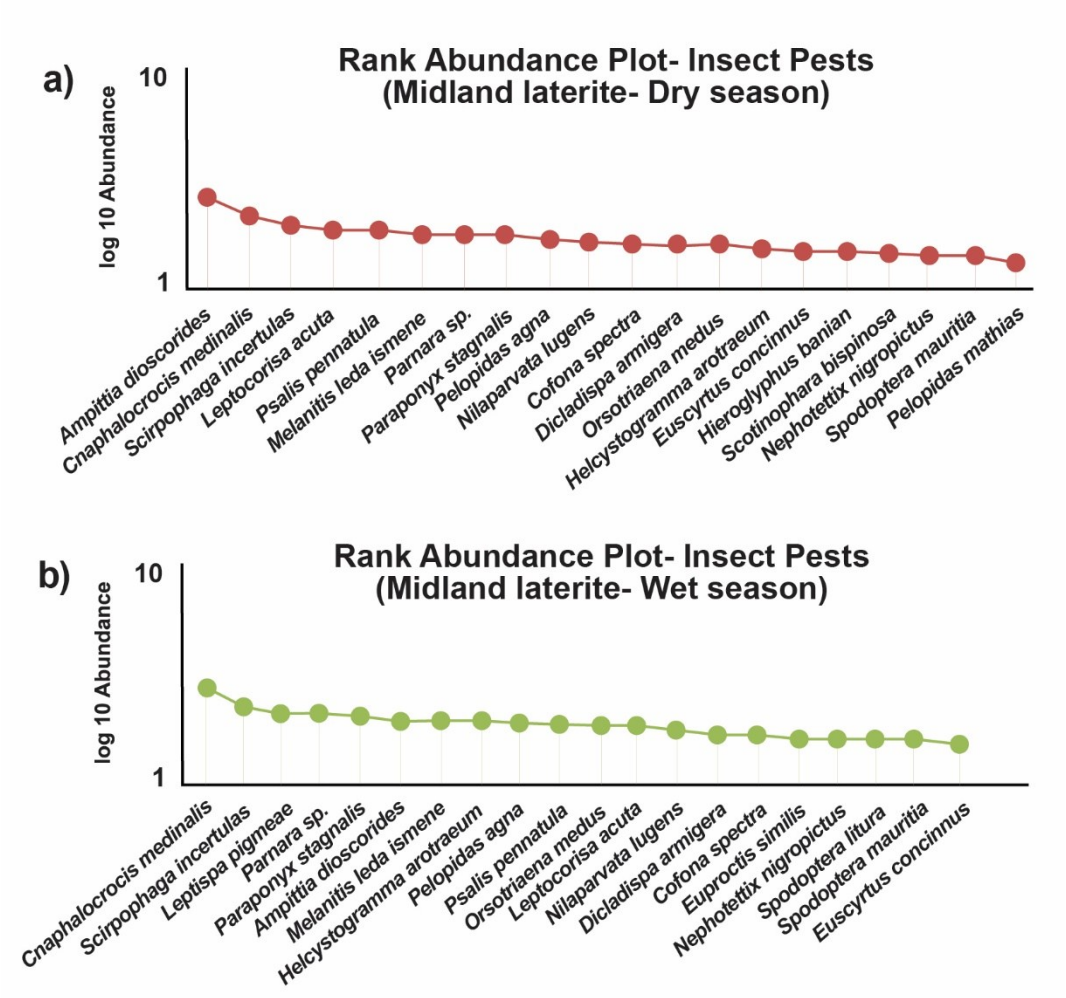


Fig. 2.13 The rank abundance plot illustrates the relative abundance of parasitoid species concerning their rank in the midland laterite region during both the dry (a) and wet seasons (b).



Relative density and Relative frequency of parasitoids

The relative density (RD) and relative frequency (RF) of the collected parasitoids from the rice fields are given in annexures 10–18.

The RD of *Apanteles* sp. 1 and *Apanteles* sp. 2 was found to be high in the high hill region in both the seasons (dry and wet seasons) during 2017–2019. In the high hill region, the parasitoids such as *Apanteles* sp. 1, *Apanteles* sp. 2*, Telenomus remus, Aphanogmus fijiensis, Macroteleia* sp., and *Telenomus oryzae* showed the highest RD during 2017–2019 (Table 2.5).

Table 2.5. The relative density and frequency of major parasitoids in the high hill region (2017–2019).

Dry season			Wet season		
Species	**Relative density (%)**	**Relative frequency (%)**	**Species**	**Relative density (%)**	**Relative frequency (%)**
High hill 2017					
Apanteles sp. 1	23.67	5.45	*Apanteles* sp. 1	18.04	2.98
Apanteles sp. 2	14.84	5.13	*Apanteles* sp. 2	13.58	3.13
Telenomus remus	10.95	5.13	*Telenomus remus*	9.13	2.82
High hill 2018					
Apanteles sp. 1	17.32	4.05	*Apanteles* sp. 1	17.2	4.08
Apanteles sp. 2	10.55	3.78	*Apanteles* sp. 2	19.8	4.31
Telenomus remus	10.87	4.32	*Macroteleia* sp.	6.7	3.40
High hill 2019					
Apanteles sp. 1	22.04	5.50	*Apanteles* sp. 1	21.09	1.17
Apanteles sp. 2	13.33	3.88	*Apanteles* sp. 2	12.12	0.94
Aphanogmus fijiensis	10.74	3.88	*Telenomus oryzae*	10.91	1.00

In the Foothill region, *Apanteles* sp. 1*, Apanteles* sp. 2*, T. remus, A. fijiensis, Brachymeria burski., and Casinaria ajanta* were the major parasitoids with the highest RD (Table 2.6).

Table 2.6. The relative density and frequency of major parasitoids in the foothill region (2017–2019).

Dry season			Wet season		
species	**Relative density (%)**	**Relative frequency (%)**	**Species**	**Relative density (%)**	**Relative frequency (%)**
Foothill 2017					
Apanteles sp. 1	12.04	4.36	*Apanteles* sp. 1	11.49	3.02
Telenomus remus	11.65	4.67	*Brachymeria burski*	10.25	3.20
Gryon sp.	9.90	3.43	*Casinaria ajanta*	8.72	3.37
Foothill 2018					
Apanteles sp. 1	15.09	5.30	*Apanteles* sp. 1	12.80	4.30
Apanteles sp. 2	10.57	4.64	*Apanteles* sp. 2	11.27	4.77
Trichogramma japonicum	10.94	5.30	*Aphanogmus fijiensis*	10.43	4.53
Foothill 2019					
Apanteles sp. 2	13.14	5.08	*Brachymeria burski*	12.89	12.89
Apanteles sp. 1	12.89	4.30	*Casinaria ajanta*	4.36	4.36
Telenomus remus	10.57	4.30	*Apanteles* sp. 1	10.22	4.14

In the midland laterite region, *Apanteles* sp. 1, *Apanteles* sp. 2*, T. remus, A. fijiensis, Mesochorus* sp., *Tetrastichus schoenobii,* and *Telenomus rowani* had the highest value of RD (Table 2.7).

Table 2.7. The relative density and frequency of major parasitoids in the midland laterite region (2017–2019).

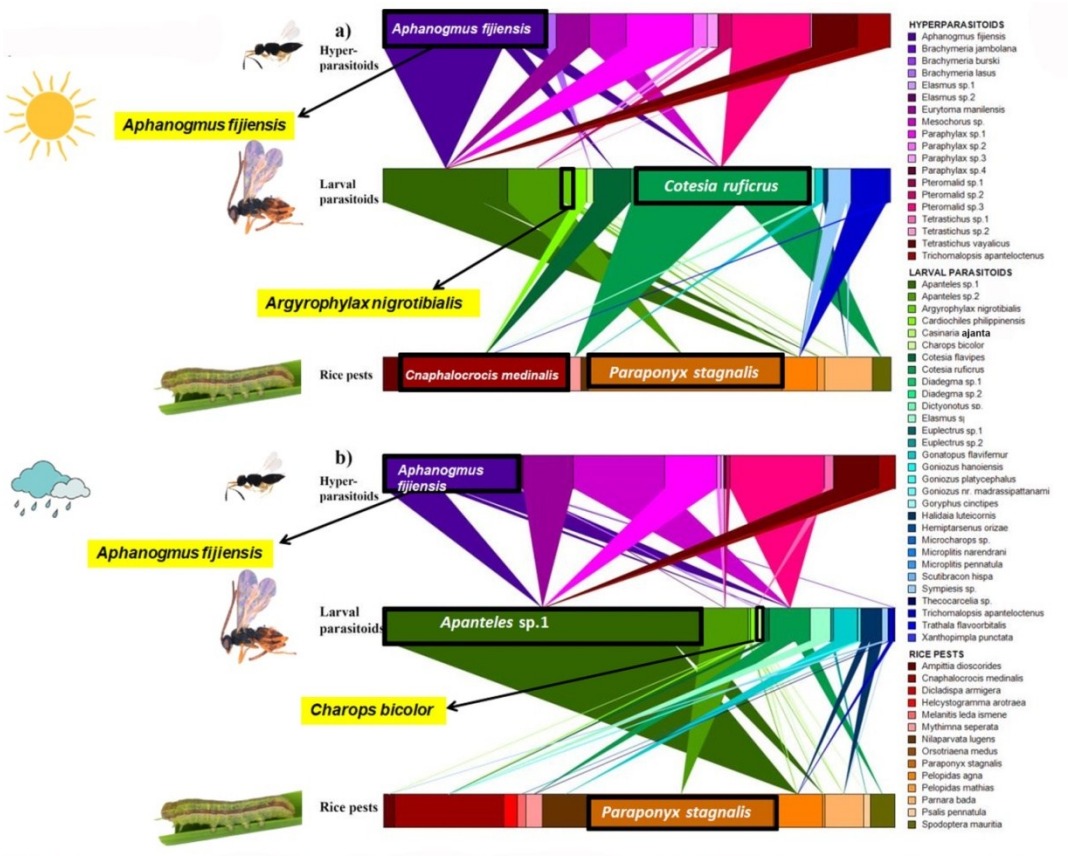
Dry season			Wet season		
Species	**Relative density (%)**	**Relative frequency (%)**	**Species**	**Relative density (%)**	**Relative frequency (%)**
Midland laterite 2017					
Telenomus remus	13.44	5.86	*Apanteles* sp. 1	10.81	4.15
Apanteles sp. 1	11.02	4.30	*Telenomus remus*	4.15	3.92
Tetrastichus schoenobii	10.48	4.30	*Telenomus rowani*	9.86	3.69
Midland laterite 2018					
Apanteles sp. 1	10.75	4.75	*Apanteles* sp. 1	9.93	3.49
Telenomus oryzae	8.18	4.75	*Aphanogmus fijiensis*	7.59	3.95
Mesochorus sp.	7.71	4.07	*Telenomus remus*	7.31	3.49
Midland laterite 2019					
Aphanogmus fijiensis	10.42	5.37	*Apanteles* sp. 1	14.08	5.16
Cotesia ruficrus	10.14	4.96	*Telenomus remus*	12.27	4.89
Apanteles sp. 1	10.14	4.55	*Cotesia ruficrus*	8.67	4.89
Telenomus oryzae	10.14	4.55			

Host-parasitoid food web

Across the twelve sampling sites and three agro-ecological zones and two seasons (dry and wet), larval stages of 15 pest species were collected. From the larvae, we reared 28 species of primary parasitoids and 20 species of hyperparasitoids

The wet season showed the highest interaction between pests, primary parasitoids, and hyperparasitoids in all three agro-ecological zones. The foothill wet season had the highest tri-trophic interaction among the three agro-ecological zones, and the foothill region had the largest number of parasitoids with 100% interaction (n=40) (Fig. 2.15b).

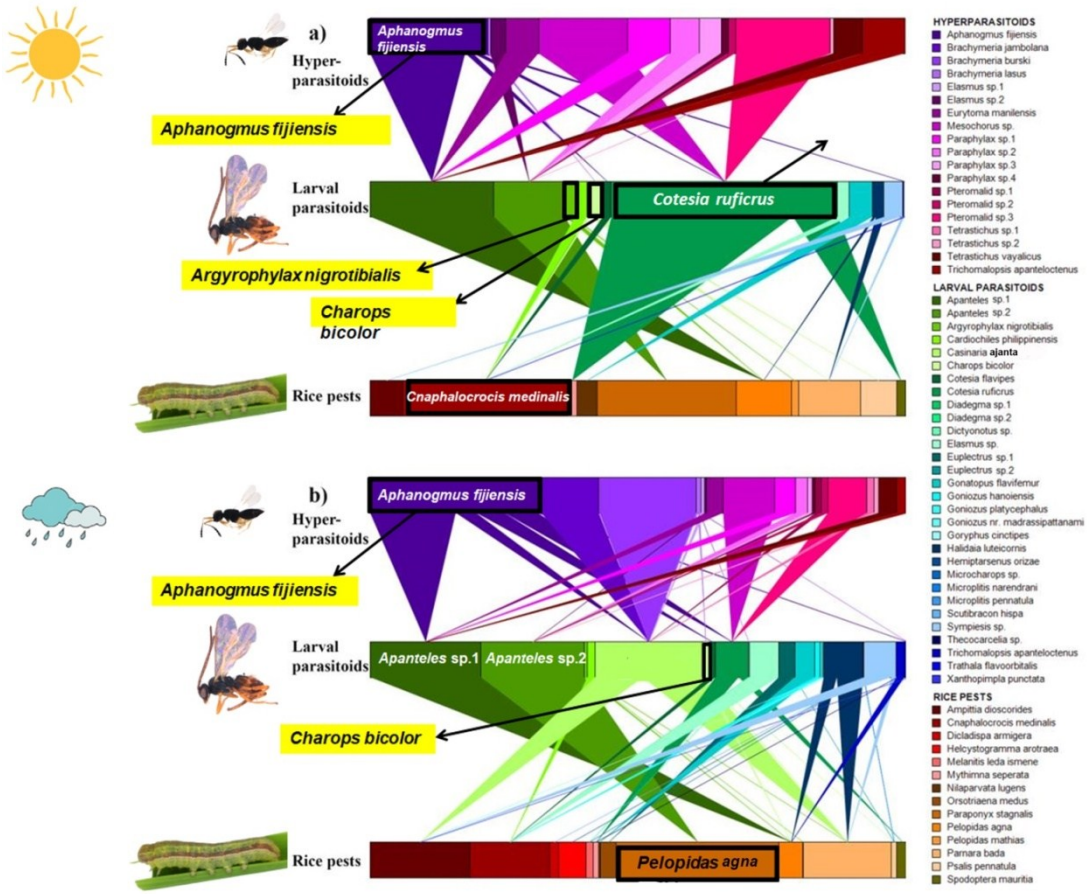
Fig. 2.14 Quantitative food web showing the parasitoid and pest community composition in the high hill region: a) dry season, and b) wet season. Rice pests are at the bottom level, larval parasitoids in the middle level, and hyperparasitoids are the top trophic level with lines indicating feeding relationships.



Aphanogmus fijiensis was the hyperparasitoid with the highest number of hosts across all zones. *Aphanogmus fijiensis* parasitized three primary parasitoids, *Apanteles* sp. 1, *Cotesia ruficrus*, and *Cotesia flavipes*, with an interaction rate of 74.07 %, 11.11 %, and 14.81 %, respectively, during the high hill dry season (Fig. 2.14a). During the High hill wet season, *A. fijiensis* parasitised four primary parasitoids: *Apanteles* sp. 1 (42.86%), *C. ruficrus* (8.23%), *C. flavipes* (48.05%), and *Trathala flavoorbitalis* (0.87%) (Fig. 2.14b). In the foothill dry season, *A. fijiensis* parasitized four primary parasitoids, viz., *Apanteles* sp. 1, *C. ruficrus*, and *C. flavipes*, and *T. flavoorbitalis* with an interaction rate of 81.25%, 6.25%, 6.25%, and 6.25%, respectively (Fig. 2.15a). In the foothill wet season, *A. fijiensis* consumed five primary parasitoids, viz., *Apanteles* sp. 1 (49.80%), *C. ruficrus* (16.47%), *C. flavipes* (19.61%), *T. flavoorbitalis* (2.35%), and *C. ajanta* (11.76%) (Fig. 2.15b). In

the Midland laterite wet season, *A. fijiensis* consumed three primary parasitoids, viz., *Apanteles* sp. 1 (17.14%), *C. ruficrus* (79.04%), and *C. flavipes* (3.08%) (Fig. 2.16b).

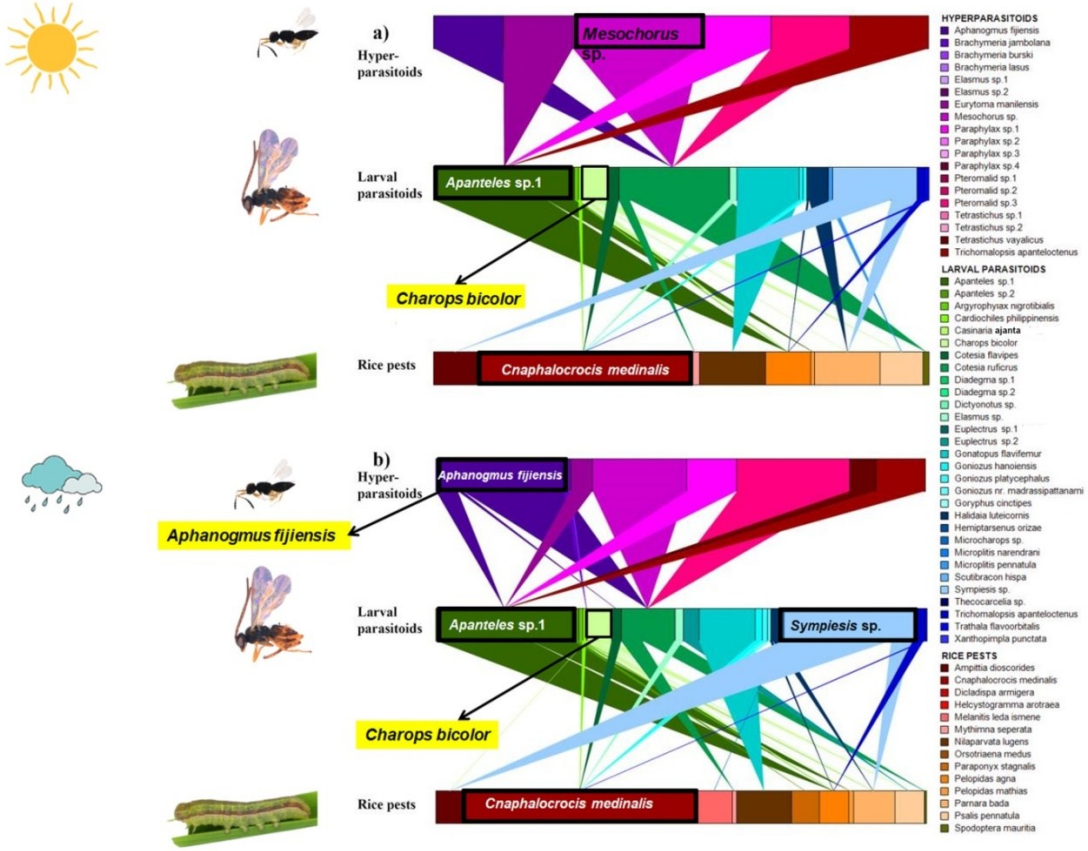
Fig. 2.15 Quantitative food web showing the parasitoid and pest community composition in the foothill region: a) dry season, and b) wet season. Rice pests are at the bottom level, larval parasitoids in the middle level, and hyperparasitoids are the top trophic level with lines indicating feeding relationships.



Argyrophylax nigrotibialis, the primary parasitoid that consumed the most rice pests during the high hill dry season, was reared from *Pelopidas agna* (57.14%), *Pelopidas mathias* (14.29%), and *Parnara* sp. (28.57%) (Fig. 2.14a). In the high hill wet season, *C. bicolor* consumed the maximum number of rice pests, viz., *P. agna* (45.21%), *P. mathias* (2.74%), *Parnara* sp. (23.29%), and *Psalis pennatula* (28.77%) (Fig. 2.14b). *A. nigrotibialis* and *C. bicolor* (n=3) were the primary parasitoids that consumed the most rice pests throughout the foothill dry season. *A. nigrotibialis* was reared from *P. agna* (79.16%), *P. mathias* (4.16%), and *Parnara*

sp. (16.66%), whereas *C. bicolor* was reared from *P. agna* (61.46%), *Parnara* sp. (15.59%), and *P. pennatula* (22.93%) (Fig. 2.15a).

Fig. 2.16 Quantitative food web showing the parasitoid and pest community composition in the midland laterite region: a) dry season, and b) wet season. Rice pests are at the bottom level, larval parasitoids in the middle level, and hyperparasitoids are the top trophic level with lines indicating feeding relationships.



In the foothill wet season, *Charops bicolor* consumed the maximum number of rice pests, viz., *P. agna* (45.21%), *P. mathias* (2.74%), and *Parnara* sp. (23.29%), and *P. pennatula* (28.77%) (Fig. 2.15b). *Charops bicolor*, which was reared from *P. agna* (30.00%), *Parnara* sp. (10.00%), and *P. pennatula* (60.00%), was the primary parasitoid that parasitized the highest number of rice pests in the Midland laterite dry season (Fig. 2.16a). In the midland laterite wet season also, *C. bicolor* consumed the maximum number of rice pests, viz., *P. agna* (33.55%), *P. mathias* (4.02%), *Parnara* sp. (9.39%), and *P. pennatula* (53.02%) (Fig. 2.16b).

Spatio-temporal variations of pest and parasitoids

Seasonal variation of pest-parasitoid diversity

The species richness and abundance were high in the wet season for both the pests (Fig. 2.17) and parasitoids (Fig. 2.18). When comparing the abundance of pests in the dry and wet seasons, there is a significant difference in the abundance (Dry Season, Taxa-31, Individuals-7190; Wet Season, Taxa-34, Individuals-18088). The result also showed a significant difference in the pest abundance (Mann-Whitney U test, U (66)=407.5, p=0.0370) in the dry and the wet seasons.

There is a significant difference in the abundance of parasitoids in the dry and wet seasons (Dry Season: Taxa-91, Individuals-4419; Wet Season: Taxa-98, Individuals-7717). The result showed a significant difference between parasitoid abundance (Mann-Whitney U test, U (196)=3438.5, p=0.0002) in the dry and the wet seasons.

Fig. 2.17. Violin plots of dry and wet seasonal variation of pest populations. Box plots overlaid represent the quantile range.

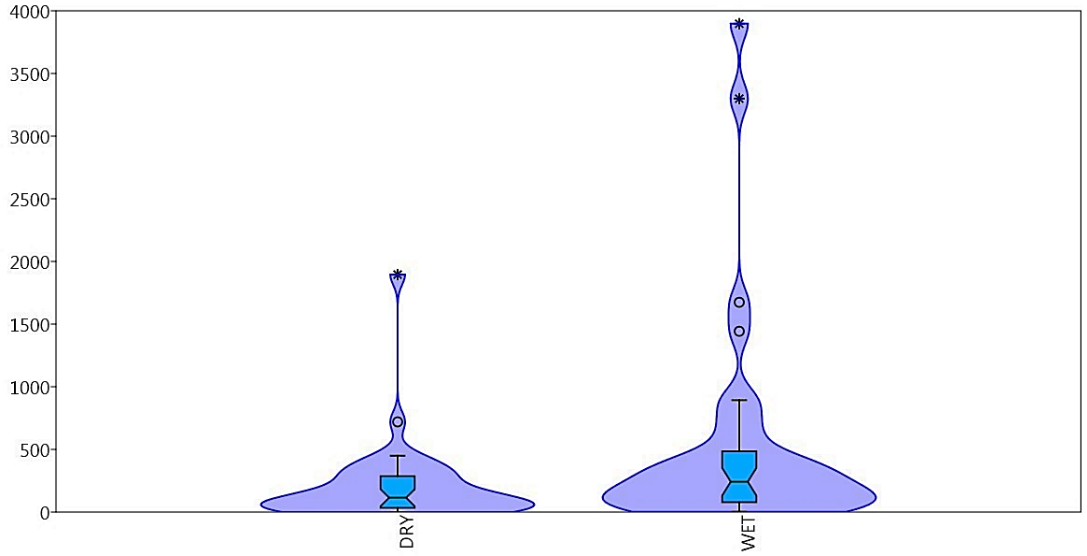
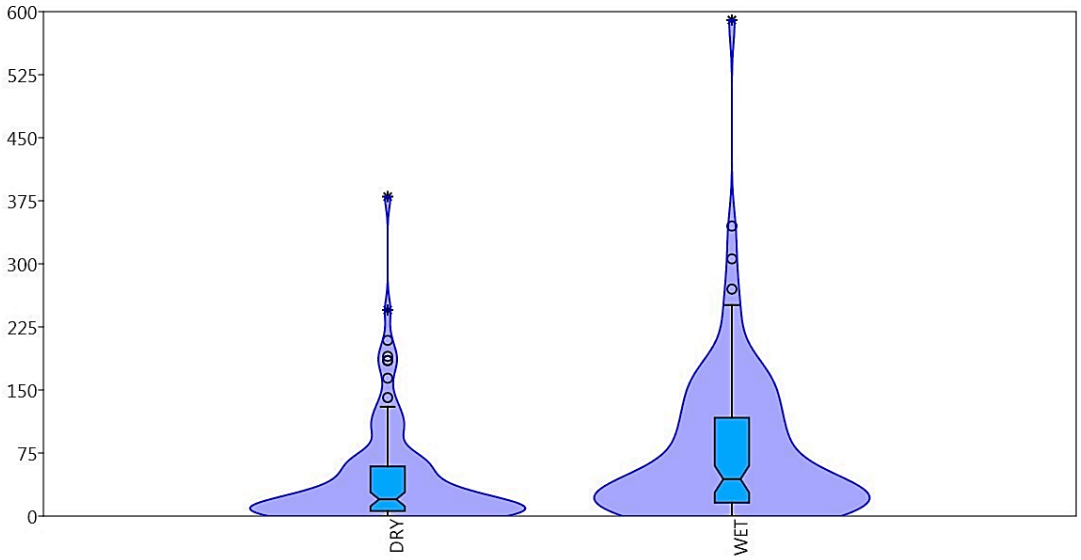


Fig. 2.18. Violin plots of dry and wet seasonal variation of parasitoid populations. Boxplots overlaid represent the quantile range.



A zone-wise comparison of the seasonal differences was also analyzed. In all seasons, there is a clear difference in the number of species and individuals observed for pests (Fig. 2.19) and parasitoids (Fig. 2.20).

Fig. 2.19. Comparison of dry (D) and wet (W) seasonal variation of pest populations in the three agro-ecological zones: HH-high hill, FH-foothill, and ML-midland laterite region.

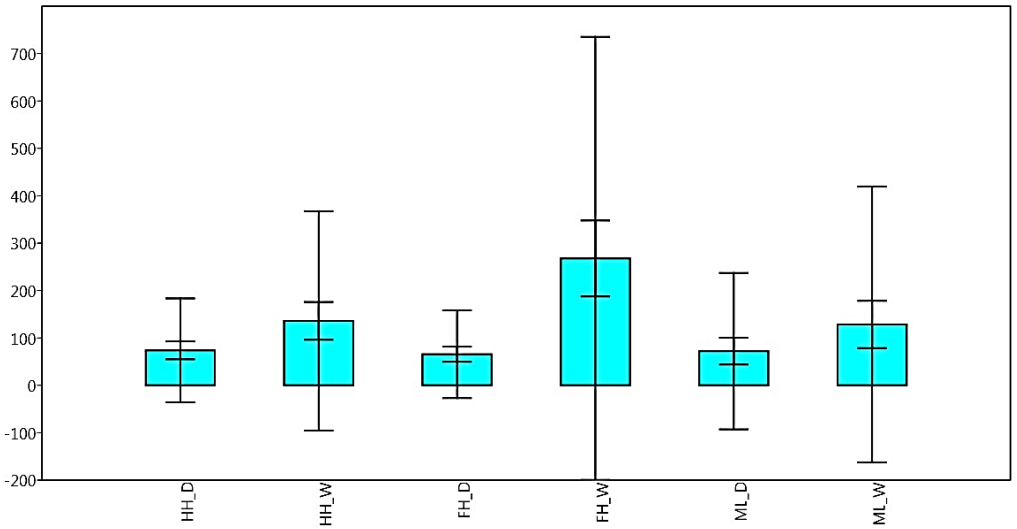
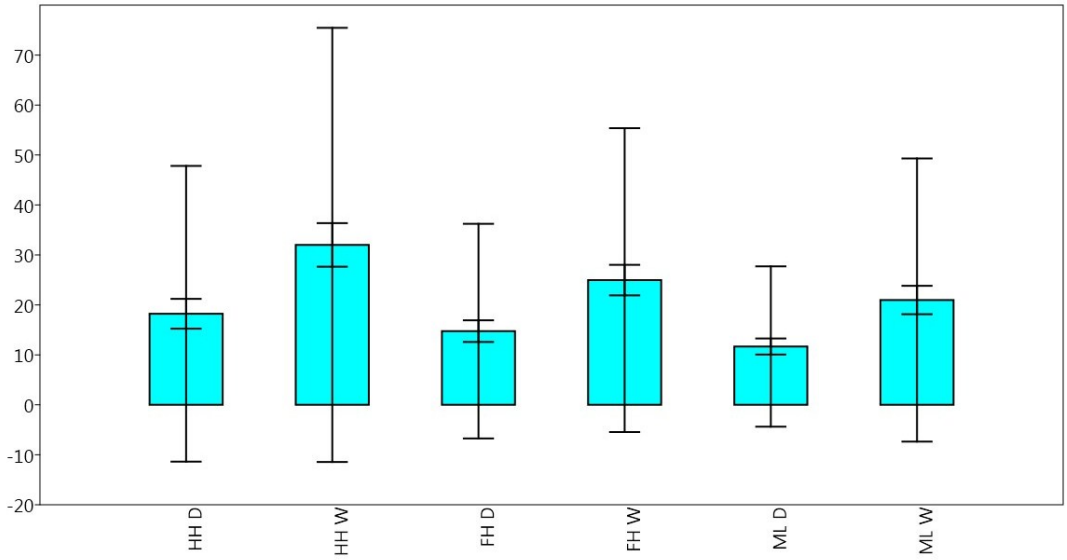


Fig. 2.20. Comparison of dry (D) and wet (W) seasonal variation of parasitoid populations in the three agro-ecological zones: HH-high hill, FH-foothill, and ML-midland laterite region.



The Species richness and abundance of pests and parasitoids was higher in the wet season compared to the dry season (Table 2.8).

Table 2.8. Agro-ecological zone wise comparison of dry and wet seasonal variation of pests and parasitoid populations.

Zones	Dry season		Wet season		*Mann-Whitney U test*
	Taxa	Total Individuals	Taxa	Total Individuals	
Pest					
High hill	26	2509	30	4621	U(60)=371.5, p=0.0264
Foothill	28	2229	29	9104	U(58)=285, p=0.0150
Midland	25	2452	31	4363	U(60)=330.5, p=0.0352
Parasitoids					
High hill	70	1804	82	3169	U(170)=2513.5, p=0.0002
Foothill	63	1460	72	2481	U(188)=3143.5, p=0.0002
Midland	44	1155	47	2077	U(124)=1396, p=0.0041

Diversity of pests and parasitoids with respect to season

Pests

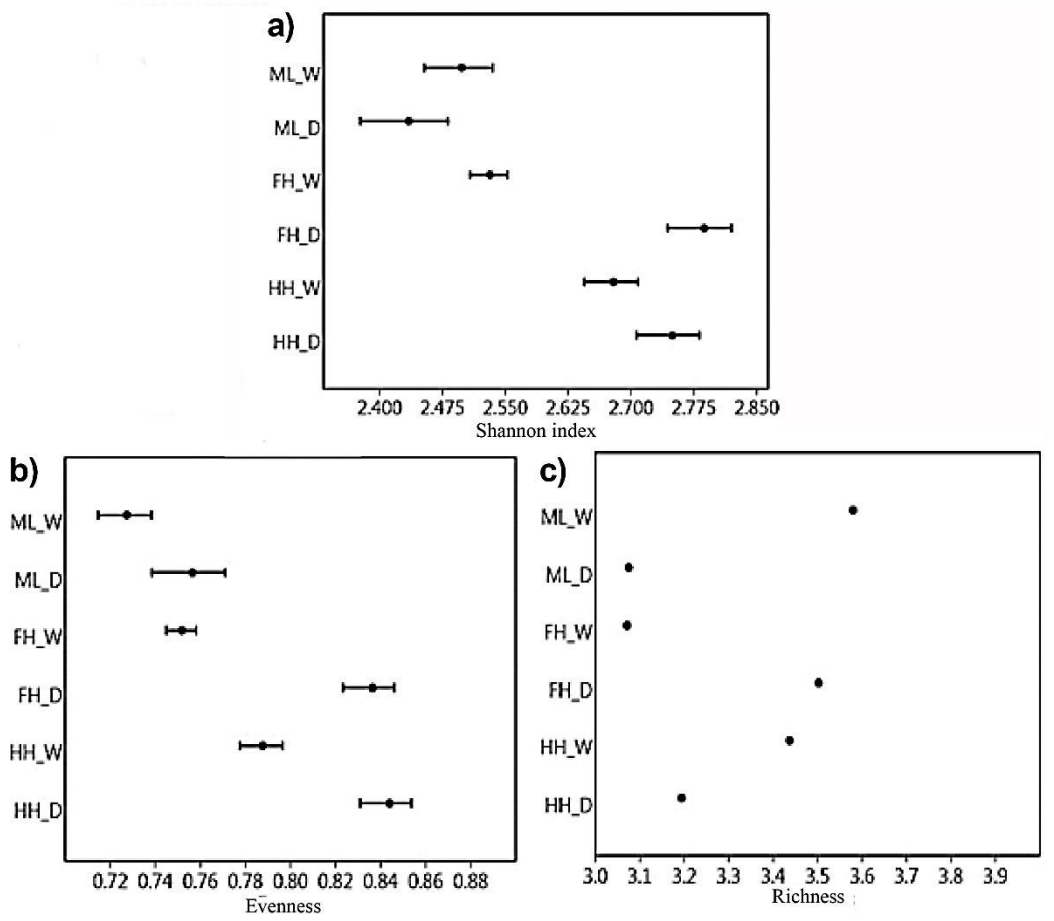
During the wet season, the number of taxa and the abundance of pests across all zones were notably higher than in the dry season. In the dry season pests exhibited considerable diversity in the high hills (H'=2.749) and foothills (H'=2.787). Conversely, the midland laterite region displayed a similar diversity value of pests between the dry and wet seasons, suggesting a lack of significant difference in pest diversity during these periods. Moreover, values for species richness and evenness were consistently high across all zones.

In the wet season, species richness is greater in the high hills (α=3.437) and midlands (α=3.58) than in the foothills (α=3.075) compared to the dry season, whereas evenness is higher in all zones during the dry season than in the wet season. A Shannon t-test was used to assess the significance of seasons in pest diversity. The high hill and foothills exhibited a significant difference in pest diversity with seasons. However, the midland had an alpha value of greater than 0.05, suggesting no significant difference in pest diversity with the season in the midland (Table 2.9).

Table 2.9. Pest diversity in the dry and wet seasons of three agro-ecological zones. The bold digits represent significant results.

Diversity	High hill-Dry Season	High hill-Wet Season	Foothill-Dry Season	Foothill - Wet Season	Midland-Dry Season	Midland-Wet Season
Taxa_S	26	30	28	29	25	31
Individuals	2509	4621	2229	9104	2452	4363
Shannon Index	2.749	2.679	2.787	2.532	2.435	2.498
Richness	3.194	3.437	3.502	3.071	3.075	3.58
Evenness	0.8439	0.7876	0.8365	0.7519	0.7564	0.7274
Shannon t test	t (5853.8)=2.805, p<0.05		t(3908.2)=11.369, P<0.05		t(5235.7)=-1.8575, p=**0.063**	

Fig. 2.21. Diversity index estimates for pests in the dry (D) and wet (W) seasons of the three agro-ecological zones: HH-high hill, FH-foothill, ML-midland laterite regions (a-Shannon index, b-species richness, and c-species evenness).



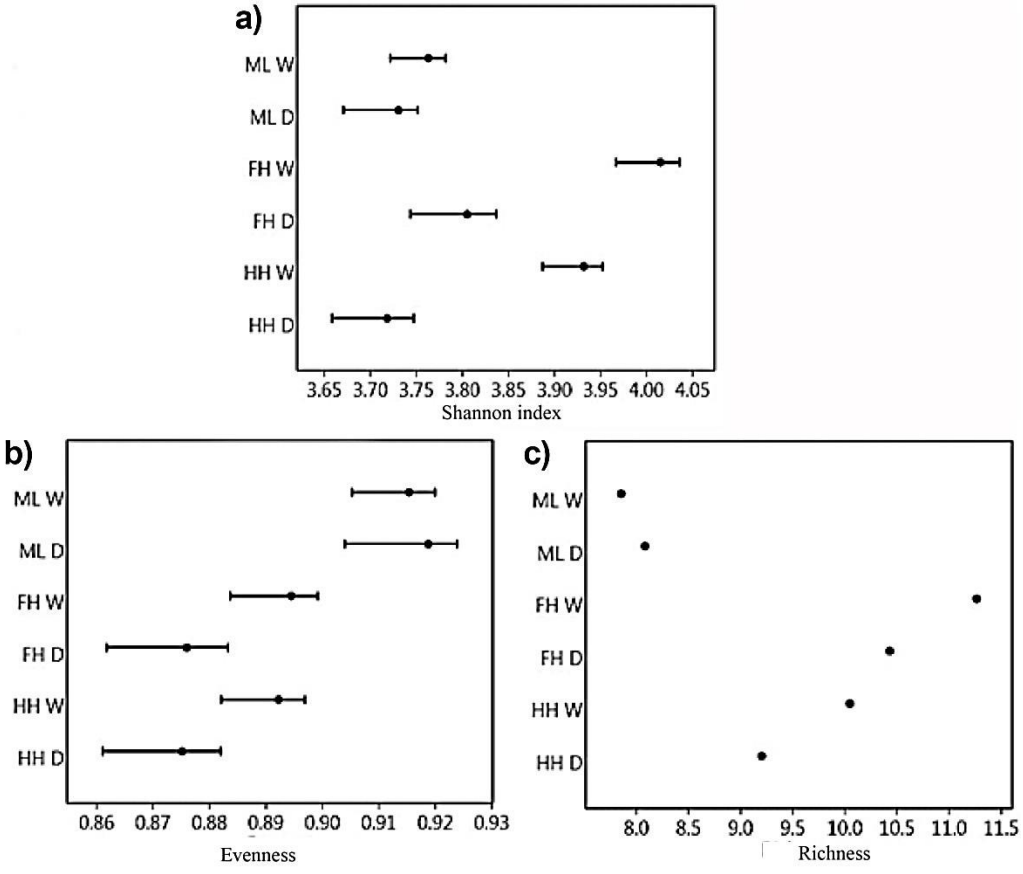
Parasitoids

The number of taxa and individuals present in all zones is higher for parasitoids during the wet season. The Shannon indices showed high diversity in all zones during the wet season. In the wet season, species richness is higher in the foothills (α=11.26) than in the high hills (α=10.05) and midland laterite zones (α=7.855). The value for evenness is higher in the midland laterite zone (E1=0.9154), indicating that all species have a similar distribution in the midland zone. In all zones, the wet season has higher evenness values than the dry season. A significant difference in parasitoid diversity between seasons was observed in both the high hills and foothills (Shannon t-test, $p<0.05$). However, in the midland region, there was no notable distinction in parasitoid diversity between seasons (Shannon t-test, $p=0.217$) (Table 2.10).

Table 2.10. Parasitoid diversity in the dry and wet seasons of three agro-ecological zones. The bold digits represent significant results.

Diversity	High hill-Dry Season	High hill-Wet Season	Foothill-Dry Season	Foothill-Wet Season	Midland-Dry Season	Midland-Wet Season
Taxa_S	70	82	77	89	58	61
Individuals	1804	3169	1460	2471	1155	2077
Shannon Index	3.718	3.932	3.805	4.015	3.731	3.763
Richness	9.203	10.05	10.43	11.26	8.083	7.855
Evenness	0.8752	0.8922	0.876	0.8945	0.9187	0.9154
Shannon t test	t(3567.5)=-7.488, p<0.05		t(2927.5)=-6.8347, p<0.05		t(2390.8)=-1.2325, p=**0.217**	

Fig. 2.22. Diversity index estimates for parasitoid in the dry (D) and wet (W) seasons of the three agro-ecological zones: HH-high hill, FH-foothill, ML-midland laterite regions (a-Shannon index, b-species richness, and c-species evenness).



Diversity of pests and parasitoids with respect to crop age

Pooled data in each zone was taken to analyze the pest and parasitoid diversity concerning crop age. The booting and ripening stages of paddy were taken

as age classes. The Wilcoxon rank test was carried out to test the significance of crop age class with respect to pest and parasitoid abundance. It is evident from the result that there is a significant difference in pest diversity between booting and ripening stages in all agro-ecological zones.

a) Pests

Higher number of pests were observed in the booting stage compared to the ripening stage in all zones and in both seasons. The result showed a significant difference in the diversity of pests in the booting and ripening stages in all the three agro-ecological zones and in the two seasons (Wilcoxon rank test, $p<0.05$) (Table 2.11).

Table 2.11. Wilcoxon rank test for pests in the different seasons and agro-ecological zones between two independent groups (booting and ripening crop growth stage).

Zone	Booting Stage (Median)	Ripening Stage (Median)	Wilcoxon rank test
High Hill-Dry Season	17.5	7	Z=3.096, p=0.0012
High Hill-Wet Season	42.5	13	Z=3.537, p=0.0004
Foot Hill-Dry Season	17	7.5	Z=3.405, p=0.0006
Foot Hill-Wet Season	33	12.5	Z=3.496, p=0.0004
Midland-Dry Season	17	7.5	Z=3.405, p=0.0006
Midland-Wet Season	33	12.5	Z=3.496, p=0.0002

Table 2.12. Diversity indices for pests in the booting and ripening rice growth stages concerning different agro-ecological zones (Dry season). The bold digits represent significant results.

Diversity	High hill-Booting	High hill-Ripening	Foothill-Booting	Foothill-Ripening	Midland-Booting	Midland-Ripening
Taxa_S	30	23	27	22	26	21
Individuals	1240	594	1401	554	1647	640
Shannon Index	2.778	2.463	2.71	2.633	2.363	2.291
Richness	4.071	3.445	3.589	3.324	3.375	3.095
Evenness	0.8168	0.7855	0.8223	0.8518	0.7251	0.7526
Shannon t test	t(1152.7)=5.7, p<0.05		t(1199.1)=1.69, p=**0.0905**		t(1409.8)=1.22, p=**0.2196**	

Dry season: The taxa and Shannon indices showed high diversity in all zones during the booting stage. In all zones, species richness and evenness were also high. In the booting stage, species richness is higher in the high hill region (α=4.071) than in the foothill (α=3.589) and midland laterite zones (α=3.375), whereas evenness is higher in the foothill region (E1=0.8223). In the foothill and midland laterite regions, the ripening stage showed high evenness and were similar, whereas, in the high hill region, the booting stage showed high evenness (E1=0.8168).

In addition, there was a significant difference in pest diversity between crop ages in the High hill region (Shannon t-test, $p<0.05$). However, no significant difference in pest diversity between crop ages in the foothill and midland laterite regions ($p=0.0905$ and $p=0.2196$, respectively) (Table 2.12).

Wet season: The Shannon indices showed high diversity in high hill (D=0.9088) and midland laterite zones (D=0.8165) during the booting stage than during the ripening stage, but the foothill region showed almost same diversity (D=0.8908 and 0.8988 respectively) in both the booting and ripening stages. High values for species richness and evenness were consistently observed across all zones. In the booting stage, species richness and evenness were higher in the high hill region (α=3.712, E1=0.828) than in the foothill and midland laterite zones. The high hill and midland laterite regions showed almost the same evenness value in the booting and ripening stages. However, in the foothill region, the ripening stage showed high evenness (E1=0.7947). There was a significant difference in pest diversity between crop ages in all the zones (Shannon t-test, $p<0.05$), indicating a significant difference in pest diversity between crop ages in all the agro-ecological zones in the wet season (Table 2.13).

Table 2.13. Diversity indices for pests in the booting and ripening rice growth stages concerning different agro-ecological zones (Wet season).

Diversity	High hill-Booting	High hill-Ripening	Foothill-Booting	Foothill-Ripening	Midland-Booting	Midland-Ripening
Taxa_S	30	24	31	26	30	26
Individuals	2473	1101	5758	1927	2812	1230
Shannon Index	2.816	2.613	2.537	2.589	2.434	2.323
Richness	3.712	3.284	3.465	3.305	3.652	3.514
Evenness	0.828	0.8221	0.7387	0.7947	0.7156	0.713
Shannon t test	t(2186.2)=5.74, p<0.05		t(3635.7)=-2.07, p=0.0379		t(2360)=2.36, p=0.0183	

Fig. 2.23. Diversity index estimates for pests in the Booting (B) and Ripening (R) crop growth stages of the high hill region (a-Shannon index, b-species richness, and c-species evenness).

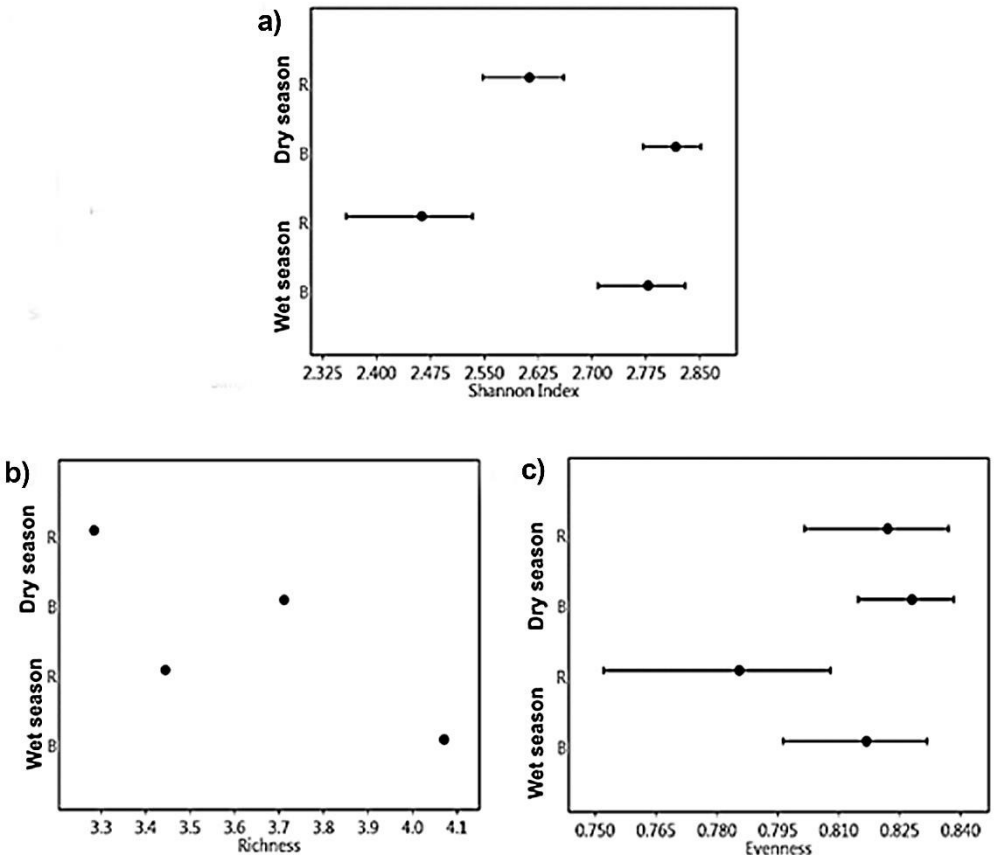


Fig. 2.24. Diversity index estimates for pests in the Booting (B) and Ripening (R) crop growth stages of the foothill region (a-Shannon index, b-species richness, and c-species evenness).

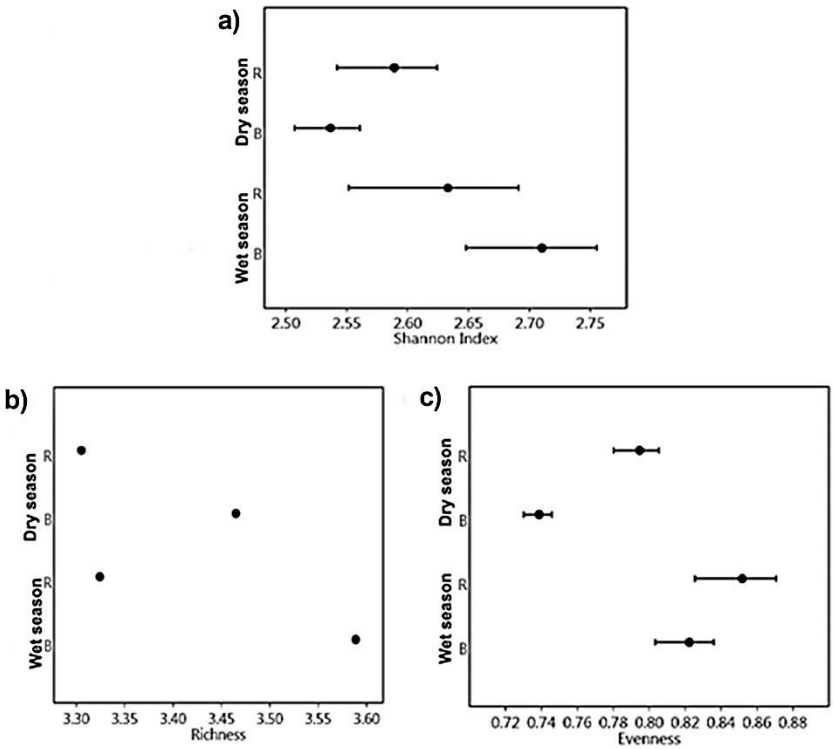


Fig. 2.25. Diversity index estimates for pests in the Booting (B) and Ripening (R) crop growth stages of the midland laterite region (a-Shannon index, b-species richness, and c-species evenness).

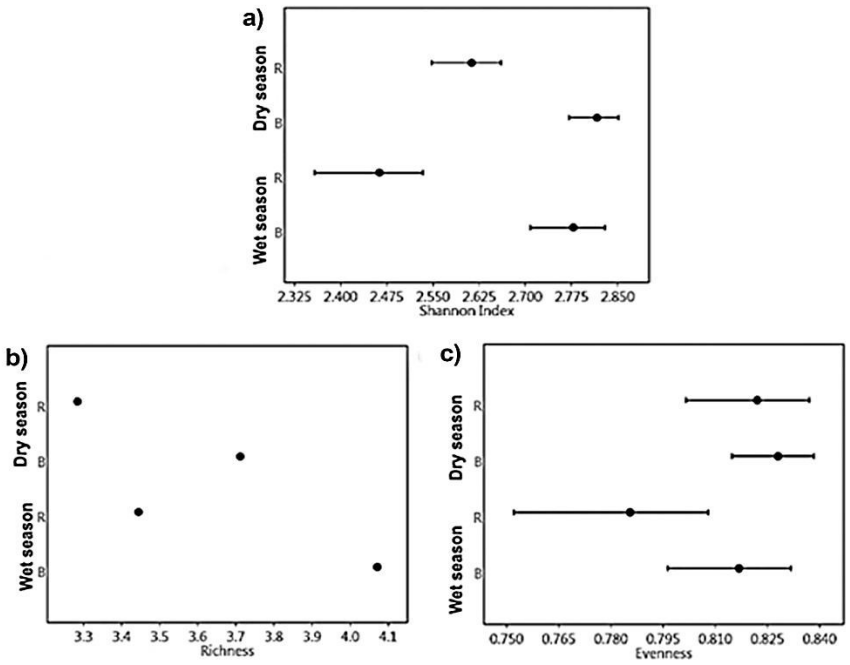
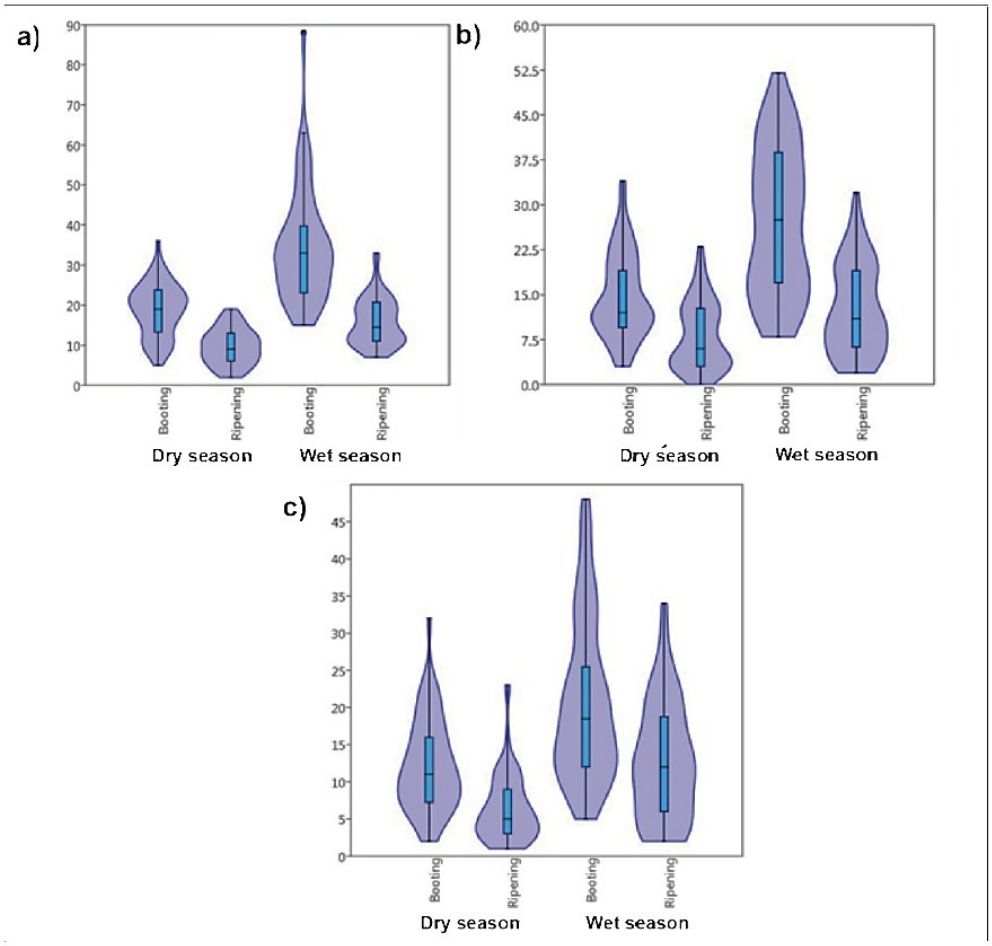


Fig. 2.26. Violin plots of variation of pest populations with respect to crop ages in dry and wet season in three agro-ecological zones, (a) high hill, (b) foothill, and (c) midland laterite regions. Boxplot overlaid represents the interquartile range.



Diversity of pest and parasitoids in relation with farming practice

The obtained F value (33.79) and the exceptionally small p-value (1.03e-08) indicate statistically significant disparities in pesticide application rates across the three agro-ecological zones. The variable "Zone" significantly influences Ekalex application rates, signifying that there is a discernible difference in the average pesticide application rate among the zones.

Pest and parasitoid data from pesticide-treated (PT) and pesticide-untreated (PUT) rice fields were pooled separately for each agro-ecological zone and analyzed to assess differences in the diversity and abundance of insect pests and parasitoids across zones. Ekalux (Quinalphos) was widely used across all agro-ecological zones,

particularly in foothill and midland laterite regions. Karate (Lambda-cyhalothrin) was predominantly used in the high hill region, while Fame (Flubendiamide) had limited use, observed mainly in the high hill and midland laterite zones. The average pesticide application rate was highest in the high hill zone at 3.75 ± 0.95 mL/L, followed by midland laterite at 2.75 ± 0.64 mL/L, and lowest in the foothill zone at 1.55 ± 0.42 mL/L.

Pests

When comparing the abundance of pests in the pesticide-treated and pesticide-untreated rice fields, there was no significant difference in the pest abundance, except for dry seasons in the high hill (Mann-Whitney U test, p=0.048) and foothill region (Mann-Whitney U test, p=0.020) (Table 2.14).

Table 2.14. Mann–Whitney U test for the pests in the different seasons and agro-ecological zones between two independent groups (pesticide-treated and pesticide-untreated farming practices). The bold digits represent significant results.

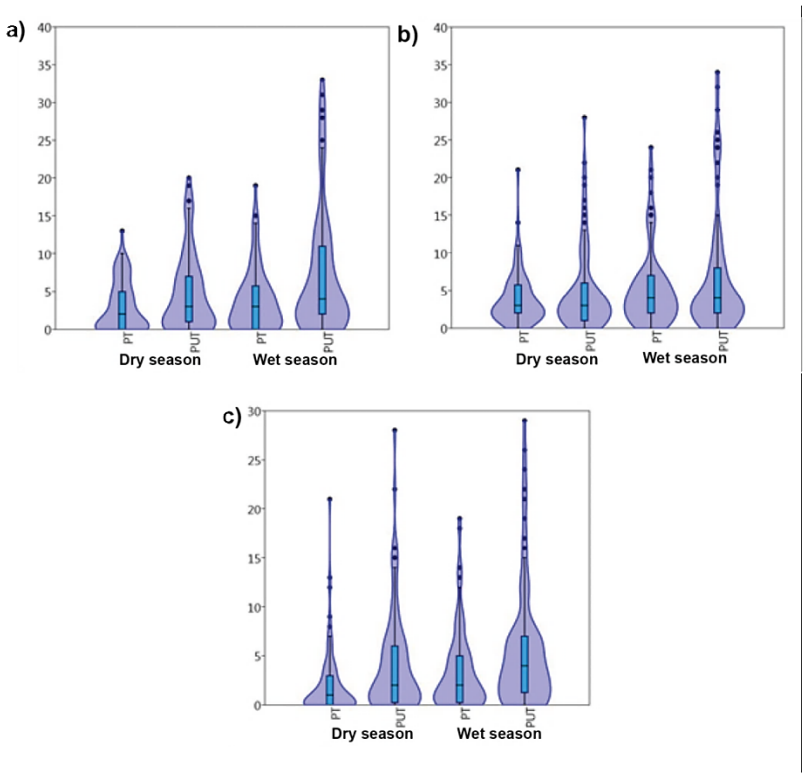
Zone-Season	Pesticide treated (Median)	Pesticide untreated (Median)	Mann-Whitney U	Significance level (p≤0.05)
High hill-Dry	34	70.5	417	0.048
High hill-Wet	66.5	71	490	**0.283**
Foothill-Dry	30.5	84	388	0.020
Foothill –Wet	89.5	96	551.5	**0.749**
Midland-Dry	37	51	435.5	**0.163**
Midland-Wet	57	84	457.5	**0.267**

There was a significant difference (Shannon t-test, $p<0.05$) in pest diversity between farming practices in all three zones. The diversity of pests is high in the PUT rice fields in all zones and seasons except for the foothill wet season (PT, H'=2.759; PUT, H'=2.65). In the wet season, the species richness in the PUT rice fields was also higher compared to PT fields, except for the foothill region (PT, S=3.579; PUT, S=3.376). Similarly, in the high hill dry season, the PT rice fields showed higher species richness than the PUT fields (PT, S=3.884; PUT, S=3.653) (Table 2.15).

Table 2.15. Diversity indices of pests in the pesticide-treated (PT) and untreated (PUT) rice fields with respect to different agro-ecological zones and seasons. The bold digits represent significant results.

Zone-season	Taxa	Richness	Shannon index	Shannon t t(df)=Shannon t	Significance p≤0.05
High hill-Dry-PT	31	**3.884**	2.662	t(4425.2)=-5.668	p<0.05
High hill-Dry-PUT	31	**3.653**	2.836		
High hill-Wet-PT	30	3.449	2.677	t(959.9)=-5.3533	p<0.05
High hill-Wet-PUT	34	3.821	2.795		
Foothill-Dry-PT	27	3.36	2.798	t(48078)=9.5716	p<0.05
Foothill-Dry-PUT	33	3.868	3.019		
Foothill-Wet-PT	**33**	**3.579**	**2.759**	t(1673.2)=6.8199	p<0.05
Foothill-Wet-PUT	**32**	**3.376**	**2.65**		
Midland-Dry-PT	26	3.203	2.452	t(5130.8)=-5.07	p<0.05
Midland-Dry-PUT	30	3.575	2.63		
Midland-Wet-PT	30	3.461	2.499	t (9304)=-2.8812	p<0.05
Midland-Wet-PUT	32	3.599	2.579		

Fig. 2.27. Violin plots of variation of pest populations with respect to farming practices (PT-Pesticide Treated, and PUT-Pesticide Untreated) in the dry and wet seasons in three agro-ecological zones, (a) high hill, (b) foothill, and (c) midland laterite regions. Boxplots overlaid represent the interquartile range.



Parasitoids

Abundance of parasitoids in pesticide-treated and pesticide-untreated fields were significantly different (Mann–Whitney U test) in high hill (dry season, p=0.028; wet season, p=0.010) and midland laterite regions (dry season, p<0.05; wet season, p=0.009). But the foothill region showed a high p-value (p>0.05), indicating no significant difference between the parasitoid abundance in both the dry and wet seasons (Table 2.16).

Table 2.16. Mann–Whitney U test for abundance of parasitoids in different seasons and agro-ecological zones between two independent groups (pesticide-treated and pesticide-treated farming practices). The bold digits represent significant results.

Zone-Season	Pesticide treated (Median)	Pesticide untreated (Median)	Mann-Whitney U	Significance level (p≤0.05)
High hill-Dry	2	3	3143	0.028
High hill-Wet	3	4	3014	0.010
Foothill-Dry	3	3	3746.5	**0.709**
Foothill –Wet	4	4	3742	**0.700**
Midland-Dry	1	2	2679	0.000
Midland-Wet	2	4	3003.5	0.009

Table 2.17. Diversity indices of parasitoids in the pesticide-treated (PT) and untreated (PUT) rice fields with respect to different agro-ecological zones and seasons. The bold digits represent significant results.

Zone-season	Taxa	Richness	Shannon index	Shannon t t(df)=Shannon t	Significance p≤0.05
High hill-Dry-PT	58	3.563	3.842	t(606.31)=-1.8816	**0.060**
High hill-Dry-PUT	68	3.283	3.915		
High hill-Wet-PT	65	3.536	**3.911**	t(755.88)=-0.62309	**0.533**
High hill-Wet-PUT	74	2.914	**3.905**		
Foothill-Dry-PT	83	4.501	**4.148**	t(760.85)=2.4261	0.015
Foothill-Dry-PUT	78	3.763	3.968		
Foothill-Wet-PT	79	3.679	**4.063**	t(1036.8)=2.4044	0.016
Foothill-Wet-PUT	77	3.146	3.916		
Midland-Dry-PT	49	3.652	3.515	t(321.45)=-4.5168	0.000
Midland-Dry-	66	3.382	3.836		

PUT					
Midland-Wet-PT	66	3.755	3.861	t(646.18)=-1.9065	0.050
Midland-Wet-PUT	71	3.172	3.939		

There was a significant difference ($p<0.05$) in parasitoid diversity between farming practices in the foothill and midland laterite zones. However, no significant difference in parasitoid diversity was found in the high hill region during both the dry season ($p=0.060$) and the wet season ($p=0.533$). The species richness in the pesticide-treated (PT) rice fields was higher than in the pesticide-untreated fields (PUT) in all seasons and zones. Interestingly, during the high hill wet season (H'=3.911) and foothill dry (H'=4.148) and wet seasons (H'=4.063), the diversity of parasitoids was also high in the PT rice fields compared to PUT fields. The result indicates that the foothill PT field favored the species richness and diversity of the parasitoids more than the PUT fields in dry and wet seasons (Table 2.17).

Spatial variation of pests and parasitoids

NMDS plots revealed a spatial separation of pests and parasitoids in each zone. NMDS ordination results with two variables of agro-ecological zones (high hill, foothill, midland laterite) and seasons (dry and wet) showed the distinct point on both of the variables. In wet and dry season, insect pests showed strong spatial dissimilarities. However, larval parasitoids and hyperparasitoids reveal strong spatial dissimilarities in the wet season (Table 2.18).

Table 2.18. The non-metric multidimensional scaling (NMDS) stress values for models with two and three dimensions, along with the analysis of similarities (ANOSIM) R-values and their significance (p), were computed for the species composition of both dry and wet seasons. The bold digits represent significant results.

Pest/Parasitoid-Season	**NMDS Stress Value R^2**	**One way Anosim R**	**Significance $p \leq 0.05$**
Pest-Dry season	0.083	**0.7014**	0.0002
Pest-Wet season	0.065	**0.8183**	0.0005
Egg parasitoid-Dry season	0.1439	0.3426	0.0152
Larval parasitoid-Dry season	0.0480	0.4525	0.0013
Hyper parasitoid-Dry season	0.1327	0.4884	0.0014

Egg parasitoid-Wet season	0.1164	0.5590	0.0007
Larval parasitoid-Wet season	0.0738	**0.7616**	0.0003
Hyper parasitoid-Wet season	0.1148	**0.9421**	0.0002

Fig. 2.28. NMDS result of pest species composition from three agro-ecological zones; high hill (1), foothill (2), and midland laterite (3) in the dry (a) and wet (b) seasons.

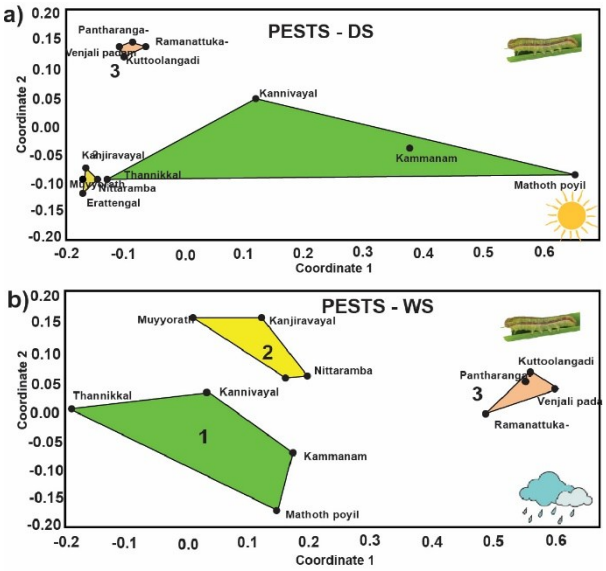
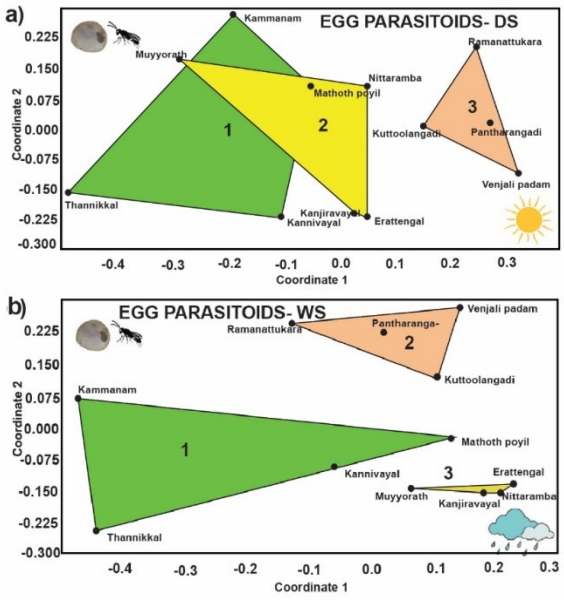


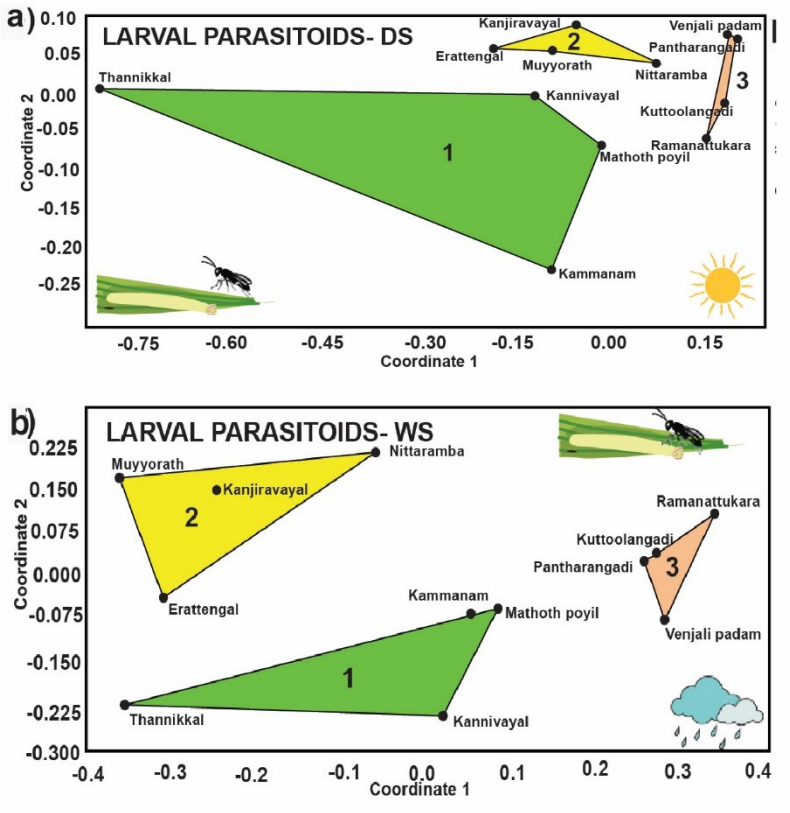
Fig. 2.29. NMDS result of egg parasitoid composition from three agro-ecological zones; high hill (1), foothill (2), and midland laterite (3) in the dry (a) and wet (b) seasons.



In this result, the final stress value is evaluated as 0.083 in the dry season and 0.065 in the wet season for the three-dimensional solution (Table 2.18). Each plot for NMDS ordination with an agro-ecological zone shows more distinctive results. The results suggest that the different zones might be more distinctive in pest composition in the dry and wet seasons (Fig. 2.28).

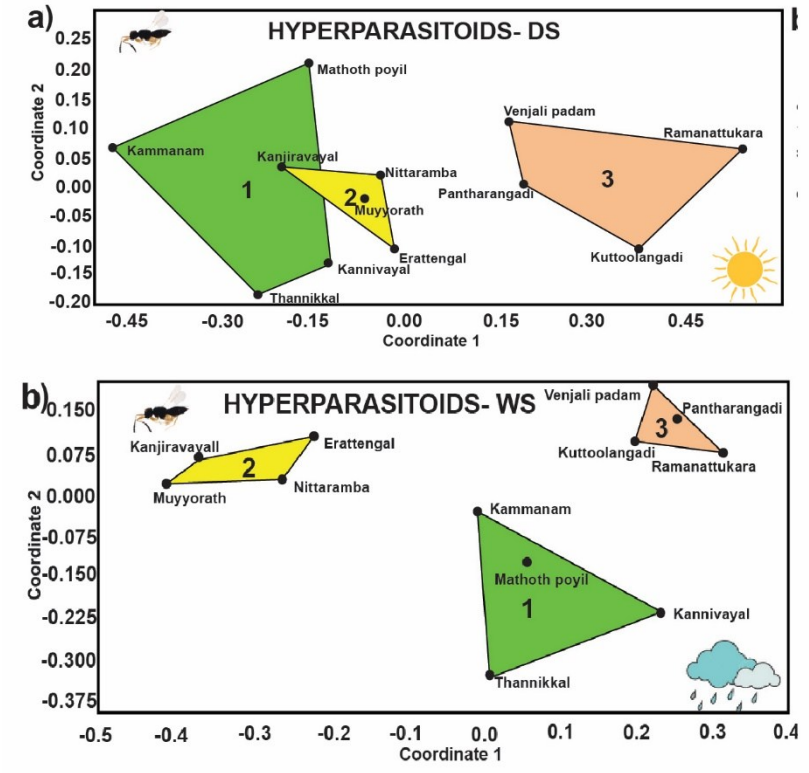
In the case of egg parasitoids, the R-value was weak (R=0.3426), indicating weak dissimilarity in the dry season but slightly stronger (R=0.5590) in the wet season (Table 2.18). In the dry season, the composition of egg parasitoids showed an overlap in both the high hill and foothill regions. However, the midland laterite zone showed a distinct species composition. In the wet season, all three zones showed the distinct composition of egg parasitoids, indicating strong dissimilarity among the zones (Fig. 2.29).

Fig. 2.30. NMDS result of larval parasitoid composition from three agro-ecological zones; high hill (1), foothill (2), and midland laterite (3) in the dry (a) and wet (b) seasons.



The R-value for larval parasitoids is weak (R=0.4525) in the dry season and strong (R=0.7616) in the wet season (Table 2.18). However, in both seasons, all three zones showed the distinct composition of larval parasitoids (Fig. 2.30).

Fig. 2.31. NMDS result of hyperparasitoid composition from three agro-ecological zones; high hill (1), foothill (2), and midland laterite (3) in the dry (a) and wet (b) seasons.



In the case of hyperparasitoids, the R-value was lower (R=0.4884), indicating weak dissimilarity in the dry season but stronger (R=0.9421) in the wet season (Table 2.18). In the dry season, the composition of hyperparasitoids showed an overlap in both the high hill and foothill regions. However, the midland laterite zone showed a distinct species composition. All three agro-ecological zones showed distinct hyperparasitoid composition in the wet season, indicating strong dissimilarity among the zones (Fig. 2.31).

Factors affecting pest and parasitoid diversity across spatial scales

Effect of climatic factors on pest-parasitoid population

The significance of abiotic variables on pest populations was tested using pooled data from each zone's dry and wet seasons. Because the data had a non-normal distribution, non-parametric tests were applied. A correlation/regression analysis was performed to examine the impact of climatic variables (mean temperature (T_{mean}), maximum temperature (T_{max}), diurnal temperature (DT), relative humidity (RH), the heat index (HI), precipitation (Pre.), and altitude (Alt)) on the pest and parasitoid population.

a) Pests

The mean temperature, maximum temperature, diurnal temperature, relative humidity and heat index exhibited a strong positive influence ($r>0.5$) on pest variability during the Foothill dry season, whereas relative humidity showed a strong negative effect (Spearman rank correlation, $r=-0.633$) on the pest abundance during the foothill wet season. During the wet season in the foothills, there was a strong positive effect of altitude on pest population (Spearman rank correlation, $r=0.827$). In the wet season, there was no effect of heat index and precipitation on the pest abundance in the high hill region, and diurnal temperature in the Midland laterite zone (Spearman rank correlation, $p>0.05$). In the dry season, pest abundance was not affected by the altitude in all the three zones, and the diurnal temperature in the high hill region. Moreover, throughout the dry season, no precipitation was observed (Table 2.19).

Regression models were formulated to estimate pest populations using climatic parameters through multiple regression equations. Multiple linear regression analyses of pest populations' abundance as a dependent variable (Y) and climatic factors, viz., maximum (T_{max}) and mean temperatures (T_{mean}), diurnal temperature (DT), heat index (HI), and relative humidity (RH) as independent variables, are presented in Table 2.23.

Table 2.19. Spearman rank correlation coefficients (r) of trend (pest abundance versus climatic factors) in dry and wet seasons of three agro-ecological zones and their statistical significance. The bold digits represent significant results. T_{mean}-Mean Temperature; T_{max}-Maximum Temperature; DT-Diurnal Temperature; RH-Relative Humidity; HI-Heat Index; Pre-Precipitation; Alt-Altitude

Zone-Season	T_{mean}	T_{max}	DT	RH	HI	Pre.	Alt
High hill-Wet	-0.334 (0.008)	0.429 (0.000)	0.303 (0.018)	0.366 (0.003)	0.224 **(0.084)**	0.236 **(0.069)**	0.462 (0.000)
Foothill-Wet	0.724 p<0.05	0.534 p<0.05	0.538 p<0.05	**-0.633** p<0.05	0.529 p<0.05	0.655 p<0.05	**0.827** p<0.05
Midland-Wet	0.537 p<0.05	0.458 (0.000)	0.234 **(0.071)**	0.361 (0.004)	0.468 (0.000)	0.336 (0.008)	-0.394 (0.000)
High hill-Dry	0.592 p<0.05	0.526 p<0.05	0.190 **(0.145)**	0.375 (0.003)	0.558 p<0.05	-------	0.156 **(0.231)**
Foothill-Dry	**0.776** p<0.05	**0.693** p<0.05	**0.815** p<0.05	**0.802** p<0.05	**0.781** p<0.05	-------	-0.090 **(0.492)**
Midland-Dry	0.372 (0.003)	0.408 (0.001)	0.312 (0.014)	0.361 (0.004)	0.374 (0.003)	-------	-0.040 **(0.756)**

Table 2.20. Multiple linear regression analysis between climatic factors and pest populations on rice in three agro-ecological zones and two seasons. The bold digits represent significant results. T_{mean}-Mean Temperature; T_{max}-Maximum Temperature; DT-Diurnal Temperature; RH-Relative Humidity; HI-Heat Index.

Zone-Season	F	R^2	$Y=\beta_0+ \beta_1X_{1+} \beta_2X_{2+}.....+ \beta_iX_i$
High hill-Wet	F(7,52)=2.216 P=0.047	0.229	----------
Foothill-Wet	F(7,52)=13.446 P<0.05	0.644	----------
Midland-Wet	F(7,52)=4.3176 P=0.0007	0.367	----------
High hill-Dry	F(6,53)=7.608 P<0.05	0.462	611.24+(-50.01xTmax)+20.77xHI
Foothill-Dry	F(6,53)=35.173 P<0.05	**0.799**	-1521.9+(-33.22xTmean)+65.93xDT+49.65xHI
Midland-Dry	F(6,53)=5.781 P=0.0001	0.399	-351.4+(-59.93xTmean)+(-6.477xRH)+63.401xHI

The result revealed that all the parameters determine the variability in rice pest populations in concert, with R^2 values ranging from 0.3-0.7 during the dry season. In the wet season, the parameters did not determine the variability in the rice pest population. The strong multiple regression equation was only seen in the foothill dry season (R^2=0.799), indicating that mean temperature, relative humidity,

and heat index determine the variability in the rice pest population during the foothill dry season. The adjusted R^2 is 0.799, which indicates that the predictor variables explain 79% of the variance in the response variable. The result suggests that any one of the predictor variables may be helpful in the prediction of pest population in the dry season in all three agro-ecological zones ($p<0.05$) (Table 2.20).

a) Parasitoids

All climatic factors had an impact on parasitoid populations in all zones and seasons, except for the midland laterite dry season ($p=0.56$). The mean temperature in the high hill wet season, relative humidity in the foothill wet season, and heat index in the midland wet season all showed a strong negative effect, indicating a decrease in parasitoid population due to these climatic factors. In all zones except for the midland laterite dry season ($p=0.56$), all climatic factors substantially impacted parasitoid populations in both the dry and wet seasons. Altitude had no effect on parasitoid abundance in all the zones in both seasons (Spearman rank correlation, $p>0.05$, $r<0.5$), except for the midland laterite wet season (Spearman rank correlation, $p<0.05$, $r=0.825$). The diurnal temperature showed no effect on parasitoid abundance in the midland wet season and the high hill dry season. The remaining climatic factors (maximum and mean temperatures, heat index, precipitation, and relative humidity) had a great influence (Spearman rank correlation, $p<0.05$, $r>0.5$) on parasitoid population in all zones and seasons (Table 2.21).

Using several regression equations, regression models were developed to estimate parasitoid populations using climatic parameters. The table 2.22 shows multiple linear regression analyses of parasitoid population abundance as a dependent variable (Y) and climatic factors as independent variables, including altitude (Alt.), maximum (T_{max}) and mean temperatures (T_{mean}), diurnal temperature (DT), heat index (HI), precipitation (Pre.), and relative humidity (RH).

Table 2.21. Spearman rank correlation coefficients (r) of trend (parasitoid abundance versus climatic factors) in dry and wet seasons of three agro-ecological zones and their statistical significance. The bold digits represent significant results. Tmean-Mean Temperature; Tmax-Maximum Temperature; DT-Diurnal Temperature; RH-Relative Humidity; HI-Heat Index; Pre-Precipitation; Alt-Altitude

Zone-Season	Tmean	Tmax	DT	RH	HI	Pre.	Alt
High hill-Wet	**-0.7444** (<0.05)	0.603 (<0.05)	0.872 (<0.05)	0.641 (<0.05)	0.738 (<0.05)	0.648 (<0.05)	0.**274** (<0.05)
Foothill-Wet	0.852 (<0.05)	0.631 (<0.05)	0.659 (<0.05)	**-0.766** (<0.05)	0.948 (<0.05)	0.707 (<0.05)	0.**274** (<0.05)
Midland-Wet	0.904 (<0.05)	0.918 (<0.05)	**0.256** (<0.05)	0.698 (<0.05)	**-0.846** (<0.05)	0.661 (<0.05)	0.827 (<0.05)
High hill-Dry	0.711 (<0.05)	0.710 (<0.05)	**0.352** (<0.05)	0.776 (<0.05)	0.769 (<0.05)	-------	**0.346** (<0.05)
Foothill-Dry	0.854 (<0.05)	0.760 (<0.05)	0.892 (<0.05)	0.849 (<0.05)	0.860 (<0.05)	-------	**0.098** (<0.05)
Midland-Dry	0.933 (<0.05)	0.885 (<0.05)	0.903 (<0.05)	0.894 (<0.05)	0.954 (<0.05)	-------	**0.074 (0.56)**

Table 2.22. Multiple linear regression analysis between climatic factors and parasitoid populations on rice in three agro-ecological zones and two seasons. Tmean-Mean Temperature; Tmax-Maximum Temperature; DT-Diurnal Temperature; RH-Relative Humidity; HI-Heat Index; Pre-Precipitation; Alt-Altitude

Zone-Season	F	R^2	$Y=\beta_0+ \beta_1X_{1+} \beta_2X_{2+.....+} \beta_iX_i$
High hill-Wet	F(7,52)=67.49, P≤0.05	0.900	P=811.1+(-38.194)xT_{mean}+8.9313xDT+8.7097xHI
Foothill-Wet	F(7,52)=47.27, P≤0.05	0.864	P=2618.4+6.4118xT_{mean}+(-159.62)xT_{max}+19.645xDT+ (-5.9863)xRH+65.213xHI
Midland-Wet	F(7,52)=61.65, P≤0.05	0.892	P=-252.43+8.0987xT_{mean}+5.048xT_{max}+(-0.01562)xPre
Highhill-Dry	F(6,53)=51.59, P≤0.05	0.853	P=- 494.83+1.6138xT_{max}+5.6167xRH+0.61753xHI+0.14599xAlt
Foothill-Dry	F(6,53)=39.45, P≤0.05	0.817	P=-299.21+(-9.5379)xT_{mean}+11.534xDT+1.4829xAlt
Midland-Dry	F(6,53)=66.58, P≤0.05	0.882	P=-239.13+3.3094xT_{max}+6.3149xDT+1.293xAlt+7.7545xHI

The findings showed that all parameters determine parasitoid population variability, with R^2 values ranging from 0.81-0.90. All zones and seasons had a strong multiple regression equation (R^2>0.5), suggesting that altitude, mean

temperature, maximum temperature, diurnal temperature, heat index, precipitation, and relative humidity influence parasitoid population variability. During the wet season in the high hill region, a high adjusted R^2 of 0.90 was observed, suggesting that the predictor variables account for 90% of the variation in the dependent variable. The whole model p-value is less than 0.05, indicating that any one predictor variable may be useful in the prediction (Table 2.22).

Effect of agricultural -practices on the pest-parasitoid population

The significance of agricultural factors on pest and parasitoid populations was tested using pooled data from each zone's dry and wet seasons. Because the data had a non-normal distribution, non-parametric tests were applied. A correlation/regression analysis was performed to examine the effect of agricultural -practices such as water depth (WD), plant spacing (PS), frequency of pesticide application (Freq.P), bund weed coverage (BWC), and home garden (HG) on the pest and parasitoid population. The frequency of pesticide application differed across agroecological zones and between seasons. In the high hill zone, pesticide usage was highest, with farmers applying pesticides 4.0 ± 0.4 times during the dry season and 3.2 ± 0.3 times in the wet season, reflecting heightened pest pressure and input reliance in upland areas. The midland laterite zone showed moderate pesticide use, with application frequencies averaging 3.0 ± 0.5 times in the dry season and 2.5 ± 0.3 times in the wet season. The foothill zone reported the least pesticide usage, averaging 2.0 ± 0.2 times during the dry season and reducing further to 1.5 ± 0.2 times in the wet season.

a) Pests

The plant spacing exhibited a strong positive effect (Spearman rank correlation, r=0.538) on pest abundance during the high hill wet season, whereas water level, plant distance, and parasitoids showed a strong positive influence (Spearman rank correlation, r>0.5) on pest variability during the dry season. During the foothill wet and dry season, there was a strong positive influence of water level, plant spacing, bund weed coverage, parasitoids on the pest population (Spearman rank correlation, r>0.5). In the midland laterite wet season, water depth, plant

distance, and parasitoids showed a strong positive effect, whereas only plant spacing showed a strong positive influence on pest abundance in the dry season (Table 2.23).

Table 2.23. Spearman rank correlation coefficients (r) of trend (pest abundance versus agricultural practices) in dry and wet seasons of three agro-ecological zones and their statistical significance. The bold digits represent significant results. WD-Water Depth; PS-Plant Distance; Freq.P-Frequency of Pesticide application; BWC-Bund Weed Coverage; HG-Home Garden; p-Parasitoids

Zone-Season	WD	PS	Freq.P	BWC	HG	p
High hill-Wet	0.205 **(0.115)**	**0.538** (p<0.05)	-0.355 (0.005)	0.340 (0.007)	-0.109 **(0.424)**	0.393 (0.001)
Foothill-Wet	0.622 (P<0.05)	0.877 (P<0.05)	-0.222 **(0.087)**	0.804 (P<0.05)	-0.527 (P<0.05)	0.841 (P<0.05)
Midland-Wet	0.525 (p<0.05)	0.535 (P<0.05)	-0.197 **(0.130)**	0.464 (0.000)	-0.602 (P<0.05)	0.600 (P<0.05)
High hill-Dry	0.580 (P<0.05)	0.518 (P<0.05)	-0.423 (P<0.05)	0.477 (P<0.05)	-0.144 **(0.276)**	0.660 (P<0.05)
Foothill-Dry	0.853 (P<0.05)	0.731 (P<0.05)	-0.474 (P<0.05)	0.704 (P<0.05)	-0.510 (P<0.05)	0.908 (P<0.05)
Midland-Dry	0.320 (0.012)	0.541 (P<0.05)	-0.343 (0.007)	0.384 (0.002)	-0.450 (0.000)	0.442 (0.000)

Regression models were formulated to estimate pest populations using agricultural parameters through multiple regression equations. Multiple linear regression analyses of pest populations' abundance as a dependent variable (Y) and agricultural factors, viz., water depth (WD), plant spacing (PS), frequency of pesticide application (Freq.P), bund weed coverage (BWC), home garden (HG), and parasitoids (p) as independent variables, are presented in Table 2.24. The results revealed that the parameters including plant distance, frequency of pesticide application, parasitoids, and water depth determine the variability in rice pest populations in concert, with R^2 values ranging from 0.4 to 0.8 during the dry season. In the wet season, plant distance, bund weed coverage, and parasitoids affect rice pest population in concert, with R^2 values ranging from 0.2 to 0.7 (Table 2.24).

The strong multiple regression equation is only seen in the foothill dry season (R^2=0.862) and wet season (R^2=0.764), indicating that water depth, bund weed coverage, and parasitoids determine the variability in the rice pest population in the foothill region. The highest adjusted R^2 value is 0.862, which means that the

predictor variables explain 86.2% of the variance in the response variable. The high hill dry season showed a high R^2 value (R^2=0.575), and the predictor variables were water depth, frequency of pesticide application, and parasitoids. The p-value for the whole model is less than 0.05, which suggests that any one of the predictor variables may be helpful in the prediction (Table 2.24).

Table 2.24. Multiple linear regression analysis between agricultural factors and pest populations on rice in three agro-ecological zones and two seasons. WD-Water Depth; PS-Plant spacing; Freq.P-Frequency of Pesticide application; BWC-Bund Weed Coverage; p-Parasitoids

Zone-Season	**F**	**R^2**	**$Y=\beta_0+ \beta_1X_{1+} \beta_2X_{2+}.....+ \beta_iX_i$**
Highhill-Wet	F(6,53)=3.304 P=0.007	0.272	-166.7+16.40 x PS
Foothill-Wet	F(6,53)=28.68 p<0.05	0.764	11.39+19.76 x BWC+2.90 x p
Midland-Wet	F(6,53)=8.511 p<0.05	0.490	-46.88+7.72 x p
Highhill-Dry	F(6,53)=11.98 p<0.05	0.575	119.8+ (-11.08 x WD) + (-14.46 x Freq.P.) +4.04 x p
Foothill-Dry	F(6,53)=55.25 p<0.05	0.862	-38.84+11.204 x WD +2.84 x p
Midland-Dry	F(6,53)=6.35 p<0.05	0.418	-15.55+ (-9.60 x WD) + 13.5 x PS + 1.76 x p

a) Parasitoids

All agricultural practices showed significant effect in parasitoid populations in all zones and seasons. The water level, plant distance, and bund weed coverage showed a strong positive effect in all zones and seasons. The pest abundance showed a strong positive effect on parasitoid abundance in all zones except for the high hill wet season (r=0.393) and the midland dry season (r=0.442). A negative relationship was shown by frequency of pesticide application and home garden in the parasitoid population, indicating that if the frequency of pesticides and home gardens increases, there will be a decrease in the parasitoid population. The frequency of pesticide application has a weak relationship with parasitoids in foothill (r=-0.316) and Midland laterite (r=-0.481) wet seasons. In the high hill dry (r=-0.458) and wet seasons (r=-0.416), the home gardens showed a weak correlation with parasitoid abundance (Table 2.25).

Table 2.25. Spearman rank correlation coefficients (r) of trend (parasitoid abundance versus agricultural factors) in dry and wet seasons of three agro-ecological zones and their statistical significance. The bold digits represent significant results. WD-Water Depth; PS-Plant spacing; Fre.P-Frequency of Pesticide application; BWC-Bund Weed Coverage; HG-Home Garden; p-Pest

Zone-Season	WD	PS	Freq.P	BWC	HG	p
High hill-Wet	0.775 (<0.05)	0.825 (<0.05)	-0.683 (<0.05)	0.721 (<0.05)	**-0.416** (<0.05)	0.393 (<0.05)
Foothill-Wet	0.793 (<0.05)	0.971 (<0.05)	**-0.316** (<0.05)	0.815 (<0.05)	-0.589 (<0.05)	0.841 (<0.05)
Midland-Wet	0.960 (<0.05)	0.906 (<0.05)	**-0.481** (<0.05)	0.829 (<0.05)	-0.996 (<0.05)	0.600 (<0.05)
High hill-Dry	0.947 (<0.05)	0.866 (<0.05)	-0.811 (<0.05)	0.791 (<0.05)	**-0.458** (<0.05)	0.660 (<0.05)
Foothill-Dry	0.898 (<0.05)	0.767 (<0.05)	-0.533 (<0.05)	0.829 (<0.05)	-0.591 (<0.05)	0.908 (<0.05)
Midland-Dry	0.860 (<0.05)	0.663 (<0.05)	-0.663 (<0.05)	0.781 (<0.05)	-0.945 (<0.05)	0.442 (<0.05)

Table 2.26. Multiple linear regression analysis between agricultural factors and pest populations on rice in three agro-ecological zones and two seasons. WD-Water Depth; PS-Plant Distance; Freq.P-Frequency of Pesticide application; BWC-Bund Weed Coverage; HG-Home Garden; p-Parasitoids

Zone-Season	F	R^2	$Y=\beta_0+ \beta_1X_{1+} \beta_2X_{2+}.....+ \beta_iX_i$
Highhill-Wet	F(6,53)=53.31, P≤0.05	0.857	P=-46.77+2.7519 x WD + 1.9911 x PS+(7.436) x Freq.P+7.1025xBWC
Foothill-Wet	F(6,53)=57.37, P≤0.05	0.866	P=-37.218+1.4591 x WD+2.2533 x PS+(-4.541) x Freq.P+0.079932xp
Midland-Wet	F(6,53)=113.23, P≤0.05	0.927	P=6.3812+0.93363 x WD+1.9207xBWC+(-0.15281) x HG+0.024653xp
Highhill-Dry	F(6,53)=106.75, P≤0.05	0.923	P=-25.373+2.7766 x WD+3.015 x PS+1.4351 x BWC+0.0647 x p
Foothill-Dry	F(6,53)=55.31, P≤0.05	0.862	P=5.9751+2.6319 x PS+0.14789 x p
Midland-Dry	F(6,53)=33.92, P≤0.05	0.793	P=11.033+(-2.8289) x Freq.P+(-0.13731) x HG+0.06901 x p

Regression models were developed to estimate parasitoid populations using agricultural parameters in several regression equations. The table shows multiple linear regression analyses of parasitoid population abundance as a dependent variable (Y) and agricultural factors as independent variables, including water depth (WD), plant spacing (PS), frequency of pesticide application (Freq.P), bund weed coverage (BWC), home garden (HG), and pests (p). The findings showed that

parameters such as WD, Freq.P, PS, BWC, HG, and pests determine parasitoid population variability, with R^2 values ranging from 0.79 to 0.92. All zones and seasons had a strong multiple regression equation (R^2>0.5), suggesting that water depth, frequency of pesticide application, plant distance, bund weed coverage, home garden, and pests influence parasitoid population variability. During the wet season in the midland region, a high adjusted R^2 of 0.927 was observed, indicating that the predictor variables explain 92.7% of the variation in the dependent variable. The whole model p-value is less than 0.05, meaning that at least one predictor variable may be useful in the prediction (Table 2.26).

Effect of vegetation types on pest-parasitoid population

Normalized difference vegetation index (NDVI) vegetation classifications were used to determine the effect of vegetation types on pest and parasitoid population. The Kruskal-Wallis test for significance revealed that the medians of vegetation types differed significantly (KW: H(5)=49.01, p<0.05). The effect of different vegetation types on the pest population was tested using Dunn's post hoc test (fallow: p<0.05, agroforestry: p=0.001, sparse vegetation: p<0.05, and emergent aquatic vegetation: p<0.05).

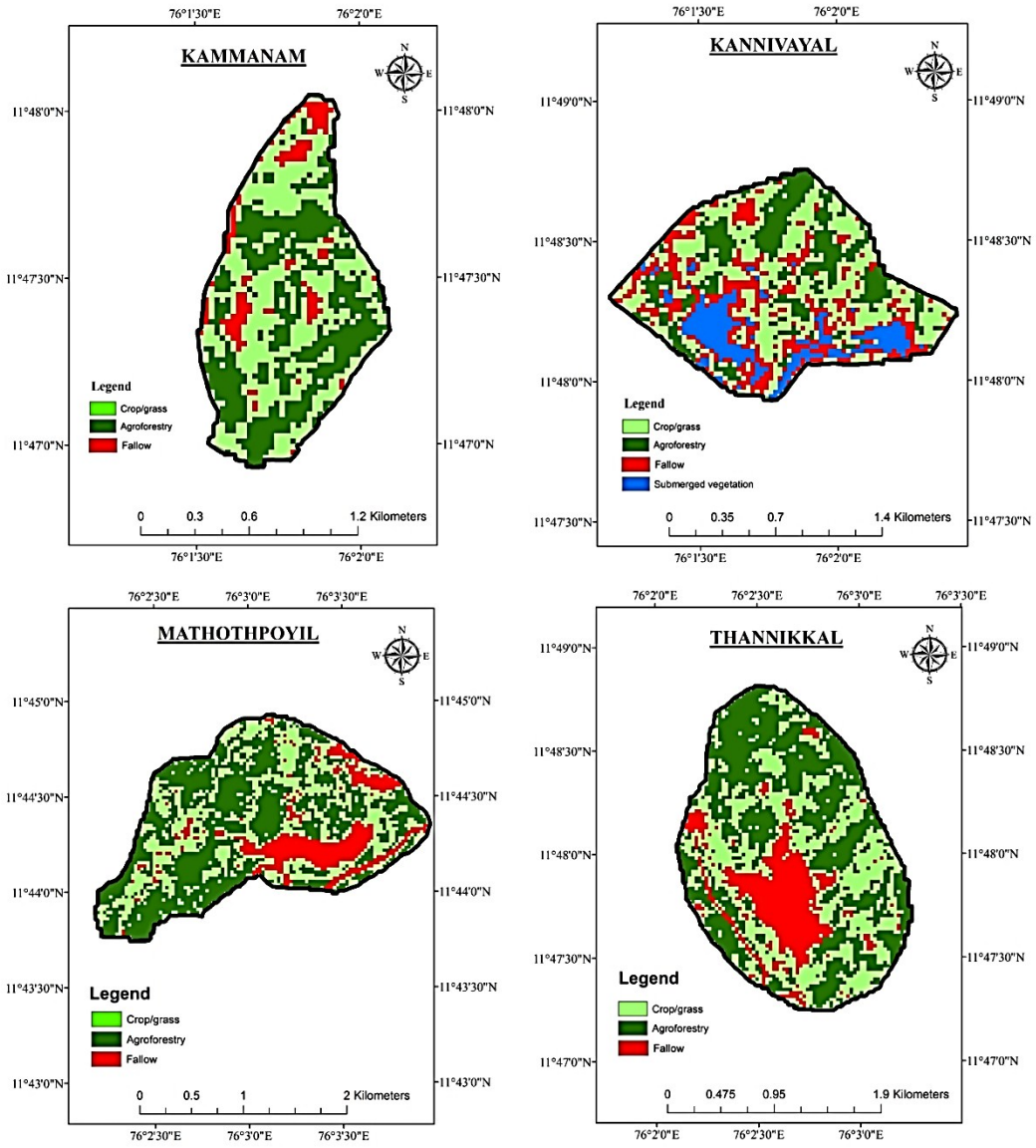
Table 2.27. Spearman rank correlation values (r) and level of significance for different vegetation types on pest and parasitoid population. The bold digits represent significant results.

Insect	Fallow	Agro forestry	Sparse vegetation	Emergent aquatic vegetation
Pest	0.758 (0.004)	0.747 (0.005)	-0.541 (p<0.05)	-0.706 (0.010)
Parasitoids	-0.348 **(0.266)**	0.309 **(0.327)**	-0.413 **(0.182)**	-0.660 (0.019)

All vegetation types affect pest populations significantly (p<0.05). The pest population had a strong positive association with fallow and agro-forestry patches (r>0.5), but sparse vegetation and emergent aquatic vegetation had a strong negative relationship (r<-0.5). Interestingly, except for emergent aquatic vegetation (p=0.019), practically all other vegetation types have no effect on parasitoid

populations ($p>0.05$). Emergent aquatic vegetation exhibited a strong negative relationship ($r=-0.660$) with parasitoids (Table 2.27).

Fig. 2.32. Normalized difference vegetation index (NDVI) images of sampling sites in the high hill region generated from Landsat 8 cloud-free composite images.



Normalized difference vegetation index (NDVI) images of sampling sites showed that the high hill region is dominated by agro-forestry, crop/grass, fallow, and emergent aquatic vegetation (Fig. 2.32). The study sites in the foothill region are surrounded mainly by two vegetation types: crop/grass and agro-forestry (Fig. 2.33).

In contrast, the sampling region of the midland laterite zone is dominated by crop/grass, fallow, sparse vegetation, and emergent aquatic vegetation (Fig. 2.34)

Fig. 2.33. Normalized difference vegetation index (NDVI) images of sampling sites in the foothill region generated from Landsat 8 cloud-free composite images.

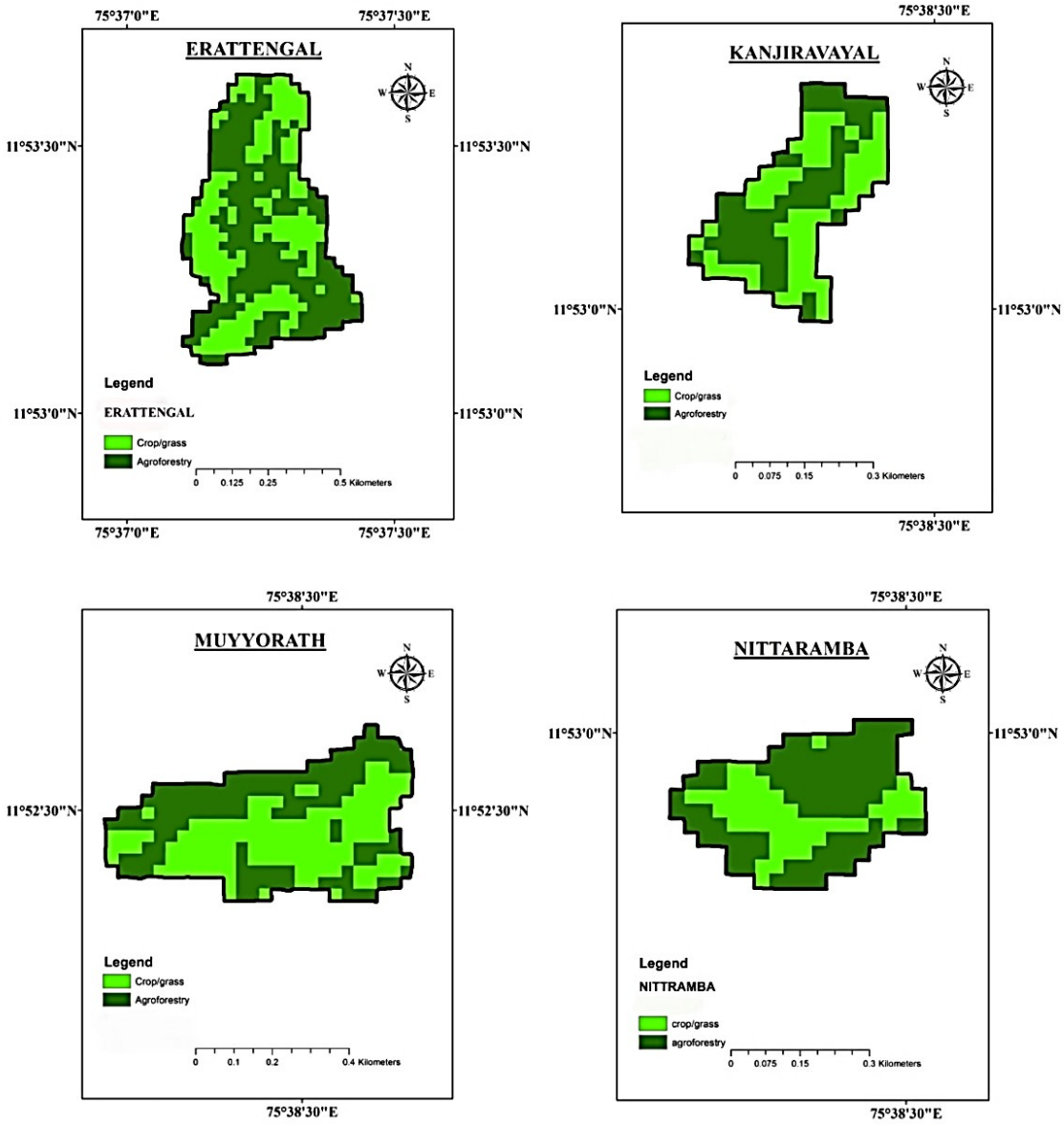
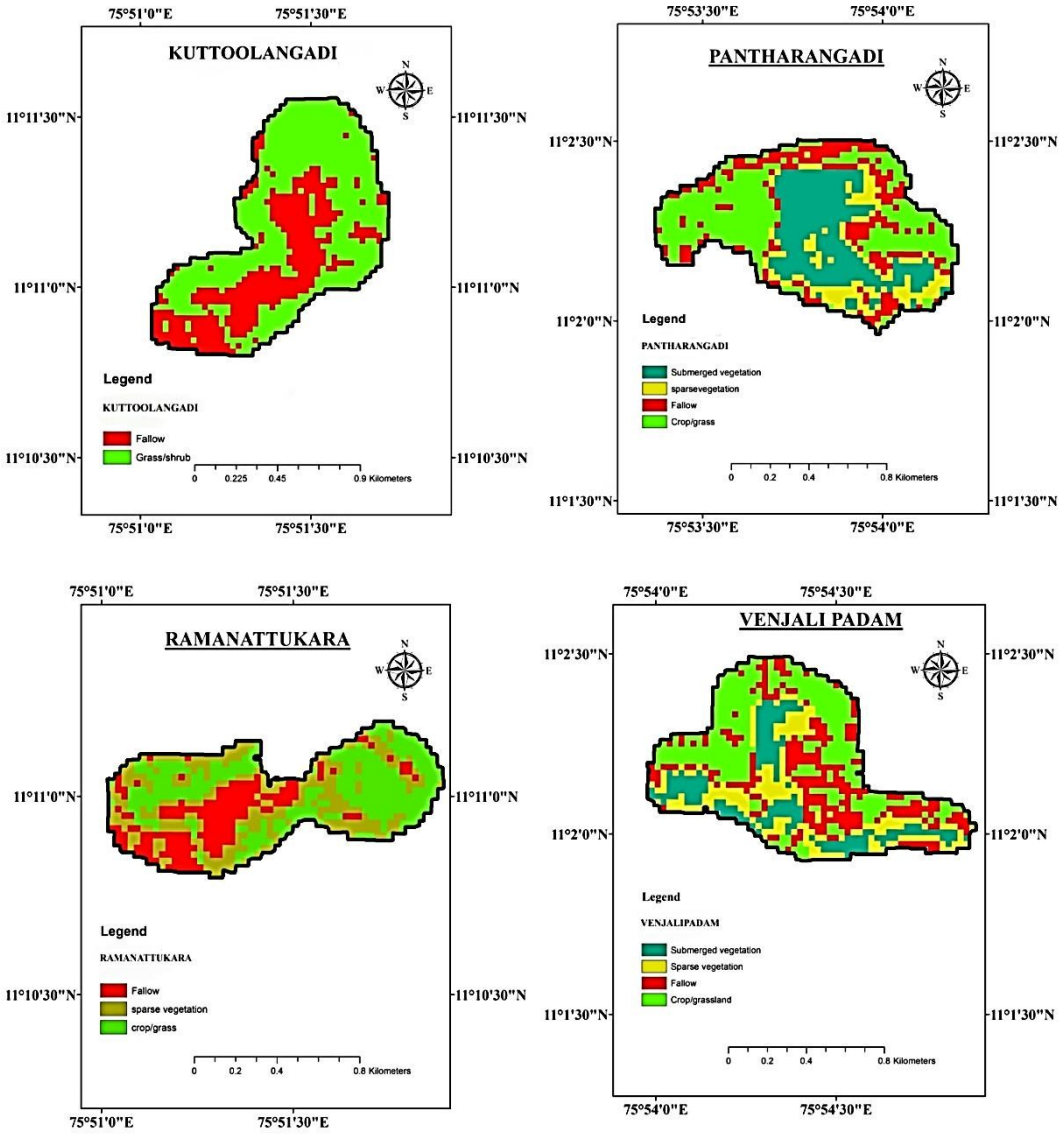


Fig. 2.34. Normalized difference vegetation index (NDVI) images of sampling sites in the midland laterite region generated from Landsat 8 cloud-free composite images.

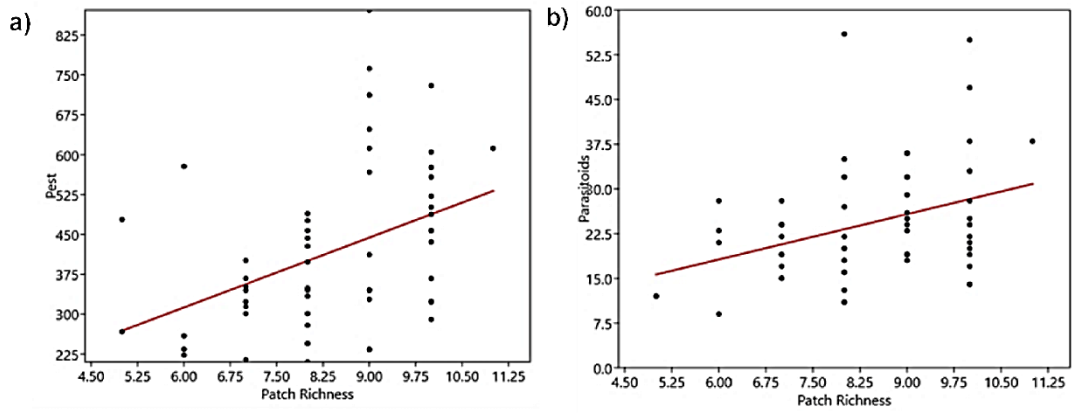


Effect of land use types on pest-parasitoid population

Patch analysis was used to determine the effect of land use types on pest and parasitoid populations. The results revealed that the abundance of pests and parasitoids increased with an increase in patch richness (MANOVA, $F(2,57)=10.32$, $p=0.0001$, $R^2=0.16$; pest-$r=0.402$, $p=0.001$, parasitoid-$r=0.365$, $p=0.004$). This

indicates that landscape heterogeneity positively impacts pest and parasitoid (Fig. 2.35) abundance in the study area.

Fig. 2.35. The relationship between patch richness of sampling sites and the abundance of pest (a) and parasitoid (b) population in the rice ecosystem of North Kerala.



The sampling sites belong to three agro-ecological zones, viz., the high hill, foothill, and midland laterite regions. Crop/grass and agroforestry were the major vegetation types surrounding the sampling sites in the high hill region. Crop/grass was the dominant vegetation type in the sites, viz., Kannivayal (40%) and Kammanam (48%), whereas agroforestry dominated the Thannikkal (45%) and Mathothpoyil (50%) sites (Fig. 2.36).

Similar to the high hill region, crop/grass and agroforestry were the major vegetation types surrounding the sampling sites in the foothill region. Crop/grass was the dominant vegetation type in the site, Muyyorath, whereas agroforestry dominated the Nittaramba (66%) and Erattengal (56%) sites. At the site, Kanjiravayal, each agroforestry and crop/grass contribute 50% of the vegetation (Fig. 2.37).

Fig. 2.36. Percentage composition of land use types surrounding the sampling sites in the high hill region.

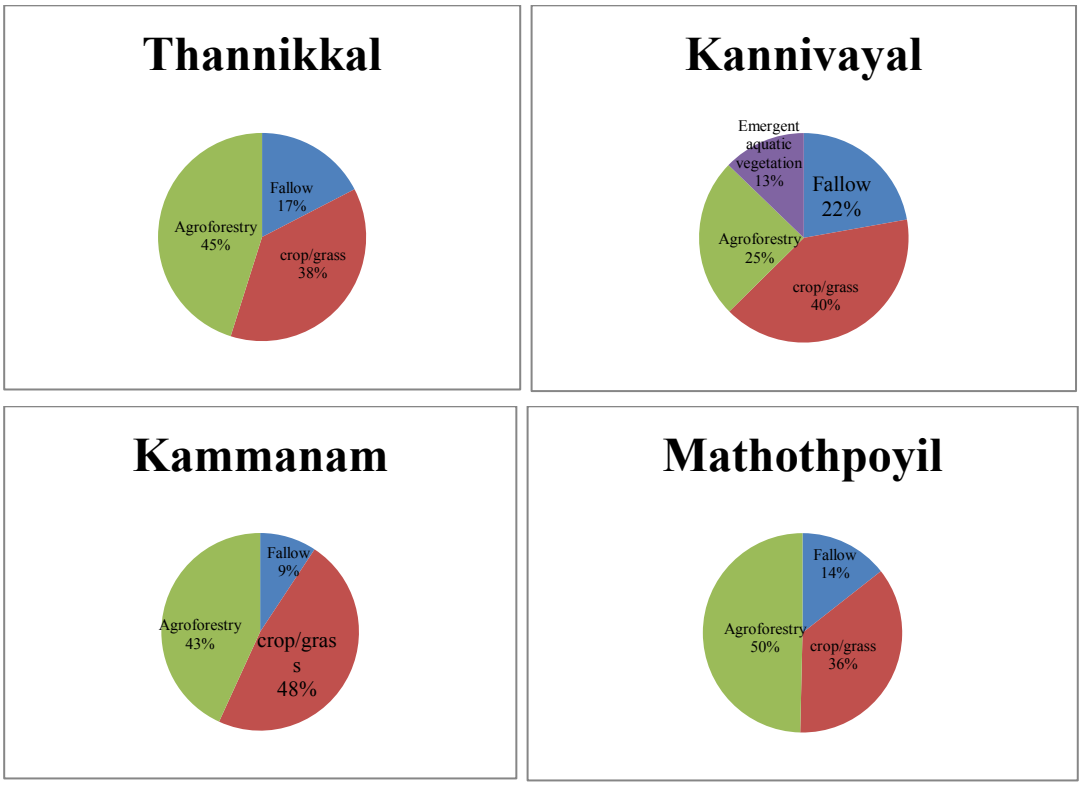
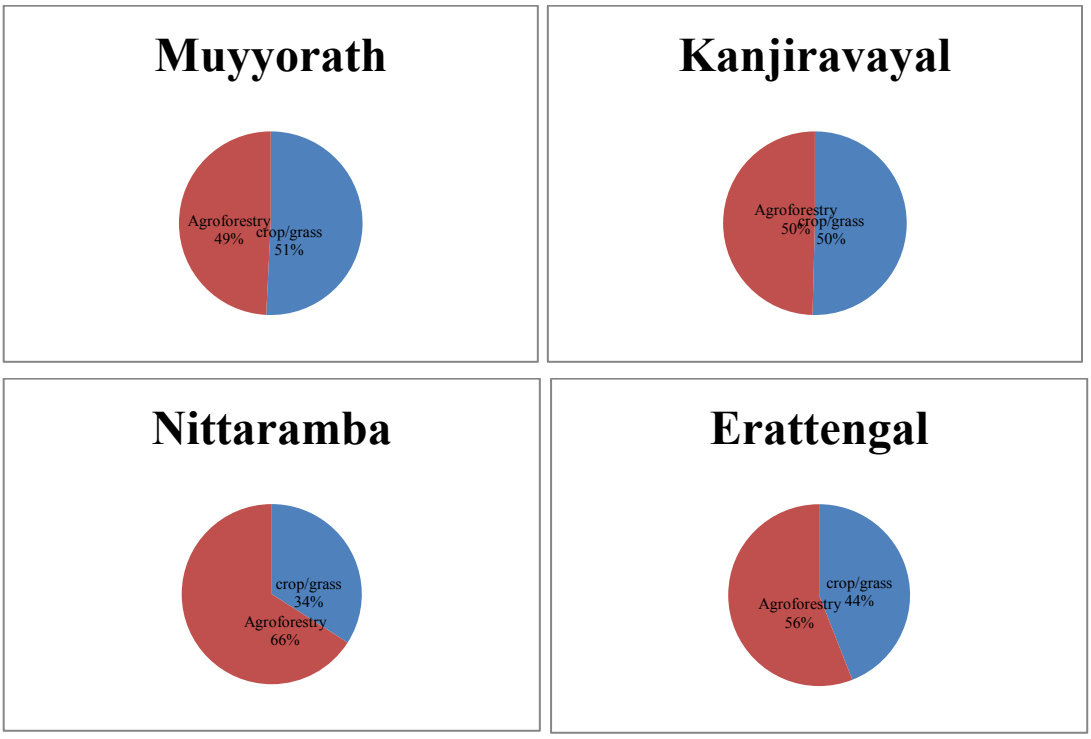
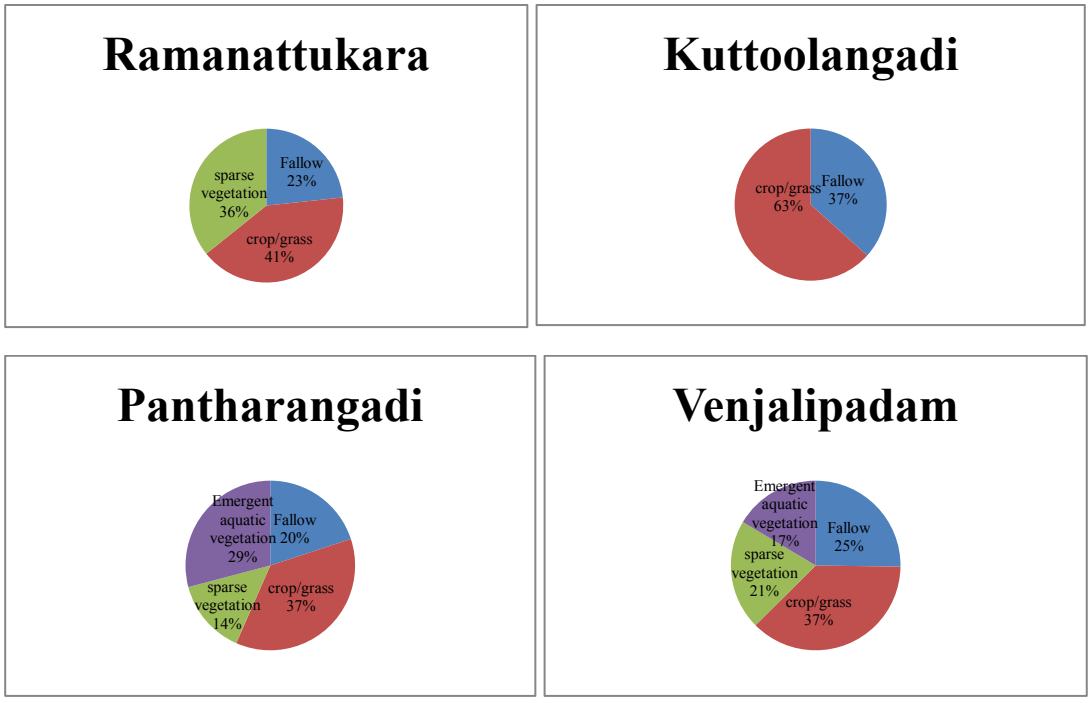


Fig. 2.37. Percentage composition of land use types surrounding the sampling sites in the foothill region.



All of the sampling sites in the midland laterite region had crop/grass as the major vegetation type. Sparse vegetation comes second in the Ramanattukara and Venjalipadam sites. In Pantharangadi, emergent aquatic vegetation takes second place (29%), whereas fallow sites occupies second place in Kuttoolangadi (37%) (Fig. 2.38).

Fig. 2.38. Percentage composition of land use types surrounding the sampling sites in the midland laterite region.



Potential distribution of major rice pests in the Indian subcontinent

This study tested the effects of various environmental variables in predicting the potential distribution of major rice pests (Fig. 2.39–2.43). Under both present and potential climate conditions, the accuracy of the predicted outcomes was evaluated using the Area Under the Curve (AUC) value. The findings revealed that all AUC values exceeded 0.9, indicating a strong model fitness for the predicted outcomes of the maximum entropy model (Table 2.28).

Table 2.28. The predictive accuracy of the maximum entropy model was assessed using AUC values in conjunction with the number of presence records for the major rice pests.

Species	Presence records	AUC value
Ampittia dioscorides	85	0.985
Cnaphalocrocis medinalis	42	0.946
Parapoynx stagnalis	43	0.971
Parnara bada	40	0.986
Pelopidas agna	31	0.976

A buffer analysis was conducted to gather maximum occurrence points of the major rice pests for use in the maximum entropy model, facilitating the selection of bioclimatic and environmental variables. The outcomes of the variable selection process are presented in Table 2.29.

The potential distribution areas were identified from the model of South Indian distribution. The results showed that both models could predict the potential distribution of rice pests in South India.

Out of the 19 environmental variables examined, it is evident that temperature seasonality and their fluctuations were the chief contributors to the pest distribution (Table 2.33).

In terms of the most crucial variables in predicting area suitability for rice pests, isothermality (BIO3) and temperature seasonality (BIO4) contributed significantly. They gave unique information in predicting the area's suitability for rice pests such as *C. medinalis*, *P. stagnalis*, and *P. agna*. For *A. dioscorides*, temperature annual range (BIO7) and temperature seasonality (BIO4) had the highest percentage contribution in prediction. In the case of *P. bada*, isothermality and precipitation of coldest quarter (BIO19) contributed significantly (Table 2.39).

Table 2.29. Percent contribution of environmental variables in the potential distribution of rice pests.

SI No	Environmental variables	Percent contribution
	Ampittia dioscorides	
1	Temperature Annual Range	31.3
2	Temperature Seasonality	29.1
3	Isothermality	13
4	Precipitation of Coldest Quarter	8.5
5	Min Temperature of Coldest Month	3.9
	Cnaphalocrocis medinalis	
1	Temperature Seasonality	49.4
2	Isothermality	23.9
3	Precipitation of Driest Quarter	5.7
4	Annual Precipitation	4.7
5	Precipitation of Wettest Quarter	4.3
	Parapoynx stagnalis	
1	Temperature Seasonality	37.4
2	Isothermality	22.5
3	Precipitation of Coldest Quarter	18
4	Precipitation of Warmest Quarter	5.6
5	Precipitation of Driest Month	5.3
	Parnara bada	
1	Isothermality	30.2
2	Precipitation of Coldest Quarter	22.1
3	Temperature Annual Range	14.1
4	Min Temperature of Coldest Month	10.3
5	Precipitation of Warmest Quarter	7.2
	Pelopidas agna	
1	Isothermality	52.3
2	Temperature Seasonality	20.3
3	Precipitation of Wettest Month	11.6
4	Annual Precipitation	7.2
5	Precipitation of Driest Quarter	2.7

Fig. 2.39. Present and potential distribution of *Ampittia dioscorides.*

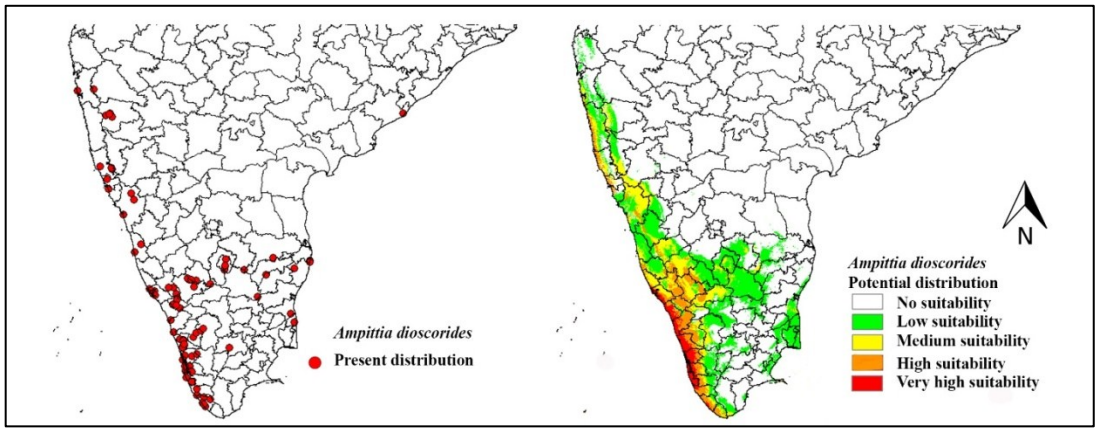


Fig. 2.40. Present and potential distribution of *Cnaphalocrocis medinalis.*

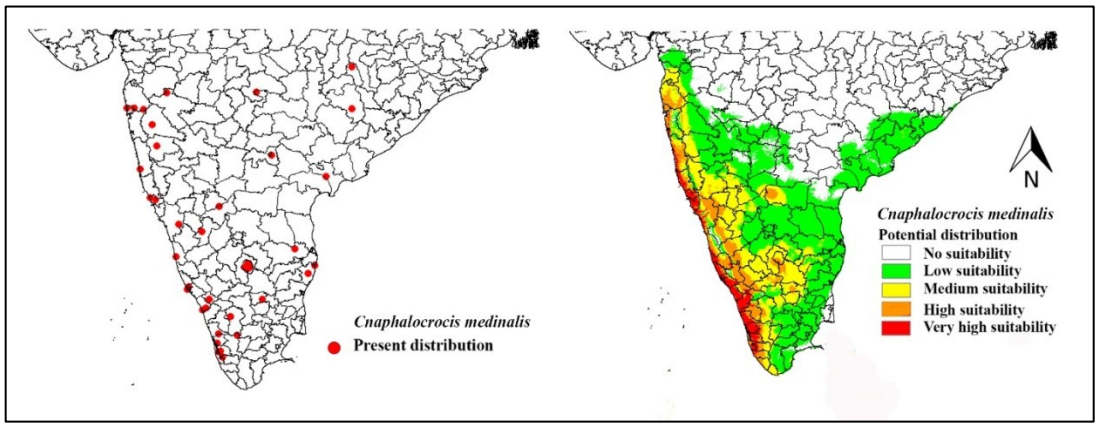


Fig. 2.41. Present and potential distribution of *Pelopidas agna.*

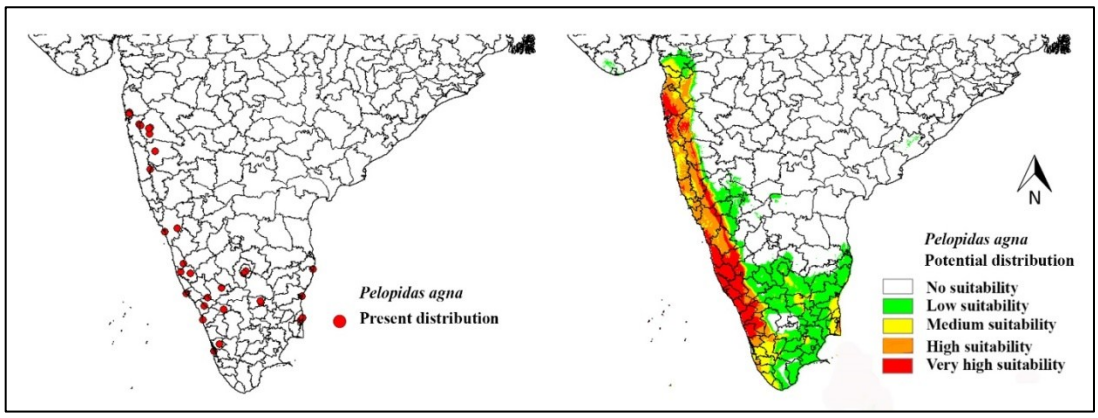


Fig. 2.42. Present and potential distribution of *Parnara bada.*

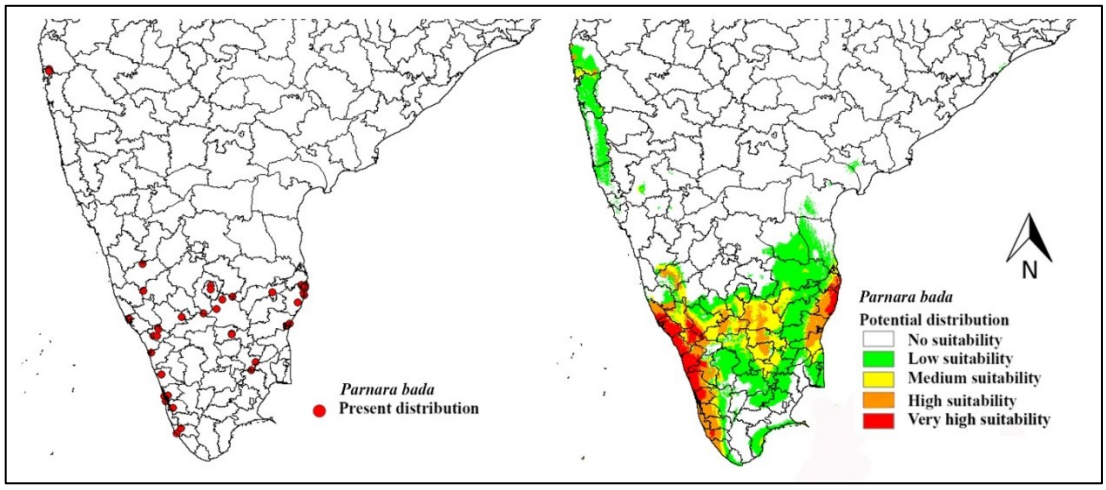
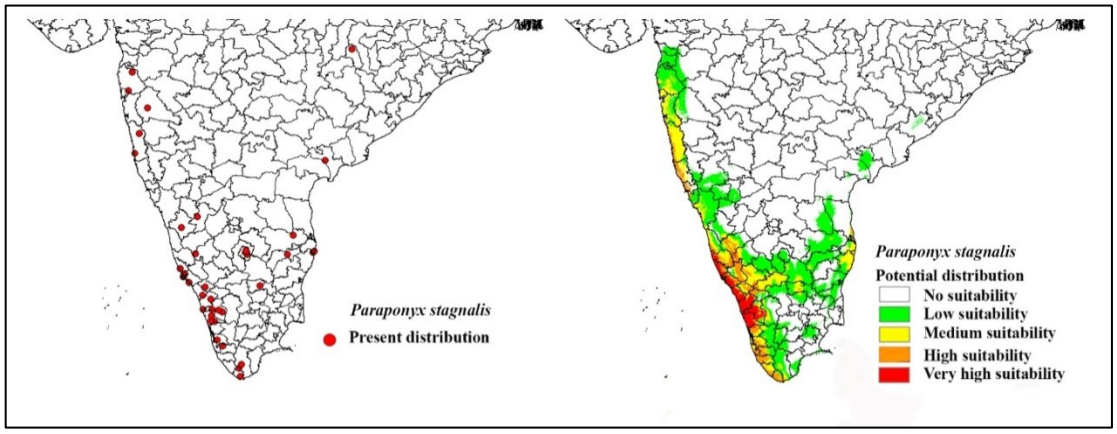


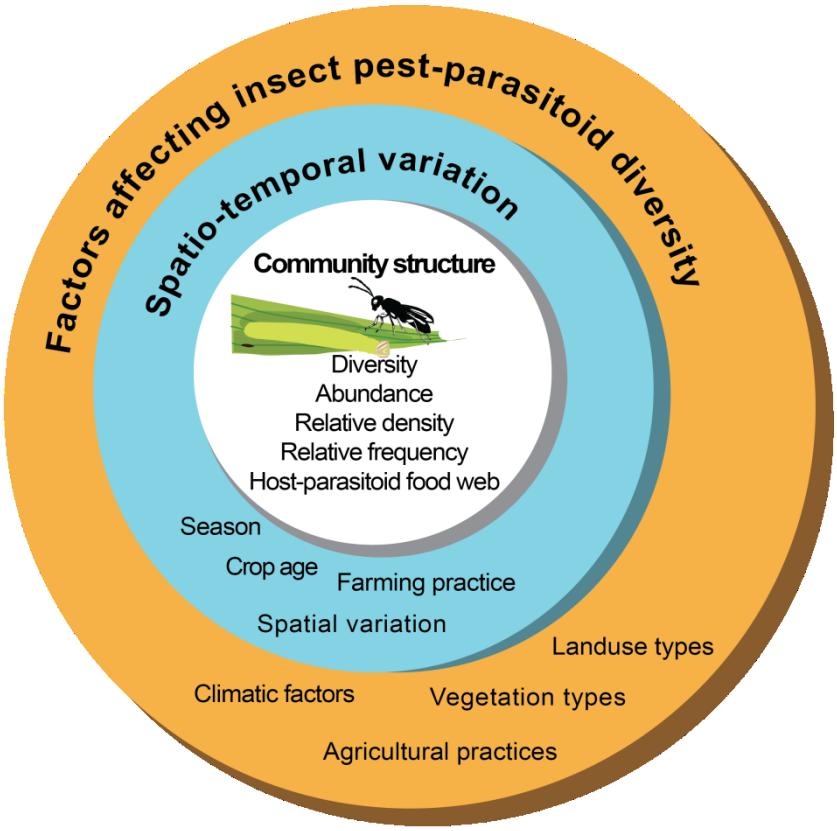
Fig. 2.43. Present and potential distribution of *Parapoynx stagnalis.*



Discussion

This study emphasizes the importance of transitioning agricultural practices from heavy reliance on pesticides to sustainable food production. This transition requires a comprehensive understanding of the dynamics between pests and their natural enemies within agricultural ecosystems (Colmenarez et al., 2018). The study conducted, as indicated, encompassed community structure, spatio-temporal variation, and the factors influencing pest and parasitoid populations, providing valuable insights (Fig. 2.44).

Fig. 2.44 The three aspects of the study carried out.



Community structure and spatio-temporal variation of rice insect pests and parasitoids

The community structure of insect pests and parasitoids within an ecosystem refers to the organization and interactions among various pest species that damage crops and their natural enemies, such as parasitoids, in a particular environment. Understanding this structure is crucial for comprehending the dynamics and relationships among these organisms, which significantly impact agricultural ecosystems.

The study emphasizes the significance of terrestrial arthropods, particularly pests and parasitoids, within rice agro-ecosystems. It presents a pioneering effort in North Kerala by conducting a comprehensive inventory of the community structure of these organisms across three distinct agro-ecological zones: the high hill, foothill, and midland laterite zones. The study examined the diversity, abundance, relative density, and relative frequency of rice insect pests and their parasitoids.

Additionally, the study sought to construct a host-parasitoid food web, shedding light on the intricate interrelationships between rice insect pests and parasitoids in both dry and wet seasons.

In the foothill region of North Kerala, the abundance of insect pests was notably higher, encompassing 32 different species with a total count of 11,470 individuals. This indicates a significantly greater population of insect pests in this particular zone compared to the other two zones studied. Referring to Vennila et al. (2020), the research underscores that examinations centering on the prevalence of distinct insect pests, such as the yellow stem borer, leaf folder, brown plant hopper, and green leafhopper, within rice ecosystems, indicate that the significance of these pests fluctuates among diverse agro-climatic zones (ACZ) and even within these zones. This implies that certain insect pests may be more predominant or impactful in specific geographical regions or microenvironments within the same zone.

Despite the observed differences in abundance, there was no significant difference in the species richness of insect pests collected from all three zones of North Kerala. This means that while the total number of different pest species was consistent across the zones, their abundance varied significantly. The study highlights the significant variation in insect pest abundance among different zones in North Kerala, the variable importance of specific pests across regions, the consistency in species richness despite abundance differences, and the complexity of insect responses to altitude and host density. These findings underscore the need for nuanced considerations of local factors influencing pest dynamics, particularly in the context of climate change studies and pest management strategies.

The two pest species, namely *Cnaphalocrocis medinalis* (rice leaf folder) and *Parapoynx stagnalis* (rice caseworm), were found to have higher abundance and relative density compared to other pests in the high hill and foothill regions throughout both wet and dry seasons, indicating a potential outbreak of these pests during the study period. The convergence of findings from various studies with our observations highlights the multifaceted nature of factors influencing pest outbreaks. The interaction between climate change (Logan et al., 2003; Ali et al., 2019),

agricultural practices (Pathak and Khan, 1994; Teo, 2011), and regional environmental conditions (Kawazu et al., 2005; Park et al., 2010a) may have played a pivotal role in the abundance and prevalence of *C. medinalis* and *P. stagnalis* in the study regions. A holistic grasp of these interconnected factors emphasizes adopting integrated strategies prioritizing climate resilience and sustainable agricultural practices to control and alleviate pest outbreaks within rice ecosystems effectively.

The study observed variations in parasitoid abundance and species richness across different agro-ecological zones in North Kerala. The high hill area had the highest parasitoid abundance, while species richness was notably high in the foothill region. This contrasts with existing studies suggesting a decrease in insect parasitism and parasitoid diversity with increasing elevation (Péré et al., 2013). However, parasitic Hymenoptera species did not show a proportional decrease, as noted by Janzen (1976), which aligns with this study's findings. Altitude, known for its impact on temperature, also influences other parameters such as precipitation, mist, air turbulence, and wind speed, which may affect the behavior and ecology of parasitoids (e.g., Messing et al., 1997). The study noted a higher abundance of parasitoids sampled from the high hills and foothills than the midlands, with certain species consistently abundant across seasons and regions. The foothill area, acting as an ecotone between the high hill and midland regions, likely facilitates the increased abundance of specific species, such as *Casinaria ajanta*, owing to the transitional nature of ecotonal zones, characterized by rapid environmental changes due to abiotic or biotic factors. Ecotonal areas are viewed as dynamic interaction zones, often harboring high species richness unique to and confined within the ecotone, as observed by Odum (1953). Overall, the study delineated the complex interplay between elevation, ecological zones, and parasitoid dynamics, showcasing varying abundance and species richness across elevational gradients and highlighting the ecotonal region's role in fostering unique species compositions and dynamics.

The study highlighted the wet season as the period with the highest interaction between pests, primary parasitoids, and hyperparasitoids across all three

agro-ecological zones. The wet season establishes favorable conditions for the proliferation and enduring presence of pests, primary parasitoids, and hyperparasitoids. This period is characterized by heightened rainfall, humidity, and temperature, creating an environment that fosters plentiful food resources and shelter for insect populations (Fuat et al., 2022). Additionally, our investigation indicates that the wet season showcases heightened insect diversity and abundance in contrast to the dry season, potentially amplifying tritrophic interactions. Both pests and parasitoids exhibited higher species richness and abundance during the wet season than during the dry season, possibly due to the distinct rainfall patterns. While differences in rainfall may not directly account for variations in parasitism, they likely impact host availability, influencing parasitoid populations as suggested by Claridge et al. (1999). They also hypothesized that diminished parasitism levels during dry seasons could be attributed to the fallow period occurring between dry and wet seasons rather than wet and dry seasons, leading to a decreased local abundance of suitable natural enemies (Claridge et al., 1999; Goane et al., 2015).

Notably, the foothill region, functioning as an ecotone between the high hill and midland laterite zones, displayed the highest tri-trophic interaction among the zones during the wet season, harboring a high species richness of specialist parasitoids (N=40). Ecotonal landscapes like the foothill region often exhibit more dynamism and diverse geographical characteristics (Ataev, 2017), potentially explaining the higher species richness observed in this zone. The primary parasitoids, such as *Argyrophylax nigrotibialis* (Tachinidae) and *Charops bicolor* (Campopleginae), played significant roles during different seasons and regions. *Argyrophylax nigrotibialis* known to parasitize leaf folder larvae was the primary parasitoid that parasitised the most number of caterpillar species during the dry season in the high hill and foothill zones, (Siregar and Matondang, 2017). *Charops bicolor*, on the other hand, parasitized the highest number of host species during the wet seasons across the zones, showcasing its potential in biological pest control against various agricultural pests, as reported in several studies (e.g., Abedi et al., 2020; Bagheri et al., 2020; Soroka et al., 2020; Di Giovanni et al., 2021). In general, the study explained the seasonal variations in tri-

trophic interactions and highlighted the influence of rainfall, seasonality, and ecological zones, emphasizing the critical roles of specific parasitoids in regulating pest populations across different seasons and regions.

Seasonal variation

The study aimed to elucidate the seasonal variation of rice insect diversity and species richness across three agro-ecological zones in North Kerala, emphasizing the importance of seasonal pest and parasitoid studies in devising tailored pest management strategies. The study observed significant differences in species richness between dry and wet seasons for pests and parasitoids. It noted notable seasonal variations in pest diversity within the high hill and foothill regions, while the midland region exhibited consistent pest and parasitoid diversity throughout the seasons. The study highlighted the wet season's propensity for higher species richness and abundance of pests and parasitoids, consistent with literature suggesting seasonal impacts on pest abundance, dispersion, and population growth influenced by weather conditions (Hmwe et al., 2020). Notably, the foothill wet season displayed higher parasitoid species richness than the other two zones, possibly due to the ecotonal effect of this region, as supported by similar findings (Ataev, 2017).

In contrast, the midland laterite zone exhibited higher species evenness of parasitoids in the study period, possibly because in ecosystems with fewer but dominant pest species, the relationships between pests and their natural enemies, such as parasitoids, might be more stable. This stability could allow for the coexistence of multiple parasitoid species, resulting in higher evenness among parasitoids despite lower evenness among pests. The parasitoids might specialize; targeting the dominant pest species, such as *C. medinalis*, more effectively can lead to higher evenness among parasitoid populations as they adapt to thrive on these predominant pest species.

The study observed that dry climates may favor the development of certain herbivorous insects due to drought-stressed plants being more susceptible to insect attacks (Yihdego et al., 2019). Despite insects constituting a significant portion of

India's biota, information regarding their ecology and seasonal abundance remains limited (Khoshoo, 1994). In essence, understanding seasonal fluctuations in pest populations helps in the development of effective pest management strategies. Identifying peak periods of pest activity allows farmers to implement timely interventions to minimize crop damage and yield losses.

Effects of crop age

The study presents observations regarding the diversity and abundance of insect pests at distinct stages of rice growth, such as booting and ripening, across different geographic zones. The findings indicate a higher diversity of insect pests during the booting stage than the ripening stage, emphasizing variations in pest populations in specific growth phases. Additionally, it draws attention to how the techniques employed in land management and the timing of data collection may impact insect abundance across different growth stages (Wiranto et al., 2022). The study found distinct patterns in pest evenness between booting and ripening stages across zones, potentially attributed to alterations in arthropod communities over the rice cultivation period, as suggested by Wiranto et al. (2022). The results revealed higher pest diversity during the booting stage in the high hill and midland laterite zones compared to the ripening stage, consistent with findings by Hurlbert et al. (1989) and Khan and Alam (2007), emphasizing the influence of management practices and rice growth stages on pest diversity indices. Specific pests tend to prefer specific crop growth stages; for instance, stemborers target the stem during vegetative and reproductive phases, while stink bugs feed on the developing grain during the ripening stage. Different rice pests exhibit preferences for specific crop growth stages, influencing their development and infestation levels (Prakash et al., 2014). Insect oviposition preferences vary across plant development stages, with more activity observed during vegetative and early heading stages. Rice insect pests exhibit distinct feeding preferences at different crop growth stages, impacting their population growth. The lack of host plants affects pest population growth negatively by impeding nymphal development and egg production (Pathak, 1968). The study

confirms that rice crop stages with increased leaf area, particularly booting and ripening stages, support higher populations of rice insect pests.

The study reveals distinct preferences of leaf-feeding pests for specific rice growth stages. Rice caseworms are most active during the vegetative and booting stages, targeting the lush, tender leaves for egg-laying and feeding. In contrast, leaf folders prefer the booting and ripening stages, exploiting conditions favorable for their development. These behavioral patterns highlight the importance of understanding pest dynamics across crop stages to design stage-specific, targeted pest management strategies that minimize damage and improve crop yield.

Effects of farming practices

The study discusses the impact of pesticide usage on pest and parasitoid populations in rice fields in North Kerala, exploring the differences between pesticide-treated (PT) and untreated (PUT) fields across different zones and seasons.

The study noted that pesticides significantly affect pest abundance, primarily in the high hill and foothill dry seasons, but have minimal impact during the wet season. The heavy rain in the wet season might wash away pesticide remnants, reducing their effect on pest populations (Willis and McDowell, 1982). Interestingly, PT fields show a slight increase in pest species richness, possibly linked to genetic resistance in pests, non-target organism harm, or pesticide residues in unexpected places (Damalas, 2009; Gould et al., 2018). Furthermore, the study indicates that farming practices influence pest diversity, with PUT fields displaying higher pest diversity than PT fields across all zones and seasons. The diversity of rice pests mainly depends on the abundance of rice pests, such as *Cnaphalocrocis medinalis* and *Parapoynx stagnalis*. The results highlight that low pesticide application rates (1.55 ml/liter of water) below the advisable rate (2.0 ml/liter of water) in the foothill area might have a limited impact on pest populations, suggesting other environmental factors may influence their abundance. The use of lower doses of pesticides, while not immediately lethal to pests, could inadvertently lead to unintended consequences by potentially increasing fertility and altering the behavior of pests, ultimately contributing to a quicker rebound or resurgence of pest

populations in agricultural settings (Dutcher, 2007). . One possible reason for presence of more species of pests in PT fields during the wet season might be that monoculture creates a perfect environment for specific types of pests to thrive and cause problems (Andow, 1983). We found a noticeable difference in the diversity of pests between different farming methods across all three zones in the study area. The diversity of pests was higher in PUT fields in most zones and seasons, except for the foothill wet season. Many other studies also reported that there is less diversity of insects in pesticide-sprayed fields compared to untreated fields, which supports our findings (McLaughlin and Mineau, 1995; Chaigarun et al., 2011; Katayama, 2016). The reason why there was no significant difference in the diversity of pests between PT and PUT fields in the foothill area might be because the amount and strength (1.55±0.42 ml/liter of water) of the pesticides used during the dry and wet seasons were not as high as those used in other zones called high hill (3.75±0.95ml/liter of water) and midland laterite (2.75±0.64ml/liter of water) regions. The significant F value (33.79) and the extremely low p-value (1.03e-08) suggest that there are statistically significant differences in pesticide application rates among the three agro-ecological zones. Additionally, the choice of farming techniques can affect the diversity of pests observed in fields across various seasons.

This study also discusses how the populations of pests and their parasitoids, differed in rice fields treated with pesticides (PT) and untreated ones (PUT) in different zones. In the high hill and midland laterite zones, the numbers of both pests and parasitoids differed significantly between fields treated with pesticides and those left untreated. However, there was no noticeable difference in parasitoid numbers in the foothill area. This could be because using lower rates of pesticides (1.55±0.42 ml/liter of water) below the advisable rate (2.0 ml/liter of water) in foothill rice fields might not have impacted the parasitoid populations much. The environmental conditions in the foothill area, both physical (abiotic) and related to living organisms (biotic), might be responsible for this. Parasitoids often rely on various crops or different natural environments for extra food sources or places to stay (Landis et al., 2000), and diverse landscapes might support a greater abundance and diversity of these parasitoids (Bianchi et al., 2006). With the exception of dry seasons in the high

hill and midland regions, the PT rice fields in the study area exhibited a slightly higher diversity of parasitoids. Farmers in the high hill and midland laterite regions tend to increase their use of pesticides during dry seasons, which could significantly impact parasitoid populations as referenced in Parveen and Nakagoshi (2001). Moreover, the management practices specific to pesticide-treated rice fields, such as water management, crop rotation, or pesticide use, may indirectly influence parasitoid diversity. For instance, reduced pesticide application during certain seasons could benefit parasitoids (e.g., Arora et al., 2019).

Moreover, in North Kerala, farmers adopt a lower pesticide application rate during the wet season because rainfall is expected to wash away the pesticides. Interestingly, this reduced pesticide use during the wet season may not notably affect the diversity of parasitoids in PT fields. This indicates that during the wet season, the diversity of parasitoids varied between different rice fields, regardless of pesticide use. There may be many reasons behind the varied diversity of rice insects in the wet season. Previous studies reported that heavy rainfall or extensive irrigation in hilly areas affects how chemicals, especially pesticides used in farming, move within the soil and are washed away from fields. These pesticides can be carried by rainwater runoff. Interestingly, rain not only moves these chemicals but can also change how concentrated they are in water bodies—sometimes increasing the pesticide levels in water and reducing them at other times (Vryzas et al., 2009; Mohaupt et al., 2020).

Overall, while this study did not include detailed information on the specific types, dosages, or frequencies of pesticide applications, the observed differences in pest and parasitoid diversity between treated and untreated fields suggest a potential influence of pesticide use and environmental conditions. These findings point to the need for more comprehensive investigations into how such factors shape insect communities. A deeper understanding of these interactions is essential for designing pest management approaches that are both effective and environmentally sustainable in rice agroecosystems.

Spatial dissimilarity in rice insects

The results showed the significance of spatial distribution in understanding the performance of parasitoids in controlling pests within agricultural ecosystems. The effectiveness of parasitoids in controlling pests depends on how the pests are distributed in space and how the natural enemies respond to this distribution (Karieva, 1990). The study observed that pest composition differed significantly across agro-ecological zones (high hill, foothill, and midland laterite) during dry and wet seasons. This variation suggests that the spatial distribution of insect pests varies across these zones, maybe influenced by interactions such as intra-and interspecific competition and predation or parasitism as mentioned by various authors (Hassell et al., 1991; Molofsky, 1994). During the wet season, the diversity and composition of parasitoids differed significantly across zones, but this dissimilarity was less apparent during the dry season. Seasonal rainfall patterns may play a role in influencing foliage conditions and flowering time, which could explain the greater dissimilarity of parasitoids in the wet season (Boinski and Fowler, 1989; Johnson, 1992). The study underscores the importance of investigating spatial variations in insect distributions to understand community composition, the relationship between species, and their responses to habitat changes. The findings of Waage (1979) suggest that the behavior of parasitoids responding more actively to regions where their prey is concentrated plays a vital role in suppressing or reducing the population of these prey insects. In essence, studying spatial patterns at various scales is crucial for predicting pest population dynamics and understanding the impact of parasitization on host and parasitoid interactions (Karieva, 1990). The study emphasizes that studying spatial patterns across different scales is pivotal in predicting pest population dynamics and comprehending the impact of parasitization on host and parasitoid interactions. Ultimately, this knowledge aids in designing more effective pest management strategies.

Factors affecting pest and parasitoid diversity

Climatic factors

The study emphasizes the influence of various climatic factors on insect population dynamics, specifically focusing on rice pests and parasitoids across different agro-ecological zones and seasons. Climatic factors profoundly influence insect populations and their dynamics (Hespenheide, 1991; Nestel et al., 1994; Stireman et al., 2005). Our study delved into the impact of these factors on rice insect pests and their parasitoids by employing regression models to estimate their populations. During the dry season in the foothills, various climatic parameters such as mean temperature, maximum temperature, diurnal temperature, relative humidity, and heat index significantly influenced pest variability. Conversely, relative humidity and altitude played crucial roles in pest abundance during the foothill wet season. However, certain factors like heat index and precipitation had minimal effects on pest abundance in specific regions (high hills and midlands) during wet seasons.

Interestingly, altitude and diurnal temperature did not affect pest abundance during the dry season in these zones. Our findings collectively indicate that these climatic elements predict variability in rice pest populations, particularly with R^2 values ranging from 0.3 to 0.7 during the dry season. Numerous studies support our conclusions, emphasizing climate's significant influence on insect life cycles (Cammell and Knight, 1992; Patterson et al., 1999), outbreaks (Kisimoto and Dyck, 1976), and population dynamics (Shi et al., 2012). Temperature, relative humidity, and rainfall are pivotal in controlling insect growth, host selection, and their interactions. Insect physiology and ecology, including dispersal and development (Harrington et al., 2001), are significantly impacted by temperature variations. The projected climate changes, including increased temperatures, are expected to directly and indirectly affect rice pests, altering their distribution, reproduction, and behavior consequently impacting agricultural ecosystems (Mochida et al., 1987; Porter et al., 1991). Moreover, our study highlighted that relative humidity and temperature substantially affect rice insect pest populations. This aligns with existing research

emphasizing the influence of abiotic factors like temperature and humidity on insect development (Zulfiqar et al., 2010). Climate change's threat to ecosystems is underscored, with projections indicating substantial temperature and precipitation changes by the end of the century, potentially influencing insect physiology, behavior, and distribution worldwide (Cammell and Knight, 1992; Huang et al., 2010; Ntiri et al., 2019).

This study investigated the influence of selected climatic variables on parasitoid abundance across different seasons and zones within the studied agricultural ecosystems. The findings revealed notable associations between climatic factors and parasitoid populations, varying significantly across different zones and seasons. The selected climatic variables significantly affected parasitoid abundance in both dry and wet seasons across most zones, except for the midland laterite and high hill dry seasons. Altitude displayed minimal impact on parasitoid abundance across all three zones during both seasons, while diurnal temperature exhibited no influence on parasitoid abundance in the midland wet and high hill dry seasons. However, factors like maximum and mean temperatures, heat index, precipitation, and relative humidity substantially influenced the parasitoid population in all zones and seasons.

Several studies, including Daniel et al. (2019c) and McFarland and Hoy (2001), have highlighted the negative association between maximum temperature and parasitoid populations, emphasizing the impact of extreme temperatures on both hosts and parasitoids. This study observed declines in parasitoid populations attributed to mean temperature in the high hill wet season, relative humidity in the foothill wet season, and the heat index in the midland wet season, demonstrating the adverse effects of these climatic parameters on parasitoid populations.

Temperature and relative humidity regimes emerged as crucial elements influencing insect species' temporal distribution, supported by various studies validating the significant influence of diurnal temperature on the developmental rates of arthropods (e.g., de Almeida et al., 2002; Paaijmans et al., 2010; García-Ruiz et al., 2011). Additionally, these climatic variables significantly impacted

insects' activity, development, and survival, influencing parasitoid behaviors, fecundity, developmental periods, and progeny survival (Burnett, 1954; Messenger, 1968; Flinn, 1991; Smith, 1994). The study underlines the substantial impact of major abiotic factors—temperature, relative humidity, heat index, precipitation, and altitude—on pest and parasitoid populations across different crop seasons and agro-ecological zones. Utilizing the regression model, the study showcased the potential to forecast pest populations during the dry season and parasitoid population abundance in both dry and wet seasons, providing valuable insights for integrated pest management programs. Furthermore, the study highlighted the variability in rice pest populations during specific seasons, especially in the foothill dry season, driven by mean temperature, relative humidity, and heat index. These predictor variables exhibited high predictive capability across agro-ecological zones, implying their potential utility in predicting pest populations during the dry season. The robustness of multiple regression equations in influencing parasitoid populations across various seasons and zones, notably with a high adjusted R^2 in the high hill wet season, signifies the potential of individual predictor variables in forecasting parasitoid populations in specific study regions. Integrating climate variables into population models can significantly enhance decision-making in pest management strategies, offering diverse and potentially more effective pest management options for agricultural ecosystems (Damos and Savopoulou-Soultani, 2010).

Agricultural practices

The present study delves into the intricate relationship between agricultural practices and the abundance of pests and parasitoids across three diverse agro-ecological zones. Employing regression models, this study investigates the influence of several agricultural parameters on pest and parasitoid populations, unveiling crucial insights into their interplay.

Plant spacing significantly impacts pest abundance, mainly observed during the high hill wet season. Consistent with prior findings, variations in planting distance have been correlated with changes in pest populations. Dense planting might aggravate the prevalence of several pests, including planthoppers,

leafhoppers, leaf folders, gall midges, black bugs, and caseworms (Rocha et al., 2012). Conversely, pests like whorl maggots, root aphids, root weevils, and leaf beetles may decrease as plant distances widen (IRRI, 2006). The link between pests and plant spacing might be attributed to additional tiller formation as plants are spaced farther apart, affecting rice tillering and dry matter production (Hasanuzzaman et al., 2009).

The study highlights the substantial impact of water level, parasitoid abundance, and plant spacing on pest variability, notably observed during the dry season. Elevated water depths in field regions are associated with extensive larval infestation (Tindall et al., 2013; Büttow et al., 2017), emphasizing the critical role of water levels for certain pests like *Parapoynx stagnalis*, a major rice paddy pest in the study region. The foothill area stands out, showing a strong multiple regression equation during dry and wet seasons, underlining the influence of water depth, bund weed coverage, and parasitoids on rice pest populations. The regression model revealed that plant distance, pesticide application frequency, parasitoids, and water depth significantly determines variations in rice pest populations in the dry and wet season.

Weed coverage on bunds is acknowledged as an alternative habitat for pests, corroborating earlier studies indicating higher pest prevalence in rice fields with bund weeds (Kureha et al., 1974; Litsinger, 1994). Additionally, pesticide applications negatively impact pest populations, aligning with established findings (Newsom, 1980; Eichers, 1981; Kogan, 1998). However, the escalating use of pesticides in agriculture raises concerns about environmental and ecological repercussions, including adverse effects on pollinators, decomposers, and natural enemies (Pimentel, 2005).

The study revealed a robust multiple regression equation across all zones and seasons, indicating that water depth, pesticide application frequency, plant spacing, bund weed coverage, the presence of home gardens, and pest abundance collectively influence the variability of parasitoid populations in the study area. The results underscore the pivotal role of host abundance as a significant limiting factor

influencing parasitoid fitness. Studies by Walde and Murdoch (1988) and Gunton and Pöyry (2016) validate this, confirming that the prevalence of hosts significantly affects parasitoid abundance and behavior. This aligns with prior studies demonstrating that in environments with higher host numbers, parasitoids tend to aggregate, as supported by Waage (1983), Bezemer and Mills (2001), and Umbanhowar et al. (2003). Furthermore, the study highlights the substantial impact of pest abundance on parasitoid populations in most zones, except for the high hill wet and midland dry seasons. This observation emphasizes the interwoven connection between pest and parasitoid populations, highlighting the pivotal role of pest abundance in governing the existence and expansion of parasitoids within agro-ecological zones.

Another key agricultural variable impacting parasitoid populations is bund vegetation. The findings draw attention to the beneficial role of bund weeds in fostering parasitoid populations. The vegetation on the elevated earthen levees surrounding rice fields is an alternative habitat for natural enemies of rice pests. Specifically, it sustains rice pests' natural enemies when their primary food sources are scarce (Horgan et al., 2017). Studies illustrated by Gurr et al. (2011) and Yu et al. (1996) highlight that planthopper egg parasitoids can flourish in these bund environments by preying on rice pests such as *Nilaparvata lugens* and *Sogatella furcifera*, found in wild grasses on rice bunds.

Furthermore, the presence of nectar plants on rice bunds supports planthopper parasitoids and aids leaf folder parasitoids (Gurr et al., 2012). The bund vegetation serves as an alternate food source and refuge for natural enemies, boosting the reproductive capacity and lifespan of various predators and parasitoids (Landis et al., 2000; Pickett and Bugg, 1998). It even facilitates the development of ichneumonid parasitoids (Voûte, 1946) and sustains parasitic Diptera (Grensted, 1946).

The study also emphasizes the substantial influence of agricultural practices on parasitoid populations across different zones and seasons. Notably, the frequency of pesticide applications and the presence of home gardens negatively impact

parasitoid populations. The detrimental effect of pesticide treatments coinciding with parasitoid mortality leads to decreased pest suppression and potential pest resurgence, highlighting the complexities of modern pesticide usage. Moreover, home gardens with diverse plant species may attract parasitoid attention due to increased alternative hosts (Landis et al., 2000), elucidating the negative correlation between home garden size and parasitoid populations.

In conclusion, leveraging agricultural variables from the study regions, the developed regression models exhibit potential for predicting pest and parasitoid populations, offering valuable insights for integrated pest management (IPM) planning. However, the study stresses the need for sustainable agricultural practices to mitigate adverse impacts on natural pest control provided by parasitoids.

Vegetation types

The investigation examined the influence of various vegetation types on pest and parasitoid populations within the study area. Findings from this study illuminate the dominance of different vegetation types across the study sites and their consequential impact on the populations of parasitoids and insect pests. Distinct vegetation types exhibited significant effects on the pest populations under scrutiny. Notably, the study unveiled a noteworthy positive correlation between pest populations, fallow lands, and agro-forestry areas. This aligns with established studies, such as Altieri (1984), which suggest that uncultivated (fallow) habitats are pivotal sources for colonization and recolonization of crop fields following disturbances. Fallow land also plays a crucial role in preserving alternative prey for beneficial insects when pest species become scarce, as evidenced by research carried out by van Emden (1964).

Additionally, studies like Sileshi et al. (2008) suggest that trees in agro-forestry settings might benefit pests by offering resources and improving microclimates or indirectly affect pest prevalence by influencing host plant nutritional circumstances or water availability. The potential of agro-forestry practices to regulate pests, diseases, and weeds remains an ongoing area of research, with implications for top-down control by natural enemies and bottom-up factors

like microclimate, soil nutrients, and water content (Sileshi et al., 2008). The work of Pumariño et al. (2015) also supports this by highlighting the role of agro-forestry practices in augmenting natural enemy populations and their impact on invertebrate pests, albeit with variations depending on the crop type.

On the contrary, our study uncovers a negative correlation between pest populations within rice fields and the presence of emergent aquatic vegetation surrounding them. Previous research, such as that by Chandler and Highton (1975) and Zalom et al. (1980), has noted that emergent aquatic vegetation serves as a beneficial microhabitat and refuge for natural enemies. These natural enemies contribute to a biological control mechanism that suppresses pest populations within rice fields, as highlighted by studies like that of Lin et al. (2023). The observed negative relationship between parasitoid populations in rice fields and the surrounding emergent aquatic vegetation suggests that the abundance and distribution of host insects within rice fields may be influenced the parasitoid populations. Intriguingly, while our results underscore the adverse impact of emergent aquatic vegetation, other types of vegetation did not exhibit a noticeable effect on parasitoid populations. This comprehensive investigation sheds light on the differential effects of various vegetation types on both pest and parasitoid populations. It underscores the intricate interplay between vegetative landscapes and insect populations, offering valuable insights into ecosystem dynamics and informing pest management strategies within agricultural settings.

Land use types

The study addresses the complexities of establishing general principles for landscape structure due to the diverse responses of different species to landscape patterns. It emphasizes the limitations of single-species studies in determining overall responses to landscape structures. It highlights the study's objective to understand the general effects of patch characteristics on insect abundance in the rice ecosystem. Fahrig and Jonsen (1998) suggest that ecological research often relies on single-species or two-species studies. However, studies focusing solely on individual species cannot comprehensively determine general responses to landscape

structure. This study aims to discern broader trends in pest and parasitoid abundance concerning landscape features. The study's results demonstrate that the abundance of pests and parasitoids increases with greater patch richness.

Furthermore, landscape heterogeneity positively influences the abundance of pests and parasitoids within the study area. The study stands out for its representation of how different parasitoids and herbivorous insects collectively respond to patch characteristics. This aggregate understanding is crucial to managing the rice ecosystem effectively. The study acknowledges the complex web of interactions between various species within and around the rice fields, such as birds, spiders, frogs, and insects. It recognizes that these species reside in natural vegetation and surrounding landscapes, affecting insect populations (Xiong et al., 2018). The presence of different vegetation types, such as agroforestry, crop/grass, and sparse vegetation, around the sampling sites, can potentially impact rice production by interacting with or competing with rice crops.

Recognizing the need for sustainable rice production, the study emphasizes the necessity of appropriate landscape management practices. It suggests that understanding land use types and landscape heterogeneity is crucial for effective ecosystem management.

Potential distribution of pests

The study focuses on utilizing ecological niche modeling (specifically, the MaxEnt model) to predict the potential distribution of major rice pests in India. It outlines the model's effectiveness in estimating current rice pest outbreaks and identifies potential suitable regions for these pests within South India. Additionally, it highlights the key environmental variables influencing the distribution of specific rice pests and their significance in predicting and understanding pest distribution patterns. It indicates that numerous regions in South India are potentially suitable habitats for major rice pests, suggesting that they might not have reached their maximum potential range yet. The study evaluates various environmental variables contributing to the distribution of rice pests. Temperature seasonality and its fluctuations emerged as the primary contributors influencing the distribution of these

pests. Different rice pests, such as *Cnaphalocrocis medinalis*, *Parapoynx stagnalis*, *Pelopidas agna*, *Ampittia dioscorides*, and *Parnara bada*, show varying degrees of sensitivity to environmental factors. For instance, temperature annual range and temperature seasonality significantly impact the distribution of *A. dioscorides*, while isothermality and precipitation influence *P. bada*. The findings emphasize that climate factors, particularly precipitation and temperature, are crucial predictors of rice pest distribution. These factors significantly influence insect population dynamics, including survival rates, development rates, fecundity, and dispersion (Kiritani, 2006; Jepsen et al., 2008; Robinet and Roques, 2010). Several studies indicate that climatic changes substantially influence insect range expansion (Bale et al., 2002; Kiritani, 2006; Le Roux and McGeoch, 2008; Robinet and Roques, 2010). This is supported by findings suggesting that alterations in climate can lead to shifts in species distribution patterns (Hickling et al., 2006; Musolin and Fujisaki, 2006; Musolin, 2007). The distribution of species is considered an essential indicator to assess the response of insect populations to changing climates. Therefore, as employed in this study, species distribution modelling becomes a valuable tool in understanding how insect populations might respond to climate change.

In essence, this study illustrates the utility of ecological niche modelling in predicting the distribution of major rice pests in India. It emphasizes the significant impact of climate factors on pest distribution. It highlights the potential implications of climate change on insect population dynamics and the importance of predicting and understanding species distribution in assessing the effects of changing climates on insect populations.

In conclusion, the study's primary focus was on comprehensively understanding the community structure of insect pests and parasitoids in rice fields. It aimed to gather information on their diversity, abundance, relative density, and the intricate host-parasitoid food web within these ecosystems. The study delved into insect diversity variations across crop seasons, crop growth stages, farming practices, and agro-ecological zones. This analysis of spatio-temporal variation

provided insights into how insect diversity changes over time and in different environmental conditions. It examined the influence of multiple factors on the diversity of rice insects. These factors included climatic variables, agricultural practices, vegetation types, and land use patterns. Understanding how these factors interplay is crucial to comprehending and managing insect diversity in rice ecosystems. The study developed regression models that used climate variables and agricultural practices to predict the populations of pest-parasitoid populations. These models serve as predictive tools for estimating the population dynamics of these organisms based on environmental and agricultural conditions. The study utilized ecological niche modeling to identify the current and potential distribution of major rice insect pests in South India. It focused on understanding the impact of climate variables on the distribution patterns of these pests, aiding in predicting their potential habitats. The comprehensive analysis and findings provided by the study are deemed valuable for devising effective pest management strategies. This knowledge offers a foundation for implementing pest control measures considering the diverse factors influencing insect populations in rice ecosystems.

ANNEXURES

Table 2.30. Relative density and frequency of rice pests in high hill 2017. The bold digits represent significant results.

Pest	Dry season		Wet season	
	Relative density (%)	**Relative frequency (%)**	**Relative Density (%)**	**Relative frequency (%)**
Ampittia dioscorides	0.97	2.40	2.20	5.15
Cnaphalocrocis medinalis	**22.44**	**6.84**	**21.36**	**5.15**
Cofana spectra	4.70	5.48	3.79	5.15
Creatonotus gangis	0.48	1.37	0.98	1.55
Dicladispa armigera	0.72	2.05	2.08	3.61
Euproctis similis	3.98	5.82	3.00	4.64
Euscyrtus concinnus	2.17	3.08	0.80	1.80
Helcystogramma arotraeum	4.34	3.08	4.90	2.32
Hieroglyphus banian	2.53	5.48	1.35	4.38
Leptispa pygmaea	0.00	0.00	0.31	0.77
Leptocorisa acuta	0.00	0.00	4.04	5.15
Melanitis leda ismene	3.26	5.14	2.20	4.38
Menida versicolor	0.00	0.00	0.31	1.03
Mythimna separata	0.60	1.71	1.10	3.09
Naranga aenescens	0.60	1.71	0.98	2.58
Nephotettix nigropictus	3.38	4.79	2.20	4.38
Nilaparvata lugens	4.70	5.48	3.00	5.15
Orsotriaena medus	1.33	2.74	2.82	5.15
Oxya hyla	1.81	3.42	1.16	4.12
Parapoynx stagnalis	**22.92**	**6.85**	**22.52**	**5.15**
Pelopidas agna	3.62	5.82	5.81	5.15
Pelopidas mathias	0.48	1.37	1.41	3.35
Parnara sp.	3.74	5.82	5.08	5.15
Psalis pennatula	2.29	4.45	2.26	4.64
Scirpophaga incertulas	1.33	3.08	0.00	0.00
Scotinophara bispinosa	0.00	0.00	0.55	1.80
Spodoptera litura	0.00	0.00	0.92	1.29
Spodoptera mauritia	2.17	5.14	2.69	3.35
Tetrix subulata	0.00	0.00	0.18	0.52

Table 2.31. Relative density and frequency of rice pests in high hill 2018. The bold digits represent significant results.

Pest	Dry season		Wet season	
	Relative Density (%)	**Relative frequency (%)**	**Relative Density (%)**	**Relative frequency (%)**
Ampittia dioscorides	2.73	5.24	2.06	4.62
Cnaphalocrocis medinalis	**18.22**	**5.24**	**19.27**	**5.78**
Cofana spectra	3.47	4.90	2.83	4.62
Creatonotus gangis	1.73	2.80	0.51	1.45
Dicladispa armigera	1.86	3.50	1.86	3.47
Euproctis similis	4.46	5.59	2.76	4.62
Euscyrtus concinnus	1.12	2.45	0.00	0.00
Helcystogramma arotraeum	**7.06**	**1.75**	4.69	1.45
Hieroglyphus banian	2.35	4.90	1.86	4.91
Leptocorisa acuta	7.56	6.99	4.75	5.78
Melanitis leda ismene	1.98	5.59	1.93	4.62
Menida versicolor	0.25	0.70	0.13	0.58
Mocis frugalis	0.50	0.70	0.06	0.29
Mythimna separata	1.12	2.10	3.53	4.34
Naranga aenescens	0.25	0.70	0.51	4.34
Nephotettix nigropictus	1.73	3.85	1.73	4.91
Nezara viridula	0.00	0.00	0.13	0.58
Nilaparvata lugens	2.11	5.24	1.67	5.20
Orsotriaena medus	2.35	4.55	3.34	5.78
Oxya hyla	1.24	3.15	0.90	2.60
Parapoynx stagnalis	**21.93**	**5.59**	**26.20**	**5.78**
Pelopidas agna	4.34	6.29	5.52	5.78
Pelopidas mathias	0.62	1.75	0.26	1.16
Parnara sp.	5.95	6.99	3.73	5.78
Psalis pennatula	0.00	0.00	1.73	3.76
Scotinophara bispinosa	0.00	0.00	2.25	2.60
Spodoptera litura	0.00	0.00	**5.78**	**5.20**
Spodoptera mauritia	1.36	3.85	0.00	0.00

Table 2.32. Relative density and frequency of rice pests in high hill 2019. The bold digits represent significant results.

Pest	Dry season		Wet season	
	Relative frequency (%)	**Relative density (%)**	**Relative density (%)**	**Relative frequency (%)**
Ampittia dioscorides	2.71	2.08	1.50	3.50
Cofana spectra	6.33	4.90	3.65	6.37
Cnaphalocrocis medinalis	**9.05**	**21.22**	**14.58**	**6.37**
Dicladispa armigera	6.79	2.82	2.93	4.46
Euproctis similis	1.81	0.74	0.21	0.96
Euscyrtus concinnus	0.00	0.00	0.64	2.23
Helcystogramma arotraeum	1.36	1.78	1.64	0.64
Hieroglyphus banian	2.26	1.04	1.00	3.50
Leptispa pygmaea	0.00	0.00	0.43	0.96
Leptocorisa acuta	8.14	7.27	4.72	6.37
Melanitis leda ismene	1.81	1.19	1.00	2.87
Menida versicolor	0.45	0.15	0.07	0.32
Mocis frugalis	4.07	1.63	0.86	2.87
Mythimna separata	6.79	3.26	4.36	5.41
Naranga aenescens	3.62	1.78	1.93	3.18
Nephotettix nigropictus	1.81	0.89	1.50	4.46
Nilaparvata lugens	0.00	0.00	1.36	5.10
Orsotriaena medus	5.88	3.41	4.07	6.05
Oxya hyla	3.17	1.34	0.43	1.27
Parapoynx stagnalis	**5.43**	**26.41**	**24.30**	**6.37**
Pelopidas agna	8.14	5.19	9.01	6.37
Pelopidas mathias	0.45	0.15	0.14	0.64
Parnara sp.	**9.05**	**8.16**	**7.58**	**6.37**
Psalis pennatula	3.62	1.19	0.36	1.59
Scotinophara bispinosa	0.00	0.00	0.43	1.59
Spodoptera litura	0.90	0.59	4.50	3.82
Spodoptera mauritia	6.33	2.82	6.79	6.37

Table 2.33. Relative density and frequency of rice pests in foothill 2017. The bold digits represent significant results.

Pest	Dry season		Wet season	
	Relative frequency (%)	**Relative Density (%)**	**Relative frequency (%)**	**Relative Density (%)**
Ampittia dioscorides	5.37	3.86	**5.51**	**13.30**
Callitettix versicolor	0.00	0.00	1.38	0.27
Cnaphalocrocis medinalis	**5.79**	**14.31**	**5.51**	**15.11**
Cofana spectra	5.37	5.58	5.51	1.81
Creatonotus gangis	0.83	0.43	0.83	0.10
Dicladispa armigera	4.55	5.58	5.23	2.05
Euproctis similis	4.13	2.43	4.68	1.40
Euscyrtus concinnus	2.89	2.00	0.00	0.00
Helcystogramma arotraeum	**2.07**	**7.73**	2.75	4.33
Hieroglyphus banian	3.72	2.00	2.48	0.58
Leptispa pygmaea	4.55	2.29	3.31	9.07
Leptocorisa acuta	6.61	5.87	5.51	2.35
Melanitis leda ismene	4.13	4.72	5.51	2.01
Menida versicolor	0.00	0.00	1.10	0.20
Mocis frugalis	0.00	0.00	0.83	0.10
Mythimna separata	0.83	0.29	1.65	0.41
Naranga aenescens	0.83	0.29	3.03	0.61
Nephotettix nigropictus	4.55	2.72	3.03	0.51
Nilaparvata lugens	5.37	2.29	2.48	0.55
Orsotriaena medus	6.20	5.72	5.51	2.46
Oxya hyla	3.31	1.57	2.20	0.38
Parapoynx stagnalis	**3.31**	**9.59**	**5.51**	**21.90**
Parnara sp.	8.26	7.87	5.51	10.98
Pelopidas agna	6.61	4.72	5.51	5.73
Pelopidas mathias	0.83	0.29	1.38	0.17
Psalis pennatula	5.37	5.29	3.86	1.33
Scirpophaga incertulas	0.00	0.00	2.20	0.34
Spodoptera litura	0.00	0.00	0.55	0.14
Spodoptera mauritia	0.00	0.00	4.13	0.89
Tetrix subulata	4.55	2.58	3.31	0.92

Table 2.34. Relative density and frequency of rice pests in foothill 2018. The bold digits represent significant results.

Pest	Dry season		Wet season	
	Relative density (%)	**Relative frequency (%)**	**Relative Density (%)**	**Relative frequency (%)**
Ampittia dioscorides	5.50	8.10	12.68	6.80
Callitettix versicolor	0.00	0.00	0.28	2.04
Cnaphalocrocis medinalis	**18.64**	**8.10**	**13.92**	**6.80**
Cofana spectra	5.26	6.48	1.59	5.44
Creatonotus gangis	0.24	0.81	0.00	0.00
Dicladispa armigera	4.42	4.86	1.50	6.12
Euproctis similis	1.19	2.83	0.75	4.08
Euscyrtus concinnus	0.60	1.21	0.00	0.00
Helcystogramma arotraeum	**11.95**	**2.83**	10.90	6.80
Leptispa pygmaea	1.43	3.24	4.59	1.70
Leptocorisa acuta	5.85	5.26	0.00	0.00
Melanitis leda ismene	4.54	8.10	1.28	5.10
Menida versicolor	0.00	0.00	0.25	1.70
Mocis frugalis	0.60	1.21	0.44	1.70
Mythimna separata	1.43	2.02	0.72	3.74
Naranga aenescens	0.84	2.83	0.47	2.38
Orsotriaena medus	6.45	8.10	3.65	6.80
Parapoynx stagnalis	**11.23**	**5.26**	**24.35**	**6.80**
Parnara sp.	8.60	8.10	**16.48**	**6.80**
Pelopidas agna	5.85	8.10	2.47	6.80
Pelopidas mathias	0.72	2.43	0.03	0.34
Psalis pennatula	3.23	6.88	1.40	6.12
Scotinophara bispinosa	0.00	0.00	0.16	1.02
Spodoptera mauritia	1.43	3.24	1.40	5.78
Tetrix subulata	0.00	0.00	0.69	5.10

Table 2.35. Relative density and frequency of rice pests in foothill 2019. The bold digits represent significant results.

Pest	Dry season		Wet season	
	Relative density (%)	**Relative frequency (%)**	**Relative Density (%)**	**Relative frequency (%)**
Ampittia dioscorides	2.79	5.29	**14.10**	**5.26**
Cnaphalocrocis medinalis	**31.62**	**9.62**	**15.33**	**5.26**
Cofana spectra	2.79	4.33	1.07	5.26
Dicladispa armigera	2.06	2.88	2.33	4.74
Euproctis similis	1.03	3.37	0.07	0.53
Euscyrtus concinnus	0.00	0.00	0.77	5.26
Helcystogramma arotraeum	**7.79**	**2.88**	3.43	4.21
Hieroglyphus banian	1.62	3.37	0.73	4.21
Leptispa pygmaea	0.59	1.44	1.97	1.32
Leptocorisa acuta	6.47	7.69	1.93	5.26
Melanitis leda ismene	5.74	9.13	1.87	4.21
Menida versicolor	0.00	0.00	0.27	1.32
Mocis frugalis	0.00	0.00	1.67	3.42
Mythimna separata	0.44	0.96	2.57	5.00
Naranga aenescens	0.00	0.00	0.57	1.32
Nephotettix nigropictus	1.47	3.37	0.70	3.42
Nilaparvata lugens	0.00	0.00	0.53	3.16
Orsotriaena medus	1.76	4.81	4.90	5.26
Oxya hyla	1.32	2.40	0.47	2.89
Parapoynx stagnalis	**10.15**	**7.21**	**21.97**	**5.26**
Parnara sp.	6.47	7.21	13.57	5.26
Pelopidas agna	4.85	5.77	5.73	5.26
Pelopidas mathias	1.76	4.81	0.00	0.00
Psalis pennatula	4.71	7.69	0.27	1.58
Scotinophara bispinosa	0.00	0.00	0.10	0.79
Spodoptera litura	0.44	0.96	0.00	0.00
Spodoptera mauritia	2.35	4.33	1.80	5.26
Tetrix subulata	1.76	5.77	1.30	5.26

Table 2.36. Relative density and frequency of rice pests in midland laterite 2017. The bold digits represent significant results.

Pest	Dry season		Wet season	
	Relative density (%)	**Relative frequency (%)**	**Relative Density (%)**	**Relative frequency (%)**
Ampittia dioscorides	0.81	2.05	5.55	6.25
Cnaphalocrocis medinalis	**40.00**	**8.20**	**34.32**	**6.25**
Cofana spectra	1.85	4.10	1.12	2.81
Creatonotus gangis	0.00	0.00	0.12	0.63
Dicladispa armigera	1.50	3.69	1.42	3.44
Euproctis similis	1.50	3.69	1.71	3.13
Euscyrtus concinnus	1.85	4.51	1.00	3.44
Helcystogramma arotraeum	2.43	3.28	5.85	3.44
Hieroglyphus banian	2.08	5.33	0.95	2.81
Leptocorisa acuta	5.20	7.38	**8.45**	**2.50**
Melanitis leda ismene	4.05	3.69	1.12	5.00
Menida versicolor	0.00	0.00	4.13	6.25
Mythimna separata	0.23	0.82	0.18	0.94
Nephotettix nigropictus	2.43	6.56	0.18	0.94
Nilaparvata lugens	2.08	4.51	1.06	3.44
Orsotriaena medus	2.08	2.87	1.36	4.38
Oxya hyla	1.39	3.28	1.83	4.38
Parapoynx stagnalis	1.27	1.64	0.95	2.50
Parnara sp.	2.31	4.10	4.31	3.44
Pelopidas agna	3.24	4.92	3.31	6.25
Pelopidas mathias	0.81	1.64	2.36	4.38
Psalis pennatula	**6.24**	**8.20**	0.35	1.88
Pyrilla perpusilla	0.00	0.00	0.12	0.63
Scirpophaga incertulas	**13.18**	**6.15**	**11.93**	**6.25**
Scirpophaga innotata	0.92	2.05	0.71	2.19
Scotinophara bispinosa	1.50	4.51	0.71	2.50
Spodoptera litura	0.35	1.23	0.41	0.94
Spodoptera mauritia	0.69	1.64	0.77	2.81

Table 2.37. Relative density and frequency of rice pests in midland laterite 2018. The bold digits represent significant results.

Pest	Dry season		Wet season	
	Relative density (%)	**Relative frequency (%)**	**Relative Density (%)**	**Relative frequency (%)**
Ampittia dioscorides	3.19	5.22	1.20	3.13
Cnaphalocrocis medinalis	**38.57**	**8.70**	**40.65**	**5.70**
Cofana spectra	1.84	3.91	1.80	5.41
Dicladispa armigera	1.97	3.04	1.66	2.56
Euproctis similis	0.86	3.04	1.53	3.42
Euscyrtus concinnus	1.11	2.61	1.26	4.27
Helcystogramma arotraeum	2.70	3.04	3.06	2.28
Hieroglyphus banian	1.35	3.04	0.80	2.56
Leptispa pygmaea	0.00	0.00	5.92	3.99
Leptocorisa acuta	**6.76**	**8.26**	2.93	5.70
Melanitis leda ismene	4.91	8.70	3.26	5.70
Mythimna separata	0.37	1.30	0.33	1.42
Nephotettix nigropictus	0.00	0.00	1.20	4.56
Nilaparvata lugens	3.19	5.22	1.26	4.27
Orsotriaena medus	1.60	3.04	2.13	3.70
Oxya hyla	0.00	0.00	0.60	1.99
Parapoynx stagnalis	2.95	2.61	3.06	3.13
Parnara sp.	4.79	6.09	**6.05**	**5.70**
Pelopidas agna	4.05	5.65	3.93	5.70
Pelopidas mathias	1.97	3.48	1.86	3.42
Psalis pennatula	5.53	6.09	3.53	5.41
Scirpophaga incertulas	**8.85**	**6.09**	**7.19**	**4.84**
Scotinophara bispinosa	1.84	3.91	1.06	3.99
Spodoptera litura	0.49	0.87	2.46	2.56
Spodoptera mauritia	1.11	2.17	0.86	2.85
Tetrix subulata	0.00	0.00	0.40	1.71

Table 2.38. Relative density and frequency of rice pests in midland laterite 2019. The bold digits represent significant results.

Pest	Dry season		Wet season	
	Relative density (%)	**Relative frequency (%)**	**Relative Density (%)**	**Relative frequency (%)**
Ampittia dioscorides	2.60	5.60	4.27	6.58
Cnaphalocrocis medinalis	**38.63**	**8.62**	**43.38**	**6.58**
Cofana spectra	0.00	0.00	2.35	6.25
Dicladispa armigera	3.29	4.74	2.35	5.26
Euproctis similis	0.00	0.00	0.44	0.99
Euscyrtus concinnus	2.19	3.88	1.13	3.29
Hieroglyphus banian	1.23	3.02	1.48	2.96
Leptocorisa acuta	4.93	7.33	3.83	6.58
Melanitis leda ismene	5.21	4.74	2.53	3.95
Mythimna separata	1.37	4.31	1.83	2.96
Naranga aenescens	0.00	0.00	0.35	1.32
Nephotettix nigropictus	1.92	4.31	1.83	4.61
Nilaparvata lugens	2.88	6.47	3.40	4.28
Orsotriaena medus	2.74	5.17	3.92	6.58
Oxya hyla	1.51	3.02	0.96	2.96
Parapoynx stagnalis	**7.67**	**5.60**	**5.57**	**4.61**
Parnara sp.	6.03	8.62	**6.97**	**6.58**
Pelopidas agna	3.42	4.31	3.66	6.58
Pelopidas mathias	0.55	1.72	0.26	0.66
Psalis pennatula	2.60	3.45	1.22	3.95
Scirpophaga incertulas	**6.85**	**5.60**	3.31	3.29
Scotinophara bispinosa	1.23	3.02	1.31	3.29
Spodoptera litura	0.41	1.29	1.13	2.30
Spodoptera mauritia	2.74	5.17	2.53	3.62

Table 2.39. Relative density and frequency of parasitoids in the high hill rice fields (2017). The bold digits represent significant results.

Parasitoid	Dry season		Wet season	
	Relative density (%)	**Relative frequency (%)**	**Relative Density (%)**	**Relative frequency (%)**
Anagrus sp.	2.83	2.24	1.36	1.41
Apanteles sp. 1	**23.67**	**5.45**	**18.04**	**2.98**
Apanteles sp. 2	**14.84**	**5.13**	**13.58**	**3.13**
Aphanogmus fijiensis	3.89	1.92	3.70	2.04
Argyrophylax sp.	2.47	1.92	1.74	1.25
Aspidobracon noyesi	3.36	2.88	4.91	2.66
Brachymeria burski	0.00	0.00	1.21	1.10
Brachymeria excarinata	2.47	1.60	2.79	2.19
Brachymeria jambolana	0.00	0.00	0.83	0.78
Brachymeria lasus	10.07	5.77	6.19	2.82
Bracon sp.	1.59	1.60	1.74	1.25
Callitula peethapada	2.83	1.60	2.26	2.04
Callitula rugosa	0.00	0.00	1.36	1.10
Callitula travancorensis	1.41	0.96	1.36	0.78
Cardiochiles philippinensis	6.36	3.21	5.43	2.51
Casinaria ajanta	0.00	0.00	0.75	0.63
Charops bicolor	1.77	1.60	2.11	1.72
Cotesia flavipes	6.71	4.17	4.68	2.35
Cotesia ruficrus	7.60	5.13	5.51	2.82
Dictyonotus sp.	0.00	0.00	0.60	0.47
Elasmus sp.	1.06	1.28	1.89	1.41
Euplectrus sp.	0.00	0.00	0.15	0.31
Eurytoma manilensis	2.30	2.24	3.55	2.35
Eurytoma sp. 1	1.06	1.28	2.19	2.04
Gonatocerus sp. 1	0.00	0.00	1.21	1.41
Gonatocerus sp. 2	1.94	1.60	1.51	1.25
Gonatopus flavifemur	1.41	0.96	1.21	0.78
Goniozus hanoiensis	0.00	0.00	0.60	0.63
Goniozus platycephalus	0.00	0.00	0.83	0.78
Gryon sp.	5.83	3.53	5.13	2.35
Halidaia luteicornis	4.42	2.56	4.08	2.35
Ischnojoppa luteator	0.35	0.64	1.96	1.41
Isotima sp. 1	0.00	0.00	0.45	0.78

Isotima sp .2	0.18	0.32	0.45	0.63
Macrocentrus sp.	2.47	1.60	1.81	1.72
Macroteleia sp.	4.24	2.56	2.94	2.51
Mesochorus sp.	3.89	2.56	1.43	1.41
Microcharops sp.	0.00	0.00	0.15	0.16
Microplitis sp.	0.00	0.00	0.23	0.31
Mymar sp.	0.00	0.00	1.13	1.10
Ooencyrtus sp.	0.00	0.00	0.30	0.47
Opius sp.	1.41	0.96	1.36	0.78
Orthocentrus sp.	0.00	0.00	0.68	0.78
Panstenon sp.	0.53	0.64	1.13	1.10
Paraphylax sp. 1	0.00	0.00	0.75	0.78
Paraphylax sp. 2	0.00	0.00	0.60	0.47
Platyscelio sp.	2.83	1.60	2.72	2.04
Sympiesis sp.	0.71	0.96	0.83	0.78
Telenomus oryzae	4.95	2.24	2.87	2.19
Telenomus remus	**10.95**	**5.13**	**9.13**	**2.82**
Telenomus rowani	3.89	2.24	3.85	2.19
Telenomus sp. 1	0.00	0.00	0.75	0.78
Telenomus sp. 2	1.24	0.64	2.94	1.72
Telenomus sp. 3	0.53	0.32	1.66	1.25
Tetrastichus schoenobii	2.12	0.96	2.19	1.72
Tetrastichus sp. 1	0.53	0.64	1.21	0.78
Tetrastichus vayalicus	1.77	1.60	0.83	1.10
Trathala flavoorbitalis	0.35	0.32	1.21	0.94
Trichogramma chilonis	4.95	2.88	4.60	2.66
Trichogramma japonicum	8.66	3.53	6.04	2.98
Trichomalopsis apanteloctena	4.06	3.21	4.53	2.51
Trichomalopsis thekkadiensis	5.48	3.53	4.00	2.19
Trichomma sp.	0.00	0.00	0.45	0.63
Trissolcus sp.	1.06	1.28	1.89	1.72
Tropobracon hayati	0.00	0.00	0.45	0.47
Tropobracon luteus	0.71	0.64	1.81	1.10
Xanthopimpla punctata	0.18	0.32	0.68	0.47

Table 2.40. Relative density and frequency of parasitoids in the high hill rice fields (2018). The bold digits represent significant results.

Parasitoid	Dry season		Wet season	
	Relative density (%)	**Relative frequency (%)**	**Relative Density (%)**	**Relative frequency (%)**
Anagrus sp.	0.94	0.81	0.00	0.00
Antrocephalus sp.	0.00	0.00	1	0.91
Apanteles sp. 1	**17.32**	**4.05**	**17.2**	**4.08**
Apanteles sp. 2	**10.55**	**3.78**	**19.8**	**4.31**
Aphanogmus fijiensis	6.61	2.97	7.8	3.63
Argyrophylax sp.	2.68	2.16	0.6	0.45
Aspidobracon noyesi	1.26	1.08	2.1	1.81
Brachymeria burski	0.00	0.00	0.7	0.91
Brachymeria excarinata	2.99	2.16	4.1	2.49
Brachymeria lasus	7.40	2.97	0.5	0.68
Brachymeria jambolana	0.00	0.00	5	2.95
Bracon sp.	3.46	2.97	4.8	3.40
Callitula peethapada	3.46	2.97	4.8	3.40
Callitula travancorensis	4.57	3.78	5.3	3.63
Cardiochiles philippinensis	5.20	2.97	6.4	3.63
Casinaria ajanta	0.00	0.00	1.1	0.91
Charops bicolor	1.89	1.35	2.9	2.49
Charops plauta	0.16	0.27	0.3	0.45
Chilonus sp.	0.00	0.00	1.8	1.36
Cotesia flavipes	7.56	2.97	3.8	2.04
Cotesia ruficrus	9.76	3.51	4.2	2.27
Diadegma sp.	0.00	0.00	0.4	0.45
Dictyonotus sp.	0.63	0.54	0.00	0.00
Dolichogenidea sp.	0.00	0.00	1.2	1.13
Elasmus sp.	0.94	0.54	2.8	1.81
Euplectrus sp.	0.94	0.54	0.00	0.00
Eurytoma manilensis	1.89	1.35	3.6	2.04
Eurytoma sp.	0.00	0.00	0.5	0.68
Glyptapanteles sp.	0.00	0.00	0.7	0.68

Gonatocerus sp. 1	0.00	0.00	0.4	0.45
Gonatocerus sp. 2	1.26	1.08	0.00	0.00
Gonatopus flavifemur	3.94	2.43	0.9	0.68
Goniozus hanoiensis	1.89	1.35	0.00	0.00
Gryon sp.	6.46	3.24	4.9	2.49
Halidaia luteicornis	2.52	1.89	3.9	2.49
Hormius sp.	0.00	0.00	1.8	1.13
Ischnojoppa luteator	0.94	0.54	0.7	0.68
Isotima sp. 1	1.57	1.08	0.5	1.13
Macrocentrus philippinensis	0.00	0.00	0.9	0.91
Macroteleia sp.	6.77	2.97	**6.7**	**3.40**
Mesochorus sp.	1.57	1.08	2.7	1.81
Microplitis sp.	1.26	1.35	0.00	0.00
Mymar sp.	1.89	1.35	0.00	0.00
Neanastatus sp.1	0.00	0.00	1	0.68
Opius sp.	1.26	1.35	0.00	0.00
Orthocentrus sp.	0.47	0.81	0.00	0.00
Panstenon sp.	0.47	0.54	0.00	0.00
Paraphylax sp. 1	2.20	2.16	2.8	1.81
Platyscelio sp.	0.94	0.54	4	2.27
Sympiesis sp.	1.42	1.35	2.1	2.04
Telenomus oryzae	1.10	1.08	5.4	2.49
Telenomus remus	**10.87**	**4.32**	2.4	1.81
Telenomus rowani	2.52	1.35	2.1	2.04
Telenomus sp. 1	0.31	0.54	0.00	0.00
Telenomus sp. 3	0.00	1.08	0.00	0.00
Tetrastichus schoenobii	1.26	0.81	0.5	0.68
Tetrastichus sp. 1	1.89	1.08	0.00	0.00
Tetrastichus vayalicus	0.47	0.54	0.00	0.00
Thecocarcelia sp.	1.73	1.35	3.7	2.04
Trathala flavoorbitalis	2.20	1.62	2	1.13
Trichogramma chilonis	3.62	1.89	3.1	2.49
Trichogramma japonicum	8.50	3.78	6.2	3.17
Trichomalopsis	5.51	4.05	5	3.17

apanteloctena				
Trichomalopsis ovigastra	0.00	0.00	2.6	2.04
Trichomalopsis thekkadiensis	2.20	1.62	4.8	3.40
Trichomma sp.	1.57	1.08	0.4	0.45
Trissolcus sp.	0.31	0.27	0.00	0.00
Tropobracon hayati	2.52	1.62	0.8	0.68
Tropobracon luteus	0.63	0.81	0.00	0.00
Xanthopimpla punctata	2.99	2.16	2.1	1.81

Table 2.41. Relative density and frequency of parasitoids in the high hill rice fields (2019). The bold digits represent significant results.

Parasitoid	Dry season		Wet season	
	Relative density (%)	**Relative frequency (%)**	**Relative Density (%)**	**Relative frequency (%)**
Anagrus sp.	0.74	0.65	0.00	0.00
Antrocephalus sp.	2.59	1.62	2.42	0.41
Apanteles sp. 1	**22.04**	**5.50**	**21.09**	**1.17**
Apanteles sp. 2	**13.33**	**3.88**	**12.12**	**0.94**
Aphanogmus fijiensis	**10.74**	**3.88**	5.70	0.76
Argyrophylax sp.	1.48	0.97	2.18	0.41
Aspidobracon noyesi	0.56	0.65	0.12	0.06
Brachymeria excarinata	1.30	0.97	0.73	0.18
Brachymeria lasus	6.48	2.91	3.39	0.47
Bracon sp.	2.59	1.62	0.24	0.12
Callitula peethapada	0.74	0.65	5.45	0.65
Callitula travancorensis	3.33	1.62	3.52	0.53
Cardiochiles philippinensis	5.56	2.59	5.94	0.82
Ceraphron sp.	5.19	2.91	2.18	0.35
Charops bicolor	3.70	2.27	3.15	0.41
Chilonus sp.	0.74	0.65	0.36	0.12
Cotesia flavipes	6.67	3.24	8.36	1.00
Cotesia ruficrus	0.00	3.88	4.36	0.53
Dictyonotus sp.	0.74	0.65	0.00	0.00

Elasmus sp.	2.96	2.27	2.18	0.23
Eurytoma manilensis	2.59	1.62	0.24	0.12
Gonatocerus sp.2	1.11	0.97	0.00	0.00
Gonatopus flavifemur	2.22	1.62	2.91	0.29
Goniozus hanoensis	0.00	0.00	1.09	0.29
Gryon sp.	3.70	1.62	3.64	0.59
Halidaia luteicornis	4.63	2.27	5.70	0.65
Hemiptarsenus oryzae	0.74	0.65	1.45	0.35
Hormius sp.	0.74	0.65	0.00	0.00
Ischnojoppa luteator	2.22	1.62	0.73	0.12
Isotima sp. 1	1.11	0.97	0.00	0.00
Macrocentrus philippinensis	1.11	0.97	0.24	0.06
Macroteleia sp.	7.22	3.24	6.79	0.82
Mesochorus sp.	1.11	0.97	4.12	0.65
Neanastatus sp. 1	1.67	1.29	2.18	0.53
Opius sp.	0.19	0.32	0.00	0.00
Orthocentrus sp.	1.11	0.97	0.00	0.00
Panstenon sp.	0.00	0.00	0.48	0.12
Paraphylax sp. 1	0.56	0.65	2.18	0.41
Pediobius sp.	0.00	0.00	0.61	0.23
Platyscelio sp.	4.63	3.56	4.48	0.65
Propicroscytus oryzae	0.00	2.59	6.79	0.65
Sympiesis sp.	0.37	0.65	4.12	0.76
Telenomus oryzae	4.44	1.94	**10.91**	**1.00**
Telenomus remus	10.00	4.21	0.00	0.00
Telenomus rowani	1.11	0.65	0.00	0.00
Telenomus sp. 2	2.59	1.62	0.00	0.00
Telenomus sp. 3	0.74	0.65	0.00	0.00
Tetrastichus vayalicus	0.19	0.32	0.00	0.00
Thecocarcelia sp.	2.22	1.29	3.64	0.53
Trathala flavoorbitalis	0.37	0.32	1.94	0.35
Trichogramma chilonis	2.78	1.94	1.45	0.29
Trichogramma japonicum	6.30	2.59	3.64	0.47
Trichomalopsis apanteloctena	4.63	2.91	4.00	0.70

Trichomalopsis ovigastra	7.22	3.88	6.06	0.88
Trichomalopsis thekkadiensis	2.04	1.62	7.03	0.82
Trichomma sp.	2.59	1.94	2.18	0.29
Trissolcus sp.	0.37	0.32	0.36	0.12
Tropobracon hayati	1.11	0.65	0.00	0.00
Tropobracon luteus	2.96	1.62	0.00	0.00
Xanthopimpla flavolineata	0.00	0.00	2.18	0.35
Xanthopimpla punctata	1.48	0.97	2.42	0.53

Table 2.42. Relative density and frequency of parasitoids in the foothill rice fields (2017). The bold digits represent significant results.

Parasitoid	Dry season		Wet season	
	Relative density (%)	**Relative frequency (%)**	**Relative Density (%)**	**Relative frequency (%)**
Anagrus sp.	0.00	0.00	0.96	0.71
Antrocephalus sp.	0.78	0.62	0.96	0.71
Apanteles sp. 1	**12.04**	**4.36**	**11.49**	**3.02**
Apanteles sp. 2	9.51	3.43	7.28	2.84
Aphanogmus fijiensis	8.16	3.43	5.08	1.95
Argyrophylax sp.	0.00	0.00	0.96	0.53
Aspidobracon noyesi	4.85	3.74	3.54	1.78
Barichneumon sp.	1.17	0.62	1.44	0.89
Brachymeria burski	0.39	0.00	**10.25**	**3.20**
Brachymeria excarinata	3.88	2.18	3.45	1.60
Brachymeria jambolana	0.00	0.00	4.79	1.95
Brachymeria lasus	9.32	4.98	2.87	1.60
Bracon sp.	1.55	0.93	2.11	1.60
Callitula peethapada	3.50	2.49	3.35	2.66
Callitula rugosa	3.11	1.56	2.49	1.60
Callitula travancorensis	0.00	2.80	2.49	1.78
Cardiochiles philippinensis	5.63	2.18	4.41	2.31
Casinaria ajanta	0.00	0.00	**8.72**	**3.37**
Charops bicolor	2.14	1.25	2.20	1.42
Cotesia flavipes	4.08	1.87	3.64	1.95

Cotesia ruficrus	2.52	1.56	2.20	1.24
Diadegma sp. 1	0.78	0.62	1.34	0.89
Diadegma sp. 2	0.00	0.00	1.15	0.71
Dictyonotus sp.	1.17	0.62	0.77	0.53
Elasmus sp.	2.72	1.56	1.25	0.89
Euplectrus sp.	0.00	0.00	0.96	0.53
Eurytoma manilensis	2.91	1.87	3.54	1.95
Eurytoma sp. 1	4.27	2.80	2.68	2.13
Gonatocerus sp. 1	2.72	1.56	0.19	0.18
Gonatocerus sp. 2	0.00	0.00	0.77	0.53
Gonatopus flavifemur	0.97	0.93	1.34	0.89
Goniozus hanoiensis	0.78	0.62	1.53	1.07
Goniozus platycephalus	0.00	0.00	0.38	0.36
Goryphus sp.	1.17	0.93	1.25	1.07
Gryon sp.	**9.90**	**3.43**	5.27	2.84
Halidaia luteicornis	1.55	0.93	1.72	1.07
Ischnojoppa luteator	2.33	1.25	1.34	0.89
Isotima sp. 1	0.00	0.00	0.77	0.53
Isotima sp. 2	1.17	0.93	0.00	0.00
Macrocentrus sp.	0.00	0.00	0.77	0.53
Macroteleia sp.	4.08	2.80	5.17	2.49
Mesochorus sp.	2.91	2.18	3.54	2.49
Microplitis sp.	0.00	0.00	1.15	0.89
Mymar sp.	0.00	0.00	0.38	0.36
Neanastatus sp. 1	0.78	0.62	0.96	0.71
Ooencyrtus sp.	0.00	0.00	0.38	0.53
Opius sp.	0.00	0.00	0.38	0.53
Panstenon sp.	0.00	0.00	0.19	0.36
Paraphylax sp. 1	2.33	1.56	3.07	1.95
Paraphylax sp. 2	1.55	0.93	0.96	0.71
Platyscelio sp.	5.44	2.80	2.87	1.42
Scelio sp.	4.08	2.49	2.68	1.42
Sympiesis sp.	1.17	0.62	1.92	1.42
Telenomus oryzae	0.78	0.62	0.86	0.71
Telenomus remus	**11.65**	**4.67**	7.28	3.02
Telenomus rowani	1.17	0.62	2.11	1.24
Telenomus sp. 1	1.17	0.62	1.82	1.42
Telenomus sp. 2	2.72	1.56	2.49	1.42

Telenomus sp. 3	1.55	0.93	0.00	0.00
Tetrastichus schoenobii	2.14	1.25	2.30	1.42
Tetrastichus vayalicus	2.33	1.56	2.59	1.95
Thecocarcelia sp.	1.17	0.62	2.11	1.60
Trathala flavoorbitalis	0.58	0.62	1.63	1.24
Trichogramma chilonis	3.50	1.56	1.72	1.24
Trichogramma japonicum	6.60	2.49	2.11	0.89
Trichomalopsis apanteloctena	3.88	2.49	4.50	2.49
Trichomalopsis ovigastra	0.00	0.00	1.72	1.42
Trichomalopsis thekkadiensis	8.35	4.05	5.46	2.84
Trichomma sp.	1.55	1.25	0.57	0.36
Trissolcus sp.	0.00	0.00	0.57	0.36
Tropobracon hayati	2.72	1.56	1.92	1.24
Tropobracon luteus	0.58	0.62	0.67	0.71
Xanthopimpla flavolineata	2.72	2.18	2.11	1.60
Xanthopimpla punctata	1.17	0.62	1.63	1.24

Table 2.43. Relative density and frequency of parasitoids in the foothill rice fields (2018). The bold digits represent significant results.

Parasitoid	Dry season		Wet season	
	Relative density (%)	**Relative frequency (%)**	**Relative Density (%)**	**Relative frequency (%)**
Anagrus sp.	3.02	2.32	0.00	0.00
Antrocephalus sp.	0.57	0.66	1.67	1.19
Apanteles sp. 1	**15.09**	**5.30**	**12.80**	**4.30**
Apanteles sp. 2	**10.57**	**4.64**	**11.27**	**4.77**
Aphanogmus fijiensis	9.25	5.30	**10.43**	**4.53**
Argyrophylax sp.	0.00	0.00	1.95	1.19
Aspidobracon noyesi	3.96	3.64	1.67	1.19
Brachymeria excarinata	2.83	2.32	2.92	1.67
Brachymeria lasus	5.85	2.98	2.64	1.91
Bracon sp.	4.34	2.65	3.89	1.91
Callitula peethapada	2.64	2.32	3.20	2.15

Callitula travancorensis	3.77	1.99	3.89	2.15
Cardiochiles philippinensis	3.77	1.99	5.84	2.39
Charops bicolor	2.45	1.66	7.51	3.34
Chilonus sp.	0.38	0.33	1.95	1.19
Chirotica sp. 1	0.00	0.00	0.83	0.48
Chirotica sp. 2	0.00	0.00	0.42	0.48
Chorebus sp.	0.00	0.00	0.14	0.24
Cotesia flavipes	5.28	2.32	2.78	1.67
Cotesia ruficrus	9.25	3.97	3.62	2.15
Dolichogenidea sp.	0.00	0.00	1.67	1.19
Elasmus sp.	1.32	0.99	3.62	1.67
Eurytoma manilensis	4.91	1.99	0.97	0.95
Eurytoma sp. 1	2.64	2.32	1.39	0.95
Glyptapanteles sp.	0.19	0.33	1.67	1.19
Gonatocerus sp. 2	3.58	2.65	2.09	1.43
Gonatopus flavifemur	2.45	1.66	3.20	1.67
Gryon sp.	7.55	3.64	4.17	1.91
Halidaia luteicornis	1.51	0.99	1.67	1.19
Hormius sp.	0.00	0.00	1.67	1.19
Ischnojoppa luteator	0.38	0.00	0.00	0.00
Isotima sp. 2	0.38	0.66	0.00	0.00
Macrocentrus philippinensis	0.75	0.66	0.56	0.24
Macrocentrus sp.	0.38	0.66	1.11	0.95
Macroteleia sp.	4.53	1.99	6.54	3.34
Mesochorus sp.	1.89	1.32	2.36	1.67
Neanastatus sp. 1	0.00	0.00	1.39	0.95
Neanastatus sp. 2	1.13	0.66	1.39	1.19
Opius sp.	0.00	0.00	1.39	0.95
Panstenon sp.	0.57	0.66	0.97	0.72
Platyscelio sp.	3.40	2.32	3.34	1.67
Scutibracon sp.	0.00	0.00	1.39	0.72
Sympiesis sp.	0.00	0.00	1.81	1.19
Telenomus oryzae	2.64	1.99	4.73	2.15
Telenomus remus	8.87	4.30	6.12	3.82
Telenomus rowani	3.77	2.65	0.97	0.95

Telenomus sp. 2	1.89	0.99	2.78	1.91
Telenomus sp. 3	0.57	0.66	1.11	0.72
Tetrastichus schoenobii	3.02	0.99	0.00	0.00
Tetrastichus sp. 1	1.70	1.66	3.89	2.15
Tetrastichus vayalicus	0.38	0.33	1.67	1.19
Trathala flavoorbitalis	2.64	1.66	3.48	1.91
Trichogramma chilonis	6.04	2.65	3.06	1.91
Trichogramma japonicum	**10.94**	**5.30**	4.31	2.63
Trichomalopsis apanteloctena	3.40	1.66	5.56	3.34
Trichomalopsis ovigastra	0.75	0.66	3.89	2.15
Trichomalopsis thekkadiensis	5.47	2.98	5.70	3.10
Trissolcus sp.	0.38	0.66	0.56	0.48
Tropobracon luteus	4.91	2.32	2.23	1.43
Xanthopimpla punctata	0.75	0.66	3.06	2.15

Table 2.44. Relative density and frequency of parasitoids in the foothill rice fields (2019). The bold digits represent significant results.

Parasitoid	Dry season		Wet season	
	Relative density (%)	**Relative frequency (%)**	**Relative Density (%)**	**Relative frequency (%)**
Antrocephalus sp.	0.52	0.78	1.12	0.87
Apanteles sp. 1	**12.89**	**4.30**	**10.22**	**4.14**
Apanteles sp. 2	**13.14**	**5.08**	8.68	3.49
Aphanogmus fijiensis	6.44	3.52	7.00	3.27
Argyrophylax sp.	2.58	1.17	2.38	1.53
Barichneumon sp.	0.52	0.39	1.40	0.87
Brachymeria burski	0.00	0.00	**12.89**	**4.36**
Brachymeria excarinata	2.06	1.56	3.08	1.96
Brachymeria jambolana	0.00	0.00	7.00	4.36
Brachymeria lasus	8.76	4.30	4.76	2.61
Bracon sp.	2.84	2.34	2.80	1.96
Callitula peethapada	3.61	2.73	3.64	1.96

Callitula rugosa	0.00	0.00	1.96	1.09
Callitula travancorensis	4.64	3.52	5.74	2.61
Cardiochiles philippinensis	6.70	2.34	6.02	2.40
Casinaria ajanta	0.00	0.00	**11.06**	**3.49**
Charops bicolor	1.55	1.17	2.38	1.96
Chirotica sp. 1	0.00	0.00	0.56	0.44
Chirotica sp. 2	2.58	1.56	0.00	0.00
Chorebus sp.	0.77	0.78	1.68	1.09
Cotesia flavipes	9.28	3.52	3.22	2.40
Cotesia ruficrus	5.67	2.73	3.92	1.74
Diadegma sp. 1	0.00	0.00	0.84	0.65
Diadegma sp. 2	0.00	0.00	1.40	0.87
Dictyonotus sp.	0.52	0.39	1.12	0.65
Elasmus sp. 1	4.64	2.73	2.24	1.31
Elasmus sp. 2	0.52	0.78	0.56	0.65
Euplectrus sp.	0.00	0.00	1.68	0.87
Eurytoma manilensis	3.61	1.95	3.08	1.74
Eurytoma sp. 1	1.29	1.17	3.08	1.31
Gonatopus flavifemur	3.09	2.34	0.28	0.22
Goniozus hanoiensis	1.55	1.17	0.84	0.65
Goniozus platycephalus	2.58	1.56	0.56	0.44
Goryphus basilaris	0.52	0.39	1.96	1.09
Goryphus sp.	1.55	0.78	4.06	2.83
Gryon sp.	3.61	1.95	3.36	2.40
Halidaia luteicornis	2.06	1.17	3.08	1.31
Ischnojoppa luteator	0.00	0.00	2.24	1.31
Isotima sp. 1	0.00	0.00	0.70	0.65
Isotima sp. 2	0.26	0.39	0.00	0.00
Macrocentrus sp.	0.00	0.00	0.56	0.44
Macroteleia sp.	2.58	1.95	2.10	1.09
Microcharops sp.	0.00	0.00	0.84	0.65
Neanastatus sp. 1	3.09	1.95	0.00	0.00
Neanastatus sp. 2	0.00	0.00	1.40	0.87
Paraphylax sp. 1	1.03	0.78	1.12	0.87
Paraphylax sp. 2	0.00	0.00	1.40	1.09
Scelio sp.	0.00	0.00	1.12	0.65
Scutibracon sp.	1.03	0.78	1.96	1.31

Spathius sp.	2.06	1.17	0.00	0.00
Stenobracon sp.	0.52	0.78	1.82	1.31
Sympiesis sp.	1.03	0.78	2.94	2.40
Telenomus oryzae	1.29	1.17	2.24	1.31
Telenomus remus	**10.57**	**4.30**	1.68	1.09
Telenomus sp. 2	1.55	0.78	2.80	1.53
Telenomus sp. 3	2.06	1.17	0.14	0.22
Temelucha sp.	1.03	0.78	2.80	1.53
Thecocarcelia sp.	1.03	0.78	1.96	0.87
Trathala flavoorbitalis	1.55	0.78	0.84	0.65
Trichogramma chilonis	3.09	1.95	3.50	2.83
Trichogramma japonicum	5.67	2.73	5.32	3.27
Trichomalopsis apanteloctena	5.67	3.13	0.42	0.65
Trichomalopsis ovigastra	3.61	2.34	5.04	3.05
Trichomalopsis thekkadiensis	7.99	4.30	1.68	1.09
Trichomma sp.	1.03	0.78	2.52	1.74
Tropobracon hayati	3.09	1.95	0.56	0.44
Tropobracon luteus	3.09	2.34	1.96	1.53
Xanthopimpla flavolineata	4.12	2.73	1.68	0.87
Xanthopimpla punctata	1.29	1.17	1.12	0.87

Table 2.45. Relative density and frequency of parasitoids in the midland laterite rice fields (2017). The bold digits represent significant results.

Parasitoid	**Dry season**		**Wet season**	
	Relative density (%)	**Relative frequency (%)**	**Relative Density (%)**	**Relative frequency (%)**
Apanteles sp. 1	**11.02**	**4.30**	**10.81**	**4.15**
Aphanogmus fijiensis	9.95	4.30	6.89	3.46
Argyrophylax sp.	0.00	0.00	1.35	0.69
Aspidobracon noyesi	0.54	0.78	3.65	2.53
Brachymeria excarinata	2.15	1.56	1.49	1.15
Brachymeria lasus	4.84	1.95	1.35	0.92
Bracon sp.	3.76	1.95	1.89	1.15
Callitula peethapada	0.54	0.78	1.35	1.15

Callitula travancorensis	5.65	3.13	4.86	3.46
Cardiochiles philippinensis	2.69	1.95	2.97	2.07
Charops bicolor	3.23	2.34	5.27	2.53
Cotesia flavipes	3.76	2.34	3.24	1.84
Cotesia ruficrus	2.15	1.56	5.27	3.69
Dolichogenidea sp.	1.08	1.17	1.62	1.38
Elasmus sp. 1	1.08	0.78	4.59	2.53
Elasmus sp. 2	0.00	0.00	2.43	1.38
Eurytoma sp. 1	6.45	2.34	3.51	1.84
Eurytoma sp. 2	4.30	2.34	0.54	0.46
Glyptapanteles sp.	0.00	0.00	2.43	1.61
Gonatopus flavifemur	2.69	1.56	2.70	1.38
Gryon sp.	2.96	2.34	4.32	2.53
Halidaia luteicornis	3.23	1.95	2.57	1.61
Ischnojoppa luteator	1.61	1.17	2.16	1.38
Isotima sp. 2	0.54	0.39	0.54	0.69
Macrocentrus sp.	0.00	0.00	0.54	0.46
Macroteleia sp.	4.84	3.13	4.46	2.53
Mesochorus sp.	6.45	3.13	2.43	1.38
Neanastatus sp. 1	1.08	0.78	1.62	1.15
Neanastatus sp. 2	0.00	0.00	0.68	0.69
Opius sp.	2.15	1.56	0.00	0.00
Panstenon sp.	0.00	0.00	1.62	0.92
Platyscelio sp.	1.08	0.78	3.92	2.30
Propicroscytus oryzae	6.45	3.52	4.73	2.07
Spathius sp.	0.54	0.78	0.00	0.00
Sympiesis sp.	1.61	1.17	2.97	1.84
Telenomus oryzae	8.33	4.30	6.35	2.76
Telenomus remus	**13.44**	**5.86**	**9.86**	**3.92**
Telenomus rowani	8.87	4.30	**8.11**	**3.69**
Telenomus sp. 2	0.00	0.00	1.89	1.38
Telenomus sp. 3	3.23	1.56	0.00	0.00
Temelucha sp.	1.08	0.78	1.35	0.92
Tetrastichus schoenobii	**10.48**	**4.30**	6.89	3.46
Tetrastichus sp. 1	2.69	1.56	2.70	2.07
Tetrastichus vayalicus	1.34	1.17	3.24	1.84
Trathala flavoorbitalis	3.23	1.95	2.43	1.38

Trichogramma chilonis	6.45	3.13	6.49	2.76
Trichogramma japonicum	8.33	4.69	8.24	3.92
Trichomalopsis apanteloctena	3.23	1.95	4.05	2.30
Trichomalopsis ovigastra	1.08	1.56	1.08	1.15
Trichomalopsis thekkadiensis	3.76	2.34	7.30	3.46
Tropobracon luteus	1.61	1.17	2.97	1.84
Xanthopimpla flavolineata	2.69	1.56	2.70	1.61
Xanthopimpla punctata	2.69	1.95	3.51	2.30

Table 2.46. Relative density and frequency of parasitoids in the midland laterite rice fields (2018). The bold digits represent significant results.

Parasitoid	**Dry season**		**Wet season**	
	Relative density (%)	**Relative frequency (%)**	**Relative Density (%)**	**Relative frequency (%)**
Apanteles sp. 1	**10.75**	**4.75**	**9.93**	**3.49**
Antrocephalus sp.	2.34	1.36	0.83	0.70
Aphanogmus fijiensis	3.74	2.37	**7.59**	**3.95**
Argyrophylax sp.	1.40	1.02	1.66	0.93
Aspidobracon noyesi	5.14	3.05	6.21	3.02
Brachymeria excarinata	2.80	1.36	1.93	1.16
Brachymeria lasus	7.01	4.07	6.07	2.79
Bracon sp.	1.64	1.69	4.14	2.56
Callitula peethapada	2.34	1.36	3.03	1.63
Callitula rugosa	1.17	1.36	5.38	3.49
Callitula travancorensis	7.24	3.39	1.66	0.93
Cardiochiles philippinensis	5.61	2.37	4.55	3.02
Charops bicolor	1.87	1.36	4.00	2.56
Cotesia flavipes	6.54	3.05	5.79	2.79
Cotesia ruficrus	5.61	2.37	5.38	3.49
Dolichogenidea sp.	0.00	0.00	0.00	0.00
Elasmus sp. 1	3.04	2.03	1.93	1.16
Elasmus sp. 2	2.34	1.69	6.21	3.26

Eurytoma sp. 1	3.50	2.03	3.03	1.86
Eurytoma sp. 2	2.34	1.02	0.00	0.00
Glyptapanteles sp.	0.70	0.68	0.00	0.00
Gonatopus flavifemur	3.27	1.36	5.38	2.33
Goniozus hanoiensis	0.47	0.34	0.83	0.70
Goniozus platycephalus	0.93	0.68	0.55	0.47
Gryon sp.	4.67	2.03	3.31	2.09
Halidaia luteicornis	3.27	1.36	4.55	2.33
Ischnojoppa luteator	0.93	0.68	0.00	0.00
Isotima sp. 2	2.34	1.36	0.55	0.47
Macrocentrus sp.	0.47	0.34	0.69	0.70
Macroteleia sp.	7.48	3.39	6.07	3.72
Mesochorus sp.	**7.71**	**4.07**	5.66	2.56
Neanastatus sp. 1	0.00	0.00	2.07	1.63
Neanastatus sp. 2	0.93	0.68	0.00	0.00
Opius sp.	0.00	0.00	0.55	0.47
Panstenon sp.	2.34	1.36	1.38	1.40
Platyscelio sp.	3.50	2.03	3.45	2.09
Propicroscytus oryzae	3.27	1.69	2.90	1.86
Scelio sp.	0.93	1.02	1.66	0.93
Spathius sp.	0.00	0.00	0.55	0.47
Sympiesis sp.	2.80	1.36	4.97	2.56
Telenomus oryzae	**8.18**	**4.75**	5.93	2.79
Telenomus remus	5.37	3.05	**7.31**	**3.49**
Telenomus rowani	4.21	2.37	1.93	1.40
Telenomus sp. 2	0.93	0.68	0.83	0.70
Telenomus sp. 3	1.40	0.68	0.55	0.47
Temelucha sp.	0.93	0.68	0.97	0.93
Tetrastichus schoenobii	6.54	3.73	4.97	3.49
Tetrastichus sp. 1	2.34	1.36	0.00	0.00
Tetrastichus vayalicus	0.47	0.34	0.00	0.00
Trathala flavoorbitalis	4.21	2.03	3.17	1.86
Trichogramma chilonis	2.34	1.02	3.45	2.09
Trichogramma japonicum	7.01	4.07	5.52	3.95
Trichomalopsis apanteloctena	4.91	3.05	3.72	2.56
Trichomalopsis	0.47	0.34	1.10	0.70

ovigastra				
Trichomalopsis thekkadiensis	5.84	2.37	6.21	2.79
Tropobracon luteus	2.80	1.36	1.66	1.16
Xanthopimpla flavolineata	1.40	0.68	0.97	0.93
Xanthopimpla punctata	3.27	1.36	2.48	1.63

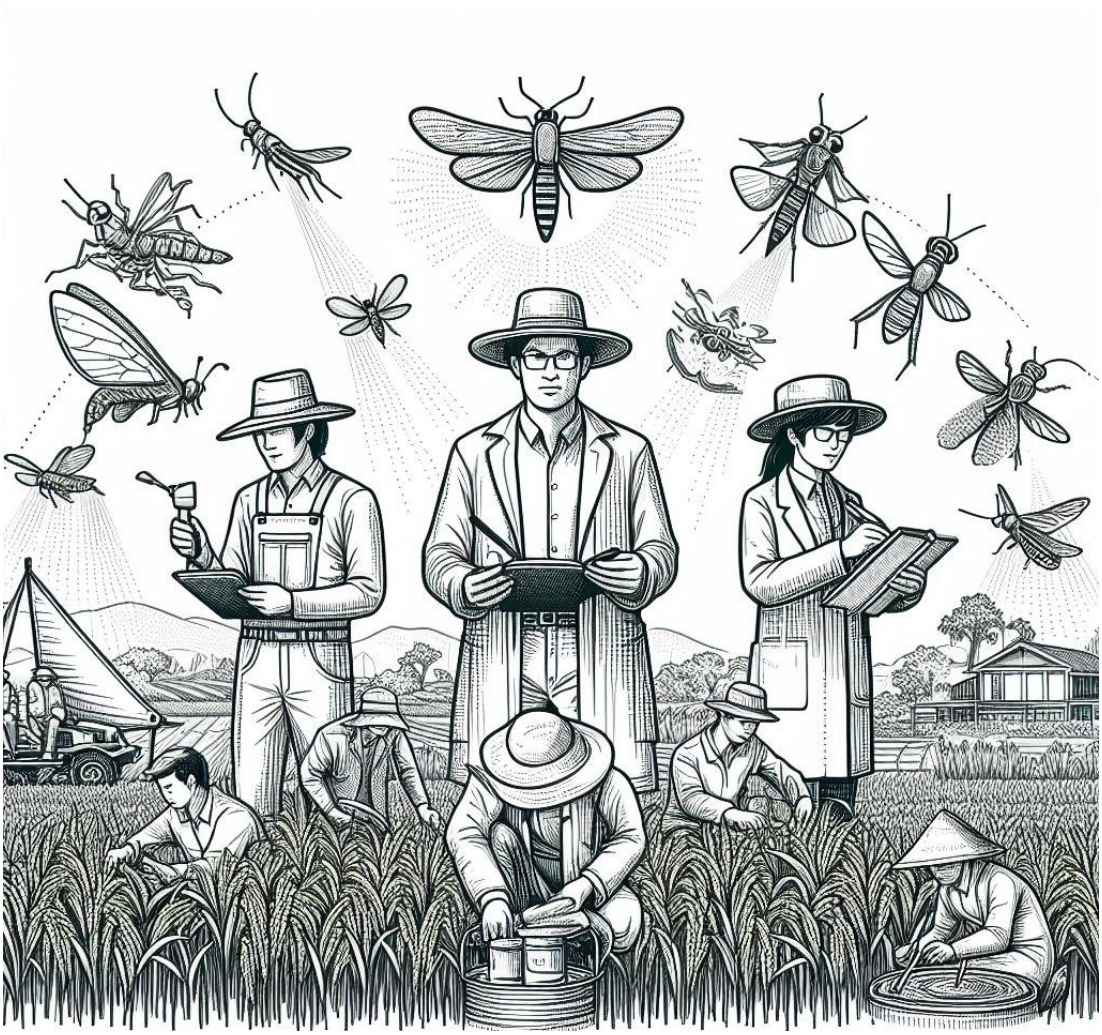
Table 2.47. Relative density and frequency of parasitoids in the midland laterite rice fields (2019). The bold digits represent significant results.

Parasitoid	**Dry season**		**Wet season**	
	Relative density (%)	**Relative frequency (%)**	**Relative Density (%)**	**Relative frequency (%)**
Apanteles sp. 1	**10.14**	**4.55**	**14.08**	**5.16**
Antrocephalus sp.	2.82	1.65	2.29	1.36
Aphanogmus fijiensis	**10.42**	**5.37**	7.69	4.35
Argyrophylax sp.	3.66	2.07	1.64	0.82
Aspidobracon noyesi	2.82	1.65	0.65	0.54
Brachymeria excarinata	0.56	0.83	1.64	1.09
Brachymeria lasus	8.45	4.96	7.53	3.26
Bracon sp.	1.69	0.83	2.13	1.90
Callitula peethapada	1.13	0.83	1.31	0.82
Callitula travancorensis	6.48	3.31	5.73	3.80
Cardiochiles philippinensis	5.63	3.31	5.07	3.26
Charops bicolor	0.85	1.24	4.26	2.45
Chorebus sp.	0.00	0.00	0.49	0.54
Cotesia flavipes	3.38	2.07	3.76	2.17
Cotesia ruficrus	**10.14**	**4.96**	**8.67**	**4.89**
Dolichogenidea sp.	1.69	1.24	3.44	1.90
Elasmus sp. 1	4.79	2.48	4.09	2.45
Elasmus sp. 2	0.00	0.00	2.29	1.09
Eurytoma sp. 1	4.51	2.07	4.42	1.90
Gonatopus flavifemur	5.92	2.89	7.04	3.53
Goniozus hanoiensis	0.00	0.00	1.64	1.09
Goniozus platycephalus	2.25	1.24	1.96	1.09
Gryon sp.	2.82	1.65	3.44	2.45
Halidaia luteicornis	4.51	2.48	5.24	2.45

Ischnojoppa luteator	0.28	0.41	0.65	0.82
Isotima sp. 2	0.00	0.00	0.16	0.27
Macrocentrus sp.	0.00	0.00	0.33	0.27
Macroteleia sp.	4.51	2.48	4.58	2.45
Mesochorus sp.	2.25	1.65	3.93	2.45
Neanastatus sp. 1	0.28	0.41	0.65	0.54
Platyscelio sp.	6.76	3.72	3.11	2.45
Propicroscytus oryzae	3.38	2.07	4.09	2.17
Scelio sp.	1.13	0.83	1.96	1.36
Sympiesis sp.	3.94	2.89	5.40	2.99
Telenomus oryzae	**10.14**	**4.55**	8.51	3.53
Telenomus remus	9.30	4.55	**12.27**	**4.89**
Telenomus sp. 2	0.56	0.41	1.96	1.36
Telenomus sp. 3			0.65	0.54
Temelucha sp.	1.69	0.83	2.29	1.63
Tetrastichus schoenobii	2.82	1.65	3.27	2.45
Tetrastichus sp. 1	2.82	1.24	1.80	1.63
Trathala flavoorbitalis	4.51	2.07	6.22	2.99
Trichogramma chilonis	3.94	2.07	6.38	3.53
Trichogramma japonicum	8.45	3.72	1.64	0.82
Trichomalopsis apanteloctena	4.51	2.07	0.65	0.54
Trichomalopsis ovigastra	1.69	1.24	0.00	0.00
Trichomalopsis thekkadiensis	9.86	5.37	4.58	2.45
Tropobracon hayati	0.00	0.00	0.98	0.82
Tropobracon luteus	3.38	1.65	1.64	1.09
Xanthopimpla flavolineata	1.41	1.24	2.62	1.63
Xanthopimpla punctata	2.25	1.24	0.33	0.54

CHAPTER 3

INSECT PESTS ASSOCIATED WITH THE TRADITIONAL RICE VARIETIES, AND THE SOCIO-ECOLOGICAL DIMENSIONS OF RICE PEST MANAGEMENT IN NORTH KERALA



Introduction

The rice crop has been grown in Kerala since 5000 BCE (Manilal, 1990). Crop selection has historically been influenced by topographical and climatic elements, soil type, irrigation availability, crop profitability, and agricultural policy (Guillerme et al., 2011; Kannan and Pushpangadan, 1990; Kumar, 2005; Narayanan, 2006). Latha et al. (2013) identified 623 distinct rice landraces in Kerala, with 532 accessions described and preserved in the National Gene Bank of the National Bureau of Plant Genetic Resources in New Delhi. The Kerala Agricultural University (KAU, 2018) conducted a study in November 2018 among 873 traditional rice farmers in the Wayanad area, and 105 rice varieties were identified. According to the Kerala Biodiversity Board, 55 indigenous rice varieties in Wayanad have been declared extinct out of over 160 varieties (PTI, 2012). Traditional rice varieties have recently been identified as a rich gene pool for features that may underlie modern rice varieties' ability to adapt to climate change (Thrupp, 2000; Zhu et al., 2003; Rekha et al., 2011). Sustainable farming necessitates thoroughly examining traditional rice cultivation because traditional crops have lower cultivation costs than modern high-yield varieties. They have evolved locally and survived for centuries, resulting in fewer pests and pathogens. They can also withstand climatic changes and offer significant medicinal, nutritional, and safety properties (Ashraf and Lokanadan, 2017; Krishnankutty et al., 2021).

Over centuries, Asian and African peasant farmers–primarily women–selected distinct varieties to fit local farming practices and demands, resulting in fragrant rice varieties. Aromatic rice cultivars with a broad spectrum of agro-ecological adaptations have arisen from this selection process (Singh, 2000). Aromatic rice varieties abound across the Indian subcontinent (Sarawgi and Bisne, 2007); the highest quality aromatic rice sells for much more money worldwide than high-quality non-aromatic rice (Singh, 2000).

Despite Wayanad's agro-climatic conditions, which are usually suitable for aromatic rice cultivation, mainly of white rice varieties such as "Gandhakasala" and

"Jeerakasala," aromatic rice production is still a challenge in Kerala. In addition, a few studies on fragrant rice cultivation in Wayanad have been conducted (George et al., 2006). Two Wayanad rice varieties, Jeerakasala and Gandhakasala, were included in the GI register among the several rice varieties of Kerala (Radhika et al., 2018).

Insects and diseases are significant constraints to rice production. One of the fundamental goals of rice improvement programs across the globe is to develop pest-resistant rice varieties (Khush and Virmani, 1985). Because cultivars with adequate resistance levels can be extensively cultivated, most rice crops are presently protected against severe insect damage and diseases. These cultivars were either produced by plant breeders or chosen over time by farmers (Bonman et al., 1992). Many traditional cultivars have been collected, and their valuable genes have been integrated into modern cultivars, restoring genetic diversity (Khush, 1995). There is a need for a rice production system based on effective resistant cultivars with extensive disease and insect pest resistance to achieve rice production sustainability in Asia (Leung et al., 2003). Even though most modern varieties have built-in disease resistance, genetic homogeneity predisposes the system to outbreaks. Diseases and insect pests may cause considerable crop losses under certain conditions (Khush, 2002). Any diversification approach has to start with functionally promising germplasm. Agronomic complementation may be achieved by combining genotypes with varied traits, adaptability, and resistance to various pests and diseases. The rice farming strategy of traditional and hybrid varieties in Yunnan has included planting two traditional varieties with various agronomic and nutritional properties. Due to years of natural and on-farm selection, traditional varieties are rich in valuable traits. The difficulty is determining or predicting the performance of these traditional varieties. Their agricultural complementarities allow them to be used with other enhanced germplasm (Leung et al., 2003).

Numerous rice varieties exhibit resilience against specific pests, yet some persist as vulnerable, causing diminished yields and financial strain for farmers. This overview delves into the susceptibilities of particular rice cultivars and delineates

strategies for effective pest management. Among the foremost threats to rice plants are stem borers. Certain hybrid rice varieties like Hira-2 and Krisan-2 demonstrate heightened resistance, whereas others like Aloron remain susceptible (Malek, 2010). While traditional rice varieties serve as bastions of biodiversity, cultural heritage, and natural adaptability, certain strains are not immune to pest pressures. For instance, employing an aromatic rice variant such as Pusa Basmati-1 as a trap crop has proven instrumental in halving damage to the primary crop. Notably, investigations have targeted the identification of pest-susceptible traditional rice varieties, particularly those vulnerable to yellow stem borers (YSBs) (Padmakumari et al., 2017). This study endeavors to illuminate the intricate dynamics surrounding pest susceptibility within traditional rice varieties, precisely pinpointing those susceptible to yellow stem borers.

Our world, which humans dominate, comprises two interconnected components: social and ecological systems (Chapin et al., 2010). Various entities including individuals, scientists, civil society groups, businesses, industries, and governments engage within the social system, leading to diverse human activities. Within the layers of the ecological system, there exists a hierarchy comprising numerous entities and processes such as evolution, population dynamics, community interactions, and ecosystem functions (Allen et al., 2014). Both systems have spatial and temporal scales that vary. Human activities influence ecological systems, affecting human behavior and generating a socio-ecological feedback loop. Future research in ecology will need a broad viewpoint to preserve the earth's ecosystem in a sustainable way (Chapin et al., 2010; Future Earth, 2013; Itoh et al., 2017). A map highlighting the interrelationships among components in the socio-ecological system is required to create a framework based on such a broad viewpoint. Due to the diversity of research and the gaps between society and science, the map has numerous lacunae. To move the map closer to completion, it is vital to identify and fill the significant gaps (Agrawal et al., 2007; Enoki et al., 2014; Nakadai, 2017).

Agricultural ecosystems are complex, dynamic systems influenced by physical, biological, and anthropogenic factors (e.g., Zimmerer and Young, 1998;

Vanbergen et al., 2020). Combining agricultural methods with their associated ecological processes and social factors is critical in encouraging resource-efficient, productive farming practices (Uphoff, 2002). Resource conservation strategies benefit the environment while also helping to enhance agricultural production, particularly for small-scale farmers in developing countries (Neuenschwander, 2004; Pretty et al., 2006). It has been challenging to identify these practices and guarantee their broad adoption in tropical small-scale agricultural systems (Uphoff, 2002). IPM was accepted as a core component in the overall crop protection program in accordance with the Indian government's National Agricultural Policy (NAP). Various efforts, including expansions of national IPM methods, have been attempted in recent decades to encourage these practices among Indian rice farmers. The package also specifies the economic threshold level (ETL) of insect pests or diseases for adopting suitable control measures on agricultural land (Prakash et al., 2014). Despite several attempts to promote Integrated Pest Management (IPM) in various subsistence farming systems, its adoption has been limited (Kogan, 1998; Matteson, 2000). These lower acceptance rates are remarkable, given that IPM initiatives address many difficulties that smallholders confront. Because certain IPM operations, such as insect biological control, are knowledge-based and localized, they may be limited in their application, especially by illiterate farmers operating in ecologically complicated ecosystems (Schmidt et al., 1997; Röling and Fliert, 1998; Morales, 2002). Researchers' alienation from the social and ecological elements of small-scale agricultural systems and their poor comprehension of the processes being developed at this interface accounts for the limited utilization of IPM (Matteson, 2000; Altieri, 2004). Interdisciplinary approaches to IPM are now frequently recommended (Heong et al., 2002; Price and Gurung, 2006). However, there is little evidence of the social and ecological impacts of adopting IPM in small-scale rice agricultural production systems.

Farmers' ecological observation and knowledge are critical to developing agro-ecological systems (Colding et al., 2003). Farmers' agricultural awareness varies by region and is influenced by the social context of farming (e.g., Bellon, 1995; Jansen, 1998). Small-scale farmers have a close relationship with their

agricultural environment, so they are knowledgeable about most of the processes involved (Altieri, 2004). Farmer awareness is often created via social activities, an essential aspect of rural life (Jansen, 1998; Berkes et al., 2008; Palis, 2006). In addition, social connections often influence farmers' choices (Röling and Wagemakers, 1998; Castillo et al., 2005). So, person-to-person information exchange may boost IPM diffusion rates (Palis et al., 2002; Rola et al., 2002). Farmer Field Schools (FFS) were established in all Kerala Panchayats under the Agriculture Technology Management Agency (ATMA) for sustainable agricultural development, including IPM (NITI Ayog, 2016). Farmers' perceptions of pests, available technology, and resources often influence better pest control approaches. Improving farmers' pest control decision-making requires examining and knowing their present methods, attitudes, and restrictions (Lim and Heong, 1984; Mumford and Norton, 1984; Norton and Heong, 1988). Knowledge of biological and ecological processes and socio-economic elements that drive decision-making is often required. Understanding farmers' perspectives might lead to better future pest control strategies and decision-making processes (Rapusas et al., 1997). Here, we look at how farmers make decisions about pest control in North Kerala's subsistent rice fields, how well they understand ecological processes, and how effectively they use biological control options and other pest management practices. We also look at how local diffusion networks and social connections influence farmers' understanding and adoption of pest management approaches.

So, this chapter addressed the questions of:

1. What are the existing traditional pest management practices?
2. How do rice varietal differences influence pest infestation?
3. Which aromatic traditional rice varieties are susceptible to rice yellow stem borer infestation?
4. What major factors affect rice pest management and farmers' perception of pest management?

5. How pest management practices differ between modern and traditional farming communities. How do socio-economic factors, agricultural institutions, social connectance, and opinion leadership affect farmers' choice of pest management?

6. What are the gaps in different pest management domains?

Review of literature

The importance of traditional rice varieties and their role in insect pest management

Traditional rice cultivars like Sali, Sashtika, and Nivara hold significance in Ayurvedic medicine, where they are utilized to alleviate conditions such as hemorrhoids and bleeding from piles. Additionally, Nivara rice finds application in the treatment of paralysis, psoriasis, rheumatoid arthritis, and cervical spondylitis (Priya et al., 2019). Traditional rice varieties have been acknowledged as a rich gene pool for qualities that may underlie current rice varieties' potential to adapt to climatic change in recent years, especially in light of climate change (Thrupp, 2000; Zhu et al., 2003; Rekha et al., 2011). Traditional rice cultivation requires a thorough investigation because it has lower cultivation expenditures than modern high-yield varieties; it has evolved natively and has survived for centuries, resulting in fewer pests and pathogens. They can also withstand climate fluctuations and offer significant medicinal, nutritional, and safety benefits (Ashraf and Lokanadan, 2017; Krishnankutty et al., 2021). Traditional rice varieties with distinctive attributes are used to treat various ailments; these varieties help to strengthen, energize, and revitalize the body by eliminating harmful metabolites, controlling blood pressure, improving the body's elements, and reducing skin problems and premature aging. Rakthasali, or red rice, is beneficial for fever and ulcers and improves eye, voice, fertility, and skin health (Kumar, 1988; Krishnamurthy, 1991; Ahuja et al., 2008; Bhat and Riar, 2015).

Furthermore, sali rice treats wounds and fractures (Kumar, 1988; Krishnamurthy, 1991; Ahuja et al., 2008; Bhat and Riar, 2015). Whole grain red rice is eaten because it is recognized in ayurvedic treatises as a nutritious diet and medicine. Danigora, Hindmauri, Karhani, Kalmdani, Muru, Punaigora, Ramdi,

Chattisgarh, and Jharkhand's nutrient-dense red rice cultivars gave energy and satiation throughout the day (Rahman et al., 2006; Ahuja et al., 2008). Red rice varieties are used to cure diarrhea, vomiting, fever, bleeding, chest discomfort, wounds, and burns, among other things (Hedge et al., 2013). While breastfeeding, tonic rice varieties from Karnataka, such as Kari Kagga and Atikaya, are utilized, and women are given Neelam Samba in Tamil Nadu (Arumugasamy et al., 2001). The Matali and Lal Dhan rice varieties treat blood pressure and fever in Himachal Pradesh. Leukorrhoea and abortion difficulties may be cured with Kafalya red rice from Himachal Pradesh and Uttar Pradesh (Ahuja et al., 2007).

In Tamil Nadu and Kerala, Seeraga Samba is a fragrant rice variety. Seeraga Samba rice, or "South Indian Basmati," is used to make biryani. Similarly, the fragrance was appreciated and valued for the rice varieties such as Ambemohar of Maharashtra, Badshah bhog of West Bengal and Odisha, Chakhao of Manipur, Dubraj of Madhya Pradesh, Gandha samba of Kerala, Jatu of the Kulu Valley, Joha of Assam, Kamod of Gujarat, Radhunipagla of West Bengal, Katrini and Kalanamak of Uttar Pradesh and Bihar, and Kalajir (Ahuja et al., 2007; Ahuja et al., 2008). Increased cultivation of these traditional varieties will inspire younger generations to consume healthy, creative rice-value-added goods. The use of traditional rice varieties as part of the cultural legacy has been widespread among practitioners of conventional medicine and other cultures. However, modern science must focus more on their functional impacts and health advantages. Due to a lack of data, there is an ignorance about the beneficial characteristics of traditional varieties. Studies on these traditional colored rice types need to taken up to optimize the health advantages and make this nutritious rice accessible to consumers as part of their daily diet (Priya et al., 2019).

Establishing pest-resistant rice cultivars is one of the primary aims of global rice development projects (Khush and Virmani, 1985). Most rice crops are now protected against severe insect damage and diseases because cultivars with sufficient resistance levels are widely grown. Either plant breeders created these cultivars, or farmers gradually selected them over time (Bonman et al., 1992). Modern cultivars'

genetic diversity has been restored by collecting several traditional cultivars and blending their important genes into them (Khush, 1995). We need a rice production system based on efficient resistant cultivars with wide disease and insect pest resistance to achieve rice production sustainability in Asia (Leung et al., 2003). Although most modern cultivars come with built-in disease resistance, genetic similarity makes them more vulnerable to pest outbreaks. Under certain circumstances, diseases and insect pests may result in significant crop losses (Khush, 2002). Each strategy for diversification must begin with functionally promising germplasm. When we refer to "excellent germplasm," we may not necessarily mean enhanced modern varieties. Instead, genotypes with distinct characteristics, tolerances, and resistances to various insects and diseases may be combined to accomplish agronomic conjugation. Yunnan has modified its initial growth plan for traditional and hybrid varieties to incorporate the cultivation of two traditional varieties with various agronomic and culinary traits. Traditional varieties are abundant in essential traits because they have undergone years of natural and on-farm selection. The challenge is figuring out or understanding how these traits work. They may be employed with other modified genotypes because of their agronomic synergy (Leung et al., 2003).

Important traditional rice varieties in North Kerala

Cultivating fragrant rice, mainly white rice varieties including "Gandhakasala" and "Jeerakasala," is often best suited to Wayanad's agroclimatic conditions, although the production is still challenging in Kerala. Also, further investigation must be done on growing fragrant rice in Wayanad (George et al., 2006). The Wayanad rice varieties Jeerakasala and Gandhakasala has been included in the Geological Indication (GI) database (Radhika et al., 2018). The names "Navara Rice," "Pokhali Rice," "Palakkadan Matta Rice," "Wayanad Jeerakasala Rice," and "Kaipad Rice" are among the 12 GIs for rice that has so far been registered in India. Moreover, Jeerakasala and Gandhakasala aromatic rice varieties were naturally farmed in Kerala's Wayanad District, mainly by the Kurichiyas tribe (Soam, 2005).

Yellow stem borer susceptible rice varieties

To date, limited research has been conducted on the susceptibility of rice varieties to the yellow stem borer (YSB). In India, susceptible rice cultivars are strategically sown along field borders prior to the main crop planting to lure stem borers, including the yellow stem borer (*Scirpophaga incertulas*) and the white stem borer (*Scirpophaga innotata*) (Sharma et al., 2019). Bt rice cultivars have been created and tested in fields in recent years, with outstanding success, particularly against crambid stem borers of the genus *Scirpophaga* (Khush, 2005). In the 1960s and 1970s, Islam (2001) documented the first use of trap crops in rice fields in China. They employed trap crops to manage stem borer populations by planting susceptible cultivars in small fields earlier than the main crop to reduce stem borer populations. Trap crops were also employed in Java in the 1960s to attract the adult white stem borer, *S. innotata* (Walker) (Lepidoptera: Crambidae) (Islam, 2001). To control *S. incertulas* on rice, the rice cultivar PB1 was used as a trap crop and a need-based pesticide treatment (Monocrotophos 36 SL at 500g a.i./ha) (Prasad et al., 2013).

There are few studies on insect pest susceptible traditional rice varieties and their use as a trap crop. Using the aromatic rice variety Pusa Basmati-1 as a trap crop for yellow stem borer, for example, revealed that the main crop accounted for half of the damage recorded, compared to the trap crop (Padmakumari et al., 2017).

Traditional farmer practices for rice pest management in India

Adivasis, or India's indigenous groups, are considered the first colonizers among tribal communities. They utilize various plant-based products, such as agricultural waste and animal products, to protect crops and stored products. Ash, red soil, cow dung, goat urine, farmyard manure, ragi (*Eleucine coracana*) husk, and many others, are readily accessible, biodegradable, harmless, and less persistent biopesticides. Fish (2 kg) and neem leaf extract (5 kg), table salt solution (4%), goat dung extract (7%), wood ash dusting (16 kg per acre), and *Adhatoda vasica* leaf extract mixed with cow dung were used to control pests in rice (Narayanasamy, 2006). A rope soaked in a kerosene-water mixture was swung in the field to control

the case worm (*Parapoynx stagnalis*). Tribal farmers in Manipur state utilize branches of *Vitex negundo* (Nishindra) to regulate the population of rice hispa (*Dicladispa armigera*). To deter the rice weevil (*Sitophilus oryzae*), leaves of *Dillenia indica* (Heigri) or *Cinnamom tamcala* were strewn over the harvested rice (Bhattacharjee and Ray, 2010). Tribal farmers in Jharkhand employ *Cleistanthes collines (Parsa) leaves* to suppress the yellow stem borer, case worm, and gall fly. *Vitex negundo* leaves were placed over stored grains to suppress rice bugs (Lakra et al., 2010). On evaluating pest and disease control strategies used by farmers in Northeastern states such as Manipur, Sikkim, and Meghalaya, Chhetry and Balbahari (2009) found that *Artemisia vulgaris*, *Croton caudatus*, *Munromia wallichi*, and *Adhatoda vasica* leaves were spread in the field to keep pests away.

Rice stem borer caterpillars were attracted to branches of *Cymbopogon khasiana* and *Saccharum spantaneum* planted in paddy fields. The residue/spent wine (pomance), primarily made from millet, was poured near the source of irrigation water in paddy fields, inhibiting paddy pests and diseases such as leaf folders and rice blasts. Oak tree bark was applied near the irrigation water's opening source to limit the occurrence of brown planthoppers. Perches were placed in the paddy field to attract carnivorous birds such as egrets to feast on leaf folders, stem borer, and grasshopper larvae. Furthermore, bird excrement acts as a fumigant, inhibiting disease development. In the highlands of Manipur, upland rice is frequently grown. The prevalent fungal diseases include blast and brown leaf spots, while the common rice pests are brown planthopper (BPH), white-backed planthopper, case worm gall midge, and stem borer. Uprooting the afflicted sections, mechanical management, mixed cropping, and cultivating broad-leaved medicinal plants such as *Clerodendron serratum* (as a repellent), *Artemisia vulgaris*, *Euphotorium odorum*, *Eucalyptus* sp., and *Meriandra bengalienis* were all beneficial in managing rice pests and diseases. Talukdar et al. (2012) studied the traditional knowledge used in Boro rice farming in Assam and discovered 57 cultural practices, 33 of which were for pest and disease control. One example of traditional knowledge is erecting bamboo poles with branches in the rice nursery and the main field as perches for birds to destroy pests in the paddy. Swaying branches

of thorny plants such as *Zizyphyus* sp. cause injuries to larvae and insects in the field. In the field, twigs of *Vitex negundo* were put in the standing water. Rice pests such as hispa and case worms are suppressed due to their repellent activity. Boro rice seedlings were tall and had to be pruned to a specified height before being transplanted, resulting in the removal of yellow stem borer egg mass (FAO, 2009).

According to Deka et al. (2006), cow dung slurry was sprayed over the field to suppress thrips in the paddy. Farmers put new bamboo branches as perches in the rice field to attract birds. The adult moth of the rice stem borer (*Scirpophaga incertulas*) and swarming caterpillars are eaten by birds. Hydrocyanic acid, found in the sap of bamboo leaves, functions as a larvicide. Farmers use the mechanical control of capturing adult insects or caterpillars from the field and eliminating them by burning them as one of their local methods for minimizing the frequency of insect pests. The burned ash is dispersed to deter insect infestations. Prior to the onset of monsoon rains, a traditional ritual known as Hareli is observed in the North region of Jharkhand's Bastar district to address pest issues. The Halba and Gond tribes attribute significance to this ritual, believing it expresses gratitude and acknowledgment to God and nature. It is believed that by performing this ritual, they invite rain to their fields from God and nature, thereby curbing pest population growth. During the ritual, green leaves and tender shrubs of various plant species such as Salphi, Bhelwa (*Semicarpus anacardium* L. F.), Tendu (*Diospryos melanoxylon* Roxb.), Chhedawari, Stawar (*Asparagus recemosus* Willd.), and Karla (*Momordica charantia*) are scattered randomly in the paddy fields along with prayers. Ethnobotanists suggest that many indigenous trees, herbs, and shrubs possess properties like antifungal, antibacterial, and anti-insecticidal attributes, which act as deterrents against insect pests. When these components are blended with water, they form an environmentally beneficial defensive mechanism that protects paddy crops. This approach is ecologically sound, economically feasible, socially acceptable, and consistent with the socio-cultural backgrounds of the farmers (Deka et al., 2006). In addition to crop rotation, crop residue burning, floods, drainage, and optimum planting date selection, these were used in rice-based agricultural systems (Singh and Rai, 2007). Rice producers in the Jeypore tract of

Odisha use hymns chanted by the Desari (astrologer/medicine man of the tribal village) and twigs of *Cleistanthes colloines* (Karada) and Kendu to keep pests out of their crops (Mishra, 2009). In drought-prone districts of Karnataka, the Karibanta ritual is performed to fight against agricultural pests and diseases. This ceremony is frequently conducted when the rains begin to fall, the grain ears develop, or the crops are vulnerable to insect infestation. A platform is built to protect the crop from bad weather and ensure a successful harvest. A large branch of the Karibanta tree (*Dalbergia paniculata*) with leaves is attached to the center of the platform, and five types of grains symbolizing widely farmed crops (ragi, horse gram, little millet, rice, and field bean) are tied to the pole with a turmeric-soaked cloth. In front of the platform, intact stones were laid. Villagers pray to the Karibanta branch for protection against pests and diseases such as millet leaf blasts and leaf spots (Ramaprasad et al., 2003).

CIKS performed paddy tests to investigate the impact of Vrkshayurveda recipes on germination, insect and disease resistance, and plant growth stimulation. The Vrkshayurvedic preparations were chosen based on the cost of ingredients, simplicity of preparation, reproducibility, and work needed in experimentation. Kullkar, a traditional paddy variety, was used in field experiments (Balasubramanian et al., 2002). Traditional varieties such as Kappasamba, Muttakar, Thooyamalli, Sempalai, and Kallimadayan were classified as tolerant or resistant to pests and diseases by Vijayalakshmi et al. (2004) in their book on organic rice agriculture. Burrows are packed with smoke from burning rice husks and native red chilies to keep the threat of rodents at bay (Chhetry and Balbahari, 2009). The exploding rat growth in rice fields has posed a serious concern for organic farmers in Sirkazhi, Tamil Nadu. The adoption of better pest control strategies is often influenced by farmers' views of pests, available technology, and resources. Improving farmers' pest control decision-making requires examining and knowing their present methods, attitudes, and challenges (Lim and Heong, 1984; Mumford and Norton, 1984; Norton and Heong, 1988). Greater knowledge of biological and ecological processes and socio-economic elements that drive decision-making is often required. Understanding farmers' perspectives might lead to better future pest control strategies and decision-making processes (Rapusas et al., 1997).

Importance of farmer perception in the rice pest management

In recent decades (Fujisaka, 1993), agricultural academics have increasingly addressed farmers' viewpoints in posing and answering problem-solving questions. Building on indigenous technological knowledge and farmer participation in trials are examples of farmer-oriented initiatives. Farmers' expertise is included in research formulation, farmers are involved in innovation testing, and research undertaken in developed countries and worldwide research institutes is supplemented (Fujisaka, 1993). The scientific approach underpins modern agriculture. On the other hand, in traditional farming farmers use a different strategy based on their knowledge and interactions in their environment (Brosius et al., 1989; Nazarea-Sandoval and Rhoades, 1994). Ethno-science examines indigenous peoples' culturally relevant domains to develop folk taxonomies, hierarchies, and paradigms.

Farming is an activity carried out by indigenous peoples based on their ethno-science, or their knowledge of what they regard as important variables and interactions in their environment and how they might be integrated to produce a useful whole (Nazarea-Sandoval, 1991; Nazarea-Sandoval and Rhoades, 1994). According to Gurung (2003), farmers see pests as either a threat to productivity or as fellow beings with a legitimate claim to a fair share. The cognized model, a subjective norm, refers to farmers' understanding of their environment and opinions. Farmers observe nature through a lens of ideas, knowledge, and purpose, and they behave based on their perceptions of nature rather than the natural structure (Brosius et al., 1989). However, people act on nature, and nature acts on them. Therefore, their perceptions of nature govern interactions between farmers and the environment. These pictures or conceptualizations play a role in determining how farmers assess, decide, and act in their everyday lives when faced with various situations and options. The cognized model represents farmers' perceptions of the world. Exploring farmers' views and knowledge enables us to clarify terminology to apply the right language and framework (Gurung, 2003). All of these features aid communication and are hence essential for IPM initiatives. Ethno-agronomy is a subclass of cognized agronomy that considers farmers' indigenous knowledge (Nazarea-Sandoval, 1991). The cognized model is always engaged with the operational world in which farmers absorb, dismiss, and refine experiences and

perceptions. Simultaneously, it influences discrimination and exploration, which direct decisions and conduct.It is imperative for researchers to grasp the ethno-agronomic practices of indigenous farmers. This understanding is crucial for devising and advocating agricultural development initiatives that are more likely to resonate with farmers and be regarded seriously within their decision-making processes (Peshin et al., 2009). Farmers' and scientists' knowledge varies greatly, although both offer advantages and disadvantages. Farmer expertise was useful in the past, but it could not keep up with the rapidly changing rice technologies that came with modern rice (Litsinger et al., 2009).

Gurung (2003) found that most Tharu farmers still see their knowledge and methods as inferior to those advocated by outsiders. Farmer surveys should come before practical research to guarantee that it is not just an academic exercise. Traditional farming, on the other hand, is often based on agriculture that has been practiced for many generations (Thurston, 1998). Since man started cultivating crops 10,000 years ago, the amount of information collected would be significant. Traditional and subsistence farming still account for 60% of the world's cultivated land (Altieri, 1984). Small farmers have created intricate agricultural methods that have enabled them to satisfy their subsistence requirements for millennia without relying on machinery or modern chemical inputs, even under harsh environmental circumstances (marginal soils, drought-or flood-prone locations, and limited resources). To the dismay of experts, most of the knowledge about indigenous and traditional agriculture is anecdotal rather than experimental. According to Altieri (1984), an assessment committee in Latin America found that no substantial new technical packages capable of producing greater net returns could be delivered to the peasant farmers after three projects. More holistic methods were required, necessitating a better understanding of current agricultural techniques, why they were done, and what criteria a new technology must meet to be accepted. Researchers have often neglected fundamental aspects of low-input peasant farming, including the willingness to take risks, labor constraints, symbiotic crop combinations, and dietary requirements, all of which influence farmers' decision-making criteria and resource allocation (Peshin et al., 2009). In assessing the adoption of new production methods, cultural values, attitudes, beliefs, and behavioral patterns frequently exert as much or more influence than economic

considerations within primitive and peasant communities (Thurston, 1990). Before efficient, established approaches may be distributed to other farmers, researchers must address challenges in the context of farmers' systems. IPM begins with an understanding of traditional agricultural systems and uses them as a foundation for development, including the application of successful traditional practices (Matteson et al., 1984).

The issue is that entomologists often dismiss traditional pest management methods small farmers use. However, contrary to popular belief, not all traditional activities are ecologically beneficial. Cultural behaviors such as pouring kerosene and whale oil into paddy water, using nicotine and chilli pepper sprays, using arsenic-laced chemicals, and using fire, for example, are all environmentally damaging (Litsinger, 1994). The core concept revolves around providing farmers with appropriate technology, which stems from agro-ecological investigations discerning the factors that shape traditional farming systems. For instance, in Batangas, Philippines, farmers adopt methods like direct sowing in furrows and utilize the same equipment for inter-row cultivation to manage weeds (known as lithao) in dryland rice cultivation (Peshin et al., 2009). During the first month of rice growth, farmers use a spike-toothed box harrow at 45 degrees to the rice rows to uproot nutsedge while pulling off some rice plants. This happens many times until the canopy is completely covered. Farmers will continue to use their old strategy until a better way to manage nutsedge is discovered. The beusani technique for grassy weed management was developed for rainfed wetland rice in Southeast Asia (Fujisaka, 1991). A traditional farm management assessment, in which labor shortages, small farm size, lack of current technology, or poor land productivity are singled out as the key limitations, cannot be used to analyze small farm systems (Altieri, 1984). As a result, an effective analysis must consider the farmers' management standards and production objectives, particularly in terms of risk. Farm diversification has historically been used to mitigate risk, with goods from one business typically being used to produce another. Understanding farmers' views of pests, current management techniques, and the costs and efficiency of control measures are the first steps in developing effective IPM strategies tailored to their needs (Adesina et al., 1994). However, there are compelling grounds for basing IPM

techniques on farmers' indigenous knowledge. One should do so with the understanding that there will certainly be gaps in their knowledge, particularly in biology and ecology. As a result, research should concentrate on both elements. To improve farmers' management abilities, social and biological experts should collaborate closely to comprehend their perspectives. The degree of relevant site-specific adaptive research undertaken to discover the optimal match of modern and traditional agronomic and pest management approaches determines the adoption rate of IPM technologies by farmers who have embraced modern varieties and agro-inputs (Reichelderfer and Bottrell, 1985).

Researchers' awareness of farmers' existing activities and the foundations for them is a vital component of the information necessary to carry out this process, which is effectively carried out by a characterization of the stakeholders. Farmers often lack proper training and misapply inputs, such as injudicious pesticide use, compromising the agricultural system's stability (Heong et al., 2002). The first reason for examining traditional farmers' agricultural operations is that certain traditional farming systems have unique histories of research management and conservation (Thurston, 1990). Traditional farming techniques and systems are not always effective, but they have persisted for millennia and should be studied. Secondly, in countries with a surplus of labor, chronic unemployment, and a scarcity of jobs in urban areas, the labor-intensive nature of many traditional activities may hold significant appeal, tempting people away from farms (Peshin et al., 2009). Traditional technologies have modest capital and technical skill requirements, and their adoption frequently requires little restructuring of traditional cultures. Although there is evidence that traditional farmers experiment and innovate, the most successful traditional agricultural practices were most likely established experimentally through millennia of trial and error, natural selection, and careful observation (Thurston, 1990). Traditional systems, particularly in the tropics, typically mirror natural ecosystems, which seem robust, resilient, and efficient due to their variety. Traditional farmers may focus more on achieving consistent, predictable yields than the highest ones. They avoid risks that may lead to starvation, the loss of their land, and the necessity of laboring in low-paying

employment in a crowded metropolis. Traditional agricultural techniques are often successful and long-lasting disease control methods. Most of today's agricultural practices and cultivars stem from traditional agricultural procedures and cultivars (landraces), underscoring their substantial influence on modern agriculture (Peshin et al., 2009). As agriculture modernizes, traditional farmers' agricultural systems, including pest management measures, are at risk of being lost and such traditions should be researched and preserved. Farmers carry out adaptive research simply by farming, a feature that planners and scientists overlook (Fujisaka et al., 1991).

The field school training method's motto is "farmer as an expert" (Matteson et al., 1994). Farmers are expert survivalists, but their abilities and expertise have yet to be completely appreciated. Many farmers' contributions to modern agricultural practices and research agendas are unclear (Thurston, 1990). Many ideas that begin in the thoughts and fields of farmers and are subsequently observed by researchers become entrenched as recommendations. According to Bentley (1992a), scientists will never be able to produce all the technology that farmers need for various agricultural situations. Anthropologists may assist farmers in doing some of their adaptation research. Their assistance lies in discerning existing knowledge among farmers and scientists, then imparting necessary information to farmers in a manner consistent with their existing knowledge base (Peshin et al., 2009). This seems to be a simple and apparent task, yet it may take years to complete. Farmers who participate in farmer-led research are more likely to conduct their trials. Some farmers are scientists who should be identified and encouraged to participate in farmer training programs. If correctly organized, farmer-led research may cover a huge gap in fine-tuning technologies to local conditions. According to Ooi (1996), Indonesian farmers, depending on information generated by other farmers, recreate foreign ideas and actively incorporate them into complicated agricultural choices. Hence, it is crucial to establish mechanisms enabling farmers to address their queries. Experimentation is inherent to the agricultural practices of farmers, thus facilitating their learning process (Peshin et al., 2009). Working with farmers is challenging for researchers, but not the other way around (Bentley, 1994). Farmers continuously experiment, and certain technologies, such as modern varieties, spread naturally, but IPM is unusual. Farmers and scientists have distinct approaches: farmers attempt one item at a time in the field, while scientists split the area into tiny

plots. Mastering farmer participatory research is a time-consuming endeavor. Moreover, filling knowledge gaps among farmers and enabling them to develop technology played a pivotal role in the successful development of practical IPM systems (e.g., Peshin et al., 2009).

There is often a socio-economic divide between university-educated scholars and low-income farmers. Bentley and Andrews (1991) found that IRRI's on-farm research initiatives partially reduced social distance because researchers resided in the local town and work crews and personnel were recruited locally. Consequently, the personnel consisted of descendants from the intended farmer demographic, serving as intermediaries between researchers and farmers. It is the farmers themselves who adopt and integrate technology into their practices, possessing a wealth of traditional knowledge alongside externally sourced information, complemented by their own experiential insights (Peshin et al., 2009). Because many pest issues are new, traditional knowledge is limited. Farmers must rely on their ingenuity and abilities to survive. Due to a lack of resources, farmers explore by planting novel types in tiny plots, but their ability to experiment and create is restricted. Their ability to observe is limited due to a lack of microscopes and a rudimentary understanding of science. Critics of the technological package approach to agricultural development claim that previous programs lacked understanding and appreciation of the ecological and socio-economic context in which they operated, excluded small farmers as collaborators and beneficiaries and promoted inappropriate technology ineffectively (Matteson et al., 1984). Thus, there is a reevaluation underway regarding the advancement and dissemination of enhanced agricultural technologies tailored for small-scale farmers in tropical regions (Peshin et al., 2009). Researchers and farmers working together can ensure that new technologies are acceptable (Watson and Mahrita, 1985). Farmers' knowledge studies should identify gaps in their knowledge and significant areas where environmental scientists and extension agents might help farmers (Adesina et al., 1994). Social and environmental scientists must collaborate closely to understand farmers' perceptions of pests, improve their pest detection and control abilities, and uncover farm-level adoption barriers. Because there is a significant gap between what farmers know and what they should know, research integrating communication sciences and focusing on the delivery end of the science-practice continuum is

critical (Heong and Escalada, 1997). A necessary aspect involves synthesizing and distilling information, including heuristics that farmers can experiment with. Essential to effecting required alterations comprehends the decision-making processes of farmers. Frequently, IPM initiatives are implemented without a comprehensive understanding of farmers' objectives, requirements, and constraints (Peshin et al., 2009).

Matteson et al. (1994) state that many farmers are too brainwashed to consider the prospect of not applying pesticides. They justify the insecticide's lack of obvious impact on the crop by assuming losses would have been greater if it had not been used. Pesticides have generated an established, unthinking, and reliant mentality among farmers in developing nations. Because of ignorance, fear, and apathy, that mentality exists. Following four decades of demonstrations and commercial promotions, certain farmers exhibit excessive confidence in their understanding of pesticide application and its efficacy (Peshin et al., 2009). Simple prescriptions for preventive pesticide treatments look appealing and undemanding compared to IPM due to a misunderstanding of costs and benefits. Most of the pesticide is used as a prophylactic measure and is thus unneeded. Extension programs are built on understanding the causes of these misconceptions. Farmers have changed numerous suggested crop production strategies, including input utilization (seeding and pesticide rates) and application frequency, which is informative to adaptive researchers. The current crop management combines modern scientific farming (new semi-dwarf seeds and bought chemicals) and traditional methods (Goodell, 1984). The results show farmers have incorporated new agricultural technologies into their production systems in less than two decades. Farmers and researchers agreed upon only eight of the twenty-one crop production and pest control strategies reviewed. Divergent approaches to technology development account for most of the disparities (Litsinger, 1993). Most suggested techniques were created via duplicated trials on research stations, with the findings being evaluated on farmers' fields. This reductionist technique featured a series of studies in which just one or two factors were examined under stress-free situations while the other activities were maintained fixed (optimal land preparation, water management, and fertilizer application were provided; frequent, high-dose pesticide applications eliminated pests). Conversely, farmers developed holistic techniques

via trial and error against dynamic stressors. The holistic approach to experimentation permits the representation of myriad interactions by modifying one or many methods among those that make up a crop production system. On the other hand, the reductionist approach is intended to avoid undesirable interactions. The trial scales are also considerably different, resulting in extrapolation mistakes. The contributions of academics' (reductionist/scientific) and farmers' (holistic/traditional) methods are considerable, but the optimal match is extremely area-specific. Farmers, in general, need aid in comprehending scientific farming, whereas researchers want farmer input on the efficacy of new technology in agricultural settings. It is sometimes just as vital to discover what farmers do not know as to learn what they do know (Bentley and Andrews, 1991), since this will help determine what to concentrate on in training programs.

Farmer perception of arthropod pests and natural enemies

Arthropod pests

As per Price (2001), Filipino farmers demonstrated the capability to recognize 26 insect species within rice fields. Through triad testing and arthropod description games, diverse categorization systems among farmers were elicited. Arthropods were initially categorized into hazardous and harmless groups by Tagalog farmers in the Philippines' Laguna area. Crop damage was one of the consequences (Nazarea-Sandoval, 1991). Farmers differentiated between arthropods harmful to plants, discerning between those that decreased yield and those that did not—an essential distinction not universally acknowledged among indigenous populations. Farmers classified beneficial arthropods that were foodstuffs, pollinators, or toys among the innocuous group, while unwanted arthropods were split into those that produced noise or generated odor. The Tharu of Nepal identified 80 arthropods and classified them as kiraa, or living creatures that are hazardous directly or indirectly, such as reptiles and tigers (Gurung, 2003). Surprisingly, according to Gurung (2003), Tharu farmers identify more insects than they can name. Small-scale farmers are engaged as workers by bigger farmers in Chhattisgarh, Nepal (Gurung, 2003), and the Philippines (Nazarea-Sandoval, 1991). Rather than the large-scale farmers, they are more acquainted with the prevalent insect pests and can point out which ones cause harm.

Farmers in the Philippines do not discriminate between the two species (Litsinger et al., 1980), although farmers in India do (bhura maho and safed maho). Furthermore, the misunderstanding of two pests may lead to incorrect conclusions. Farmers in Malaysia's Muda irrigation scheme mistook white-backed planthopper symptoms for tungro virus sickness (Heong, 1984). As a result, Farmers who mistakenly perceive white-backed planthopper damage as tungro may initiate a multi-spray program aimed at eradicating a disease vector. However, white-backed planthoppers, which do not transmit disease, typically require only a single application for management. Even though there are at least three species with diverse moth morphologies, all stemborer species in the Philippines and India are given the same name (Litsinger et al., 1980). In India, stemborers are referred to as tana chedak, which means "stemborer." As a conceptual framework, farmers' perceptions of pests are impacted by their observations, knowledge, and experience in the field, as well as their contacts with extension workers, researchers, the media, their observations and experiences, chemical sales agents, family, and other farmers (Rubia et al., 1996). Farmers' awareness of pests is unequal over the globe, according to Bentley (1992b), but it follows a similar trend. According to his assertion, farmers' categorization of pests could be classified based on two axes: (i) the ease of observing pest occurrences and (ii) the significance attributed to them according to farmers' perceptions, which may not necessarily align with those of scientists. As a result, farmers are more likely to detect species of arthropods that are both significant and easily observable. On the other hand, important and difficult-to-observe arthropods tended to be little known. There are many more factors to consider. According to several scholars, folk classifications of arthropods are based on their cultural significance and physical characteristics. In Honduras, Bentley and Rodriguez (2001) created a folk classification based on the physical appearance of various arthropod groupings, such as Linnaean orders and major families, as well as cultural importance. Large species ("impossible to ignore and thus named"), sociable, colorful, plentiful, loud, and diurnal species were the easiest to notice. Recognition was based on being a nuisance to crops, people, or animals, hazardous or painful, and utilized for games, toys, decorations, rituals, or art. Farmers are often old, and their vision is typically poor (Matteson et al., 1994). This ability should be considered when farmers are trained to monitor tiny pests. Because of their tiny size and unnoticeableness, most farmers underestimate insect infestations.

Only 45% of farmers in the Ivory Coast could identify several rice insect pests found in dryland and wetland habitats (Adesina et al., 1994). Surprisingly, a large percentage of Malaysian farmers (38%) could not identify a single rice insect pest (Heong, 1984). Although stemborers were the most common insect pest observed, some farmers thought the "wrath of the moon caused dead hearts." Other significant pests cited were the rice bug *Leptocorisa* and black bugs (*Scotinophara* spp.), both cryptic. While weeding, farmers would come upon black beetles. Rice bug names might be translated as "foul odor" or "beetle." Some people mistakenly assumed every worm discovered in the field was a stemborer. Farmers in Central Luzon, Philippines, used to believe that a second rice crop sown in the dry season would perish due to hot, dry wind, but this was stemborer damage (Cendaña and Calora, 1967). In many cases, larger pests are readily identified by most farmers. For instance, in Leyte, the rice bug holds considerable significance due to its size and its tendency to feed on grains (Heong et al., 1992). Various large insects in Leyte are given specific names, such as greenhorned caterpillars, armyworms, and leaf folders, although most are generally referred to as "worms." The greenhorned caterpillar was notably present in the rice plains of Chhattisgarh; however, it was only discernible by women tasked with weeding, not by farmers themselves, thus remaining nameless. In Batangas, the term "leaf folder" (uod sa dahon) denotes a "leaf worm" (Litsinger et al., 1980). Filipino farmers demonstrate greater familiarity with mobile insects like leafhoppers and moths. Approximately six leafhopper species are known to feed on rice and typically graze on its leaves, often exhibiting a tendency to flee when disturbed. The assumption that *Nisia atrovenosa*, a leafhopper species observed feeding on nutsedge (*Cyperus rotundus*) found in rice bunds, is a rice pest from individual observations. However, research indicates that it does not feed on rice (dela-Cruz and Litsinger, 1986). In rice fields, there are also many moths, which are readily flushed away by people passing by. When farmers in the Philippines observe moths flushed from the foliage, they spray (Bandong et al., 2002). To the trained eye, coloration, markings, and flying behavior can be used to identify any moth species. These abilities have only been gained by farmers who have been taught. *Hydrellia philippina*, the rice whorl maggot fly, is less common and neglected in rainfed rice fields (Litsinger et al., 1980).

The damage signs of certain pests are more well-known than the insects themselves. Stem borers, for example, are more well-known for causing white ear heads. During a survey spanning three provinces, each inhabited by distinct ethnic groups, only one province (Batangas) possessed a term for "dead heart," while all three regions had a designation for "whiteheads" (Litsinger et al., 1980). Although other variables like drought and diseases may create whiteheads, Filipino farmers have seen larvae digging at the base of the wilted panicle. The least visible insects (whorl maggots, defoliators, and leaf folders) were tracked by observing the damage they caused (Matteson et al., 1994). According to Malaysian farmers, leaf folders cause specific harm (Heong, 1984). Farmers detected scarification damage at the ends of leaves after the larvae had fled and caused significant harm. Many Filipino farmers were astonished to see leaf folder larvae in their webbed shelters. Now and then, a spider will be discovered among the folded leaves. In the rice bowl of Central Luzon in the Philippines, weekly Integrated Pest Management (IPM) training sessions were held, featuring field tours to assess the pest scenario. Farmers seemed to be more attentive than scientists in several circumstances, according to Goodell et al. (1982), resident anthropologists. The symptoms of rice leaf injury, known as aksep in Tagalog, were documented in detail. The manifestation of larval feeding injury differs depending on the species. Farmers, delving deeper into characterizing the damage symptoms than researchers, identified them as a blend of injuries caused by rice whorl maggots, rice caseworms, semi-loopers, hairy caterpillars, and occasionally the uncommon armyworm or cutworm. These symptoms include discolored (whitish) dots and streaks, holes in leaves, cleanly cut leaf tips resembling scissor cuts, scrapings leaving only the veins intact, and chewed portions transitioning to brownish colorations. Damage symptoms developed over time and changed color from white to light green to yellowish to brownish as they aged. The percentages of each species' feeding would vary from field to field, causing these symptoms to change. The same insect complex was also found in the rain-fed rice regions of the Philippines, although infection there is considerably lower.

Farmers still do not know what whorl maggots are, but they have a word for the damage, similar to aksep but less detailed. Early seasons pest damage signs, such as whorl maggot, caseworm, and defoliators, are referred to as "gutalo" by

Pangasinan farmers (Litsinger et al., 1980). In Chhattisgarh, India, farmers use the term "chitri banki" to describe a complex of pests including caseworms, leaf folders, and the unexpected white-backed planthopper. These pests cause a yellowish appearance during the vegetative stage. In Koronadal, irrigated rice farmers of the Ilocano and Ilongo ethnic groups refer to these hoppers as "ulmog" or "waya-waya." Stemborers are specifically named "tamasok" in Ilongo, causing damage characterized by dead hearts (aglabbaga ti uggot or malaya ang ugbos) or whiteheads (agpuraw ti unga or magaputi ang bunga), as they bore into the stem and consume the plant's shoot. The armyworm is named in Ilocano Arabic and is notorious for slicing the panicle. It also consumes leaves, but panicle damage is the most visible and concerning for farmers. The whorl maggot, identified as a small fly (kusim) or langaw na gagmay, is known to cause white leaves. Mole crickets, referred to as ararawan or mara-mara, are recognized for cutting, feeding, and scraping roots. The green-horned caterpillar, characterized as a "worm with a horn" in Ilocano, stands out due to its large and unusual appearance. Rice seed bugs, known as dangaw or tiyangaw, emit a foul stench (nalapod nga dangaw) according to Ilocanos and are believed by farmers to cause empty grains by sucking out the grain's liquid. Untrained farmers in a dryland region of Claveria, Mindanao, Philippines, accurately described common rice insect pests such as bugs and stemborers (Fujisaka et al., 1989). From panicle initiation through the milk stage, the rice bug suckles the milk material from the grain. The grains that have been damaged are empty, dark, half-filled, and bitter. The damage could be as serious as 50% from the vegetative stage through panicle initiation and stemborer infestation. Because larvae pierce the nodes near the plant root and devour the soft section within, the larval stage is the most devastating. Panicles become white as empty grains accumulate. Damage is estimated to be in the range of 20–40 percent. Farmers in the Ivory Coast, on the other hand, cannot link whitehead damage to stemborers (Adesina et al., 1994).

Insects exhibit morphological differences between male and female adults, as well as between juvenile stages. Planthoppers and leafhoppers appear pale during their youth, with approximately five intermediate stages displaying diverse patterns before reaching maturity, where adults exhibit significant color variations. In the context of the Development of Integrated Pest Management Programs for Rice in

Asia, 153 farmers showed minimal interest in egg stages. Field encounters with farmers revealed that the majority of Filipino farmers do not recognize the egg masses of stemborers (Litsinger et al., 1980). According to Goodell et al. (1982), the metamorphosis perplexed farmers in C. Luzon. She found that just knowing the name of a pest does not guarantee that farmers will be able to identify all phases of the pest in the field. The beautiful colors and elegant flight of butterflies were sources of attraction in Laguna. The larva was an immature butterfly stage, but none of the informants knew it (Nazarea-Sandoval, 1991). Caterpillars mate and lay eggs, according to the farmers in Tharu of Nepal, since they are observed together in one location and are not recognized as butterfly immatures. Insects of all sizes are thought to be the offspring of bigger insects. Farmers in Chhattisgarh thought that dung flies evolved from smaller flies and eventually expanded to the size seen today. Insects grow spontaneously from the soil or fertilizer, according to many Honduran farmers who were unaware of fundamental insect biology facts (Bentley, 1989). Farmers also saw a rise in pest numbers after using pesticides, but they did not know why. Insecticide resistance and insect revival are tough topics for farmers to understand since they contradict previous knowledge about pesticides. Farmers in Honduras believe that pesticide corporations inject new bugs into each container (Bentley, 1989). Because of their limited understanding, farmers saw no alternatives to pesticides. Honduran farmers thought storage weevils spawned spontaneously from the grain (Bentley, 1989). Farmers, with their limited understanding of insect reproduction and ecology, predominantly subscribe to the concept of spontaneous creation to explain insect origin. They often observe that the stomach contents of caterpillars are green, resembling the color of plants, leading them to believe that the insects originate directly from the plants. However, although many Filipino farmers who were randomly questioned were aware of the stages of insect metamorphosis, a considerable percentage was not.

Only a few people can tell the difference between a caterpillar and an adult moth, and even fewer are aware of the egg stage. In Laguna (Nazarea-Sandoval, 1991), the immatures and the blood-feeding adults of mosquitoes were not connected by the farmers in the area. The Mayans did not associate butterflies with caterpillars, only recognizing several leaf-feeding phases and ignoring the adult stage (Nazarea-Sandoval, 1991). This demonstrates that folk science is mostly

applied, with just a few exceptions. In a rigorous study conducted by an anthropologist in Kalimantan, farmers demonstrated a thorough understanding of pest ecology, claiming that rice bugs are more prevalent when a long dry season precedes the wet planting season (Watson and Mahrita, 1985). Both nymphs and adults suck immature grain, according to farmers. According to them, mole crickets like damp but not flooded ground and are less severe in years when the rainy season suddenly arrives. Despite Gurung's (2003) finding, Nepalese farmers accurately concluded that rice bugs in wooded regions stayed dormant between rice seasons. Based on the accounts of the majority of Javanese farmers, white stemborer moths are believed to migrate into their fields from various sources, including neighboring fields (34%), surrounding villages (19%), or districts (23%) (Rubia et al.1996). Additional remarks indicated that they might be transported by wind or attracted to light, originate from affected plants, carry over from the previous season, be influenced by weather or seasons, or simply be unknown (3%). According to the researchers, rice farmers were unaware that white stemborer moves through the stubble during the dry season. Although some Filipino farmers know that caseworm larvae float inside rolls of leaves on water, most pests arrive by aerial movement (Bandong et al., 2002).

Natural enemies

Rapusas et al. (1997) interpreted "natural enemies" as "arthropods in the field that did not harm rice," which does not communicate the concept of a "natural enemy." Many arthropods live in rice fields, yet they do not eat rice or eliminate pests. Farmers named spiders, damselflies, dragonflies, praying mantises, ground beetles, frogs, and wasps in response to the concept. Farmers, for the most part, have observed insect pests ensnared in spider webs or are aware of dragonflies preying on insects while in flight. In the study conducted by van de Fliert and Matteson (1990), it was revealed that 69% of Sri Lankan farmers surveyed demonstrated the ability to recognize natural predators of rice. Among the identified creatures, birds were the most frequently mentioned at 73%, followed by dragonflies at 23%. Nonetheless, a notable deficiency in comprehension regarding predatory and parasitic arthropods was observed, as indicated by Brown and Marten (1986). Conversely, in Guimba, all 30 interviewed farmers exhibited knowledge of natural adversaries against insect pests.

Notably, spiders emerged as the most commonly recognized natural enemy, cited by 80% of respondents, with frogs following closely at 70%. Farmers expressed the belief that the application of insecticides in agricultural fields would have deleterious effects on all groups except birds, with a mere 3% indicating potential harm to avian populations. The majority of farmers (93%) listed natural enemies in the rainfed wetland region of Solana in the Cagayan Valley, with spiders (87%) topping the list, followed by frogs (53%), and birds (18%) (Litsinger et al., 1982). Only 70% of farmers could identify natural enemies such as birds, spiders, frogs, and dragonflies in three rainfed rice locations (Litsinger et al., 1980). Among Claveria dryland rice growers, 85% identified various natural enemies, including birds (72% of farmers), cats (22%), chickens (20%), reptiles (12%), spiders (8%), frogs (3%), and dogs (2%). Insecticides are said to poison 60% of people. Many farmers in the Philippines are unaware that pesticides might harm beneficial arthropods (Palis, 1998). Bentley's (1992a) experience with Honduran farmers was strikingly comparable to research in the Philippines and other Asian countries. Except for the bigger and more visible kinds, most farmers are ignorant of the presence of natural enemies. According to a farmer, weevils the size of a pinhead "generate" in stored grain and then develop to full size. However, the insect found by the farmer was a parasitoid wasp, which is beneficial to humans. When asked to name useful creatures, Honduran farmers named spiders and various vertebrates, such as birds and toads. Spiders have been caught in their webs, catching moths (Bentley, 1989). Untrained farmers in the Philippines reply by listing bigger predators such as birds, spiders, frogs, and dragonflies (Litsinger et al., 1980). Nobody had heard of parasitoids or other tiny predators (Nazarea-Sandoval, 1991).

According to a survey, 60% of C. Luzon farmers think that all insects are dangerous, even though one-third of them acknowledge the existence of helpful insects (Palis, 1998). Gurung (2003) found that Tharu farmers in Nepal could not identify parasitoids or beneficial predators. Farmers spray on insects in the field whether or not they are pests. Some people spray or pull down spider webs when they observe dragonflies (Matteson et al., 1994). Farmers in Laos identified spiders, dragonflies, beetles, and wasps (Rapusas et al., 1997), but farmers in Cambodia sprayed beneficial insects when they observed them in their crops (Jahn et al., 1997). Many Chhattisgarhi farmers questioned whether spiders, dragonflies, and bees were

all considered pests. Farmers in Laguna, Philippines, claimed that "rice spiders" spun thick cobwebs that caused the foliage to adhere together and fold back, causing the plant to turn yellow; hence, they were considered pests (Nazarea-Sandoval, 1991). The farmers observed the egg mass cocoon or shelter that the spider created. Natural enemies are less well-known among farmers, although certain bigger ones, such as web-building spiders and dragonflies, are well-known. Certain arthropods were almost unknown to the Laguna farmers as pest-control agents. Farmers mistakenly believe ladybeetles are pests because they witness adults and larvae feasting on pollen (they do not realize that rice self-fertilizes inside the blossom; therefore, pollen is unnecessary) (Bandong et al., 2002). Conversely, farmers have observed these insects consuming grains and express concerns over potential impacts on seed set. Given that a majority of Filipino farmers engage in vegetable cultivation, they are also familiar with phytophagous ladybeetles such as *Epilachna philippinensis*, contributing to the perception that ladybeetles may be detrimental to rice plants. Ladybeetles were also a nuisance for farmers in Leyte (Heong et al., 1992). In a study by Heong et al. (1994), farmers in Leyte targeted ladybeetles for 5% of pesticide treatments. In the Philippines, a similar outcome happens. Furthermore, most rice farmers in Hunan, China, consider ladybird beetle pests (Shao-Shi et al., 1997). Farmers in the Philippines identified spiders, dragonflies, and grasshoppers as friendly in another study based on a questionnaire by C. Luzon (Rola and Pingali, 1993). Grasshoppers were most likely mistaken for katydids. *Conocephalus* is an omnivore that attacks growing rice grains (Barrion and Litsinger, 1987).

According to Rola et al. (1988), Filipino farmers could not distinguish between pests and natural enemies, with 31% believing that all arthropods in a rice field were pests. During a training session that involved gathering with a sweep net, comparable farmers in C. Luzon responded intriguingly. The collection was put in a huge, translucent plastic bag filled with buzzing insects, which boiled over. When the field owner saw this, he quickly returned to get his sprayer and began treating his field. Most Honduran farmers, meanwhile, believe that all insects in a crop are hazardous (Bentley, 1989). Many farmers, according to polls, have this perspective (Heong et al., 2002). In Kenya, farmers are advised to burn stalks because they carry stemborer larvae. However, straw is utilized as fodder in the dry season (75% of

respondents), fuel (48%), and granary building (56 percent) (Conelly, 1987). Despite the encouragement for early planting, a significant portion of farmers (60%) expressed the belief that pests, notably birds, were more prevalent rather than reduced as a consequence of the earlier planting practice. Early planting is unsafe because of erratic precipitation, and replanting is too expensive. Many people believe insect damage is only a problem during drought and heavy rain washing away insects. For land preparation, farmers want early rain. In these cases, it will not be easy to persuade farmers to accept IPM. An anthropologist heavily criticized suggestions for rice insect pest cultural control based on early plowing after harvest to destroy stemborers and synchronous sowing as unacceptable to farmers (Goodell et al., 1982).

Farmer rice pest management strategies

Traditional systems use a lot of physical and mechanical control mechanisms (Litsinger, 1994). Most of the methods precede the invention of modern pesticides and are labor-intensive and useful. Many of these approaches may be employed inexpensively in certain regions of Asia where field labor is still predominant (Litsinger et al., 2009). According to a study (Litsinger et al., 1980), 84% of farmers in the Philippines' rain-fed regions reported having insect pests on at least one crop. On 38% of Laguna farms, Marciano et al. (1981) discovered hand-picked stemborer larvae and moths. In certain rice-growing communities in Cambodia, grasshoppers and crickets are caught by hand and with nets during communal hunts. This approach looks quite successful (Jahn et al., 2007), with the bonus of utilizing them as fried human food, livestock feed, or compost. Crab trapping seems to be effective in Thailand and Laos, but it is not effective in Cambodia.

Crabs are considered a severe danger because they burrow through rice bunds, causing water loss. Farmers reported storing rice seeds in airtight clay containers (kothi) coated with a specific mud from Pakistan (multani miti) that possesses water-sealing capabilities, according to a PRA survey in Chhattisgarh, India (IGAU, 1997). Although this method effectively prevents stored product pests from infesting the grains, it does not eliminate those entering the field. Consequently, it is imperative to air-dry the grains and regularly expose them to sunlight. Rice farmers are experts in developing cultural control strategies that are

also part of regular crop care and harm insect pests, making them dual-purpose (Litsinger, 1994). The Guimba, an irrigated location in the C. Luzon rice bowl, has the most thorough inventory of rice producers' cultural management measures. Eight cultural control approaches were proposed by the 30 farmers surveyed. Roughing up or removing infected plants was the most commonly used method for reducing tungro spread (83%), while one farmer reported eliminating stemborer-infested whiteheads as a mechanical control method. According to Marciano et al. (1981), the rouge virus infected 94% of the plants and whiteheads in Laguna. The former is a suggested practice, while the latter would have a negligible impact. Regarding insect and vertebrate pest management, 60% of Guimba farmers reported planting in tandem with their neighbors, which is a sustainable approach. Instead of eliminating the pest, 37% of farmers correctly identified the positive benefit of diluting the harm among neighbors. Field drainage is a suggested management method for brown planthoppers and caseworms (Litsinger, 1994). Plowing shortly after harvest is suggested to control weeds and stemborers, and it also has the additional advantage of eliminating rat habitat. The practice of plowing under stubble is favored over burning due to its provision of increased organic matter and fertility to the crop. The survey indicated that farmers were cognizant of and employed diverse non-pesticide control methods. Few farmers in Claveria reported cultural control measures such as recall and persuasion. Farmers did not usually correlate cultural management measures with pest control since these procedures are familiar with crop husbandry. When questioned, 97% of farmers claimed that early planting averted seedling maggot damage, confirmed by field studies (Litsinger et al., 2003).

Upon encouragement, farmers embraced a multitude of cultural management practices at notably high frequencies. These methods included field cleaning, crop rotation, early stubble plowing, synchronous planting, roguing, overseeding, stubble burning, and wider spacing. According to the KAP study (Litsinger et al., 1980), 6% of farmers in the Philippines used at least one cultural control strategy. The following were the most common rice-integrated pest management programs developed in Asia: 1. the rate of sowing has been accelerated (58%); 2. rice intercropping in dryland (46%); 3. crop rotation (34% of the time); and 4. planting time (approximately 22 percent). In irrigated Laguna, Marciano et al. (1981)

discovered that 86% of farmers employed water management to control pathogens and insect pests, 70% claimed weed eradication controlled some insects, and 38% said minimal fertilizer use reduced insects and diseases. Water management is also employed for pest control in rainfed rice nations (Fujisaka, 1990). To combat rice seedling maggots, farmers flood their fields. During the monsoon season, wetland farms get additional water from reservoirs. In the early phases of development, sandy soils are usually devoid of standing water, enabling the Atherigona flies to spread. Farmers drain rice fields to combat the rice hispa, *Dicladispa armigera*. However, it was also discovered that numerous pests lacked control measures. To manage mole crickets, Kalimantan farmers segregate seedbeds from the previous year's seedbeds and transplant them into flooded areas (Watson and Mahrita, 1985). These methods seem to be both practical and successful. Ninety-three percent of Sri Lankan farmers surveyed were aware of synchronized planting among neighbors as a cultural control practiceNonetheless, they asserted that adherence to this planting schedule was mandatory due to water delivery through turnout areas, which necessitated simultaneous planting by all farmers within a turnout. Fifty-eight percent of respondents stated that they adjusted their planting times to either early or late in order to mitigate pest pressures. However, this simultaneously violates the synchronous planting requirement, according to van de Fliert and Matteson (1990). In practice, synchronous planting serves to mitigate pest infestations across all fields, while adjusting planting timing offers an alternative strategy when pest populations are naturally low for specific reasons during certain seasons. Combining early and synchronous planting would enhance pest control efficacy by synergizing these two approaches. Most farmers know the advantages of synchronous planting since planting out of step invites insect pests, rodents, and birds (Litsinger et al., 1980).

Many Sri Lankan farmers recognized that healthier crops were more pest-tolerant (i.e., resistant) (van de Fliert and Matteson, 1990). Rainfed farmers in Sri Lanka adopt a risk-averse approach by endeavoring to minimize expenses through reducing urea application from one-third to one-half, thereby implementing a cost-cutting measure. At the same time, such farmers should not waste their limited resources on prophylactic pesticide uses, and if funds were available, they should increase fertilizer rates to increase tolerance (Litsinger, 1993). Farmers in Cambodia

stated they used fertilizer to treat insect-infested regions (Jahn et al., 1997). To manage rice bugs in Kalimantan, producers burn weeds in adjacent non-cultivated regions and time plantings, so crops do not develop in March (Watson and Mahrita, 1985). Other crops in rice-based farming systems have evolved notable cultural management strategies. A week before harvest, legumes such as cowpea and mungbean were manually seeded into the rice. By treading on the seeds, harvesters effectively embed them into the moist soil, eliminating the necessity for additional inputs to achieve a harvest yield of up to 1 t/ha. According to research (Litsinger and Ruhendi, 1984), the remaining rice stubble left after harvest was shown to protect the legume crop from aphids, leafhoppers, bean flies, and thrips. Intercropping systems such as maize and legumes, which attract predators such as spiders to remain in legumes such as groundnuts at the bottom of maize plants, have been discovered by IRRI (Litsinger and Moody, 1976). However, studies have shown that the legume's or wide-spacing control of maize borer was only successful in plots of 50 m2 or less (Litsinger et al., 1991). As previously said, genetic resistance can only defend against 3–4 insect pest species. Hence, IPM encourages farmers to depend on natural management and build tolerance through sound agronomic methods. Insecticides should only be used after all other options have failed since they disturb beneficial insects, which are nature's gift to farmers. A wealth of scientific data supports natural enemies' positive influence on rice insect pest control (Ooi and Shepard, 1994). Wetland rice, more than other crops, possesses intrinsic stability mechanisms, according to Way and Heong (1994).

To effectively manage their crop, rice producers must understand many interconnected principles related to biological management. Insecticide misuse may result in secondary pest outbreaks and resurgences. Natural enemies, which are more effective than most pesticides, must thus be controlled to increase their numbers. Except for spiders and certain vertebrates like birds and toads, most natural enemies were unknown to Honduran campesinos, according to Bentley (1992a). This is the same finding as the prior surveys, which were largely conducted in Asia. Because biological management was deemed too complex for small-scale farmers, it was assumed that they would be unable to grasp it (Glass and Thurston, 1978). Many farmers see natural enemies as pests, and spiders' simple appearance would prompt some to spray. As a result, IPM training programs make a concerted attempt to

change this mindset. Farmers get enthralled when learning about the range of natural enemies in rice fields and what pests they feed on in farmer field school extension courses (Ooi, 1996). Farmers are urged to build "insect zoos" in which natural enemies are kept in captivity alongside rice insects to test whether pest populations drop. Farmers establish traditional procedures using local resources, which vary from cultural controls in that the techniques employed are not standard crop husbandry approaches. Traditional knowledge may be idealized or overrated, according to Thurston (1990), but dismissing it or ignoring it is a mistake. According to Watson and Mahrita (1985), indigenous crop protection measures are often site-specific, and there are no procedures for all pests or in all places. Farmers control pests in an ecological framework, considering interactions among crop varieties, soil, water, and socio-economic issues. Farmers' reactions are also varied and dynamic, depending on where they farm and how seasonal and long-term their agricultural environment is. Most farmers' methods focus on reducing rather than eradicating agricultural pests and achieving good yields. Many farmers' small-scale approach contrasts sharply with academics' and institutions' regional focus and single crop or pest focus. Litsinger (1994) lists several traditional rice insect pest management strategies. Farmers growing in marginal and risky settings use more traditional approaches than those producing in irrigated regions with modern rice and agrochemical applications.

According to Watson and Mahrita (1985), in swampy rice habitats, Kalimantan farmers used fires to smoke away rice pests and disseminate the leaves of various aromatic plants (lemon grass) as control techniques. Some farmers use table salt to keep mole crickets away. Smudging is a method of repelling rice bugs used by 22% of dryland rice producers in Claveria. A botanical pesticide, a rice bug bait, a handmade tobacco extract spray, and burning animal fats as a general repellent for a smaller percentage of people. In Asia, decaying protein-based rice insect bait is widely used (Dresner, 1958). Even in irrigated areas where modern rice farming is practiced, 19% of Laguna farmers stated they used baits and smudging to manage rice bugs (Marciano et al., 1981). Farmers in Cambodia utilized salt to ward off pests in general, ashes to ward off caseworms, and smoke and bait to ward off rice bugs (Jahn et al., 1997). Various traditional customs emerged due to the research in three rain-fed districts of the Philippines. At least one traditional

approach was used by 60% of farmers (Litsinger et al., 1980). Fire ash serves as a protective barrier around migratory armyworm larvae or can be applied to crop plants to deter sucking insect pests. The suffocation of rice bugs and other insect pests is achieved through smoke exposure. Additionally, rock salt is introduced into the soil to combat white grubs in dryland rice cultivation. Other pests are killed with kerosene and soap. 15% of Laguna farmers admitted to spraying hoppers with soap (Marciano et al., 1981). With 13 plant species identified, plant components were prevalent (Litsinger et al., 1980). *Gliricidia* branches planted in paddy are used by 72 percent of Pangasinan farmers to control caseworm and whorl maggots. In Batangas, a significant proportion of farmers (28%) utilize branches from *Cordia* sp., a renowned medicinal plant, for pest management purposes, either as a repellent or as an attractant (trap crop) in their crops. *Gliricidia sepium*, recognized for its termite-resistant properties, finds common usage as an orchid stand in domestic yards. Additionally, eleven additional plant species are comprehensively delineated for their pest management attributes. Guided inquiries revealed that 65% of dryland rice farmers in Claveria incorporate plants in various capacities as botanical pesticides. There were six plant species found, with bamboo being the most common. Laotian farmers cited *Gliricidia* and neem as botanical insecticides (Rapusas, 1997).

For caseworms and other pests, 44% of farmers in Laguna indicated they employed some form of botanical pesticide (Marciano et al., 1981). Farmers in the Ivory Coast practiced various plant-based traditional customs, such as tossing lemons into the field to repel flies or spreading palm leaves on the field (Adesina et al., 1994). In Chhattisgarh, farmers, expressing dissatisfaction with the efficacy of pesticides against chitari banki, turn to herbal insecticides sourced from the indigenous forest flora. They have reported the practice of collecting karra tree branches laden with leaves and strategically placing them in the affected areas of the farm, utilizing approximately 15 kg of leaves per 0.2 hectares (Litsinger et al., 1980). The medicinal herb bantulasa is another botanical. Dried flowers from the Mahuawa tree can be used to absorb the kerosene used to make chitari banki. Also suggested were neem trees. Guimba farmers also employed a variety of botanicals by soaking the leaves in paddy water in caseworm-infested regions. Botanical pesticides like neem have become popular, but these are seed extracts rather than

leaf extracts. Farmers employ neem leaves to safeguard grain in restricted containers because their odor repels pests. The impact of putting them in the field would be substantially diluted, and they tested *Gliricidia* leaves against caseworm in the lab and found no positive results. With doubtful results, rock salt was used to combat tungro and caseworm. The intended result might be achieved using cooking oil as a sticker and kerosene for caseworm control. Kerosene has been utilized as a film in paddy water across rice-growing Asia (Litsinger, 1994) and would undoubtedly be harmful. It is also phytotoxic to rice, so after a few days, it must be drained. In the past, rice growers in the Ivory Coast used hot water to kill termites (Adesina et al., 1994). Farmers drain rice fields and use a botanical substance to combat rice hispa (Fujisaka, 1990). In Cambodia (Jahn et al., 2007), botanical repellants keep crabs at bay. In a study of Guimba, C. Luzon, farmers discovered a remarkably significant number of traditional treatments recognized by local farmers in an irrigated rice bowl where pesticides are the standard insect pest management approach. Among the surveyed respondents, the most prominent method, employed by 40%, involves utilizing detergent either as a pesticide sticker or directly applying it to rice fields for the management of caseworm and tungro infestations.

According to Goodell (1984), some farmers spray a washing detergent in Zaragoza, a neighboring location. Moore et al. (1979) tested a variety of detergents against garden pests in the United States, and soap products are now widely used by amateur gardeners for aphid management. A distinct boundary delineates between the knowledge and beliefs held by farmers. What may appear to us as mere belief or superstition often constitutes a significant portion of farmers' understanding. A credence embedded in a local belief system is more valuable than information because of the offered supernatural sanction. To the untrained eye, what seems to be a ridiculous scenario is a reality for many farmers. This is especially true if pests are associated with local mythologies, such as the Tharu tribe in Nepal, whose deity created the rice bug to destroy rice and needs ritual management (Gurung, 2003). Farmers use rituals to help them adapt to the ecological limits they have faced for centuries (Prill-Brett, 1986). Rituals underscore the connection between the human social realm, the material world, and the supernatural domain. They provide solace, affording indigenous communities the perception that they possess a degree of influence over the unforeseen natural occurrences that frequently challenge them.

Rituals also help to shape people's long-term interactions with their surroundings. To guarantee a successful crop, ritual sacrifices are performed. A rest day is proclaimed for the chickens' bile sacs, and a rest day is proclaimed if the prognosis is unfavorable. In Bontoc, the allocation of rest days is deemed indispensable for mitigating insect-induced harm to the rice crop. Delays in harvesting, as each phase of the agricultural cycle is synchronized across the community, afford pests, particularly rice insects, the opportunity to concentrate on late harvests and inflict considerable damage. Superstition is characterized as an irrational belief, conduct, or ceremonial practice stemming from a lack of understanding of natural principles or reliance on magic or chance. It often encompasses the supernatural realm and is frequently accompanied by rituals. In Uttar Pradesh, India, women engage in the practice of plowing semi-naked fields with the intention of inducing rainfall. These methods entail the capacity of specific actions or the avoidance of certain behaviors to mitigate or divert adverse effects (caused by pests) or enhance positive outcomes (such as the disappearance of pests).

Farmers use superstitious pest management methods, which are typically based on pagan religious observances that have been passed down through generations. These procedures are used as a last choice when farmers believe they have no other alternatives and are powerless in the face of serious output losses from pests they cannot manage, which might cause significant suffering for their families. Farmers grow desperate, and they have few choices other than superstitious rituals. Even though they worship more popular faiths simultaneously, they summon the powers of spirits from old pagan religions. They sometimes enlist the help of local shamen. When asked whether they used superstitious behaviors, 53% of farmers in Claveria, the Philippines' richest source of such practices, agreed to do so. These activities are described in a hierarchical order, starting with procedures comparable to conventional practices and progressing to higher levels of irrationality, culminating in occult rituals. Many of the procedures listed by farmers imply that they are aware of them, but it is difficult to say how many are followed regularly. Some rice farmers in the Philippines avoid planting during full moons, as is customary in many civilizations throughout the globe (Litsinger et al., 1980). The vast majority of people (72%) believe that they plant according to the phases of the moon. However, the methods perceived to result in fewer pests exhibited

inconsistency, encompassing various practices such as planting during the third quarter (12%), full moon (10%), 3, 5, or 7 days after the full moon (ranging from 2% to 7%), last to the first quarter (9%), or even during a new moon (9%). Additionally, 2% of alternative strategies rely on chance. Farmers also refrain from planting on days associated with superstitions, such as those with the number seven or on relatives' death anniversaries. In Guimba, 13% of farmers avoid planting on unfavorable days, including Tuesdays and Fridays or Mondays in August. Some 24% of Laguna farmers believe in unfortunate planting days, believing that if a crop is planted, it will be infested by pests (Marciano et al., 1981). The following list of customs is based on religious beliefs. The first is from Litsinger et al. (1980), who had a priest bless the seed for planting on Holy Saturday to ensure a successful yield. Farmers offer prayers as they circle the field to persuade a higher power to save their produce. In Laguna, 21% of rice farmers pray to avert insect issues (Marciano et al., 1981). In Sri Lanka, a Buddhist nation, religion had little impact on farmers' pest management techniques, with 15% of Buddhist respondents stating that they do not enjoy killing animals, including pests, for religious reasons (van de Fliert and Matteson, 1990).

The Tharu people of Nepal are Buddhists, but they think they can only kill kiraa (Gurung, 2003). In Claveria, a significant majority of farmers (97%) reported using spraying as a method to safeguard their crops from pests. Alternative practices include conducting rituals such as planting a bamboo pole at each corner of the field, although this ceremony can only be performed by one individual. This action is believed to deter insect pests from infesting the field (Litsinger et al., 2009). These rituals encompass a diverse array of activities, such as capturing a mating pair of insects and releasing them to intimidate other insect pests. Another method involves riding a horse or carabao around the rice field at dusk to discourage rice bugs, or encircling the field with a flaming bamboo pole. Two rice bugs are collected, painted red and black, and taken to a village in Nepal, where farmers perform rice bug worship before releasing them outside the community to keep them away from their crops (Gurung, 2003). Food offerings and the lighting of candles accompany this rite. Others use shamen or other local religious figures to communicate with the ghosts. A variety of indigenous techniques, such as contacting traditional herbalists, were mentioned by African farmers (Adesina et al., 1994). The majority of farmers,

on the other hand, do it themselves. Others use spirits to keep pests at bay. In the Philippines' rainy regions, 39% of farmers donate food (rice, eggs, and chicken) to please the spirits and protect their crops from pests (Litsinger et al., 2009). They taught that spirits would retaliate if the farmer became angry while dealing with pests. To pacify ghosts, trial plantings are also conducted. Farmers in Malaysia are used to sowing their crops and abandoning them to the mercy of "invisible diseases." It is equally common for people to be unaware of harm caused by a causative agent. This is due partly to superstition's cultural component and a lack of information (Heong, 1984). Farmers in Claveria have amassed a massive collection of rituals and magical activities. Because no two were taught in precisely the same manner, there is a lot of variation in how each is done. According to reports, 57% of farmers use at least one of these methods. Rituals such as offerings and ceremonies are employed to compel pests to avoid or vacate the fields. Some rituals involve the utilization of animal blood, while others entail the burning of specific plants. Local shamans frequently conduct these ceremonies. Animal pests (insects and rodents) are the most common targets, with plant diseases receiving minimal attention. This is likely due to their lack of eyesight, which prevents them from seeing the results of the ceremonies.

Black magic, or witchcraft, the final type of superstitious tradition, involves animal sacrifice and voodoo-like rituals to "scare" pests away from rice fields. The line between magic and black magic is blurred in many of them since pieces of both sorts are mixed. Torture, ritualized slaughter, and threats of murder are some black magic tactics employed to terrify the bugs. For instance, rice bugs are intimidated through methods such as brandishing needles or subjecting them to torment. Many of these techniques bear resemblance to Haitian voodoo rituals and are conducted clandestinely. In Chhattisgarh, farmers are acquainted with numerous superstitious practices aimed at controlling rice caseworms (chitri banki). One method involves collecting leaves from a tree near a site of suicide and planting them in the field as the initial step in pest management. The second method entails a person born with only one leg consuming puffed rice, creating a crunching noise while circumnavigating an infested field and loudly proclaiming that they are consuming caseworms to frighten them away (Litsinger et al., 2009). Fujisaka et al. (1989) collected data on several similar superstitious behaviors from the same Claveria

location and inquired whether farmers had similar procedures for other crops. Farmers found amusement in the reaction, attributing it to the perception that crops other than rice are cultivated with the aid of fertilizers and pesticides, whereas rice holds sacred significance. Rice is intertwined with life in many Asian nations, spawning a slew of religious traditions (De Datta, 1981). Many farmers in the Philippines, mostly Catholic, nonetheless believe in ancient faiths that existed before the advent of the Spanish. Farmers were asked about their beliefs in the existence of a rice god and whether they made offerings to make it rain and ensure a healthy harvest in the baseline survey for IRRI's Constraints Program in Yogyakarta, Indonesia (Widodo et al., 1979). The majority of farmers questioned traditional notions and favored modern inputs. Litsinger et al. (1982) pointed out that ethnicity might explain disparities in adopting superstitious behavior across areas. Ilocano and Ilongo farmers in North Luzon, the Visayas, and Mindanao use fewer practices and are less superstitious than Tagalog farmers in the more developed C. Luzon and Batangas (Litsinger et al., 1980; Fujisaka et al., 1989).

In Zaragoza and Calauan, the majority of farmers belonged to the Tagalog ethnic group, whereas in Guimba, a blend of Tagalog and Ilocano ethnicities was observed. Pangasinan exhibited a distinct ethnic identity, while Ilongos predominated in Iloilo. Each of these communities maintains superstitious customs inherited from generations of farmers, rooted in beliefs predating modern rice farming and pesticide usage. On the other hand, newer generations of farmers are less likely to use these practices. According to the authors, many of these strategies reveal rich imaginations that have evolved out of desperation. Only planting by moon phase would be scientifically sound since many rice insect pests utilize the moon for scheduling their dispersion phases (Perfect and Cook, 1982). Many of these techniques have vanished after the invention of insecticides. Conversely, pesticides are expensive, and only farmers who live in favorable areas with high yields can afford them. Rice growers started using insecticides in the 1950s when organo-chlorine and organo-phosphate pesticides were developed and marketed. By 1966, Philippine rice farmers had largely embraced pesticides due to ten years of free insecticide treatments provided by government specialists. They were qualified for a credit package under the government's Masagana 99 production program (Kenmore et al., 1987). Insecticide use on rice predates the Green Revolution,

although new modern rice varieties undoubtedly increased use, especially in less risky irrigated areas. In a similar vein to the use of inorganic fertilizers, extension services promoted the use of pesticides to ensure the claimed high-yield potential. Kenmore et al. (1987) used a collection of 30 independent surveys conducted across the Philippines from the 1950s to the mid-1980s to track use. From a low of 30% of farmers in 1960 to a high of >90% in 1980, use grew in a straight line. Farmers that used a lot of inorganic fertilizers were more likely to buy pesticides.

Importance of transdisciplinary research in pest management

Agriculture and food system research is now divided into several initiatives organized by disciplines, focusing on relatively small portions of the overall picture. Production and economic returns give efficiency metrics based on current monetary measurements, and they are considered separate from any assessment of a system's environmental and social implications. As we try to cover all critical parts of the food system at each of our research and teaching institutes, there is frequent duplication across national or state borders. Given the complexity of agricultural and food concerns, one goal is to devote more resources to transdisciplinary techniques that allow us to look at the big picture from a systemic perspective. The word "transdisciplinary" refers to the integration of techniques and information from several disciplines, as opposed to "multidisciplinary," which refers to a collection of fields that are not necessarily connected (Caporali et al., 2007).

The efficacy of environmental and natural resource management initiatives frequently hinges on the synchronized efforts of decision-makers across various levels, ranging from local entities such as farms and protected natural areas, to regional entities and beyond. It is not always simple to get people to participate in these projects and then coordinate them, particularly when it comes to pest control challenges, which are fraught with competing societal attitudes and worldviews (Allen et al., 2001). Promoting a more integrated strategy that freely distributes information and experience among the many parties engaged is a big issue (Margles et al., 2010). Collaborative or social Enhancing a more comprehensive approach that facilitates the free exchange of information and experiences among diverse stakeholders is a significant concern (Margles et al., 2010). Collaborative or social

efforts are essential in addressing this issue. Learning methodologies are being used to build many scientific research programs in natural resource management (Tress et al., 2005; Allen et al., 2011; Robinson et al., 2012). To be effective, the science in these initiatives must go beyond the traditional method, which often entails the scientific team planning and overseeing the research process mainly without participation from stakeholders. Often, a single discipline defines such research-led inquiry management procedures at the expense of other academic conceptual frameworks (Miller et al., 2014). The scientific team develops a theory, seeks data to confirm or refute it, and develops conclusions, which may be shown in a model or published in a paper (Wadsworth, 1998). The stakeholders are subsequently provided with this scientific product, which they are supposed to use in their decision-making. A broader perspective on science incorporates disciplines and stakeholders more openly in creating hypotheses and considering how to implement the findings. The objective of these endeavors is to ensure that research is more attuned to the requirements of stakeholders, thereby enhancing its capacity to effect tangible change at the grassroots level. Involvement at this level also ensures that stakeholders are aware of the science's biases, hypotheses, and limits.

Many instances exist of research leaders, scientists, and their stakeholder partners embracing this broader perspective on research. These research projects facilitate collaboration between scientists and practitioners, fostering the exchange of ideas and methodologies that bridge the gap between scientific theory and practical application, emphasizing collaborative adaptive management through experiential learning. These programs are based on collaborative problem-solving and conflict-resolution ideas, which emphasize the need to collaborate with a variety of stakeholders to build standard terminology and frameworks, cultural awareness and connectedness, and a feeling of inclusion and empowerment (Allen and Kilvington, 2005; Plummer and Armitage, 2007; Jacobson et al., 2009). The integration of collaborative and social aspects in research endeavors is often overlooked in conventional research proposals and published findings, resulting in limited examination and implementation of these components in both design and practice (Litsinger et al., 2009). Suppose the scientific community wants to ensure

the relevance and rigor of collaborative and learning-based projects. In that case, it must be specific about using rigorous methodological practices that ensure that these aspects are subjected to proper peer review and then implemented with care (Allen and Kilvington, 2005; Reed, 2010). Hence, the objective is to promote methodologies that facilitate the equitable engagement and mutual respect among a diverse range of disciplines and stakeholders, thereby fostering a more inclusive approach to research and management. This is true for the philosophy and design of integrated program activities and the necessary connection and trust building for effective involvement. Furthermore, since these programs are increasingly geared to enable collaboration and adaptive management (Plummer and Armitage, 2007; Allen and Jacobson, 2009), these engagement activities must be continuous. Researchers increasingly emphasize how they tackle the social difficulties these more inclusive, adaptable, and learning-based techniques entail. For example, Campbell (2005) identifies some practical barriers to transdisciplinary study in general and then suggests ways to overcome them. The writers of a special edition of this journal in 2010 were asked to consider how they contributed to multidisciplinary methods (Margles et al., 2010). Recent publications have reaffirmed the importance of learning through real-world experiences that bring together decision-makers and academics from many fields (Podestá et al., 2013; Robinson et al., 2012).

To quote Margles et al. (2010), all of these writers and journals attempt to give ideas, techniques, and experiences to those trying to foster collaborative approaches to conservation concerns rather than rehashing the plethora of impediments in conservation research and practice. Apart from considering the dynamics of interdisciplinary collaboration among researchers, another challenge emerges in identifying the most effective methods for incorporating alternative knowledge systems (such as local and traditional knowledge) into the research process. This endeavor necessitates the active engagement of practitioners, community members, and Indigenous groups as equal partners. This introduces the idea of cross-disciplinary partnerships (Apgar et al., 2009; Jahn et al., 2012). There is no universally accepted definition of transdisciplinarity (Jahn et al., 2012). In

contrast, transdisciplinary collaborations are recognized for their capacity to incorporate discussions that blend the insights and viewpoints of researchers with diverse stakeholder groups, including land managers, policymakers, local communities, and indigenous populations (Allen et al., 2014). Such partnerships often aim to define objectives and then support research that aids multiple parties in achieving shared goals while also generating new information and insight (Allen et al., 2011). These debates will likely include epistemological and ontological viewpoints specific to the context and may be unfamiliar with the scientific fields (Eigenbrode et al., 2007). The discussions focus not on the specifics of methodology or technology but on the topics and interests to be investigated, as well as people's values. Issues of ethics and authority, such as who has the right to profit from, decide on, or manage new technology, are likely to be discussed at this level (Allen et al., 2011).

Study area

The state was divided into agro-ecological zones and units based on climate, soil type, and landform in 2007–08. Kerala has 23 agro-ecological units, with panchayats serving as the primary unit. Moreover, this initiative was directed by the National Bureau of Soil Survey and Land Use Planning (NBSS) and organized by the state planning board of Kerala (KSHIS, 2019). Our survey on farmer perception was conducted in three communities, one each from the high hill (Wayanad District), foothill (Kannur District), and midland laterite (Kozhikode and Malappuram District) regions of North Kerala. They are located 12 to 746 above mean sea level (AMSL) (see Map.1.1 in Chapter 1). In all areas, agricultural practices consist of subsistence production, including rice farming and cultivating banana plants and vegetables. high hills contain the largest region; the Western Ghats and highlands are about 600 AMSL, with several peaks rising over 1800 meters. Furthermore, the zone occupies 15,53,225 ha of land (39.97%). Foothills include rolling terrain (land with many gentle ups and downs, no steep slopes, and unusual features) and low hills between the western midland laterite and the eastern highlands. The field occupies 4,60,074 hectares (11.84%) with an altitude range of 300 to 600 meters, and the region has only very narrow valleys. Midland laterites

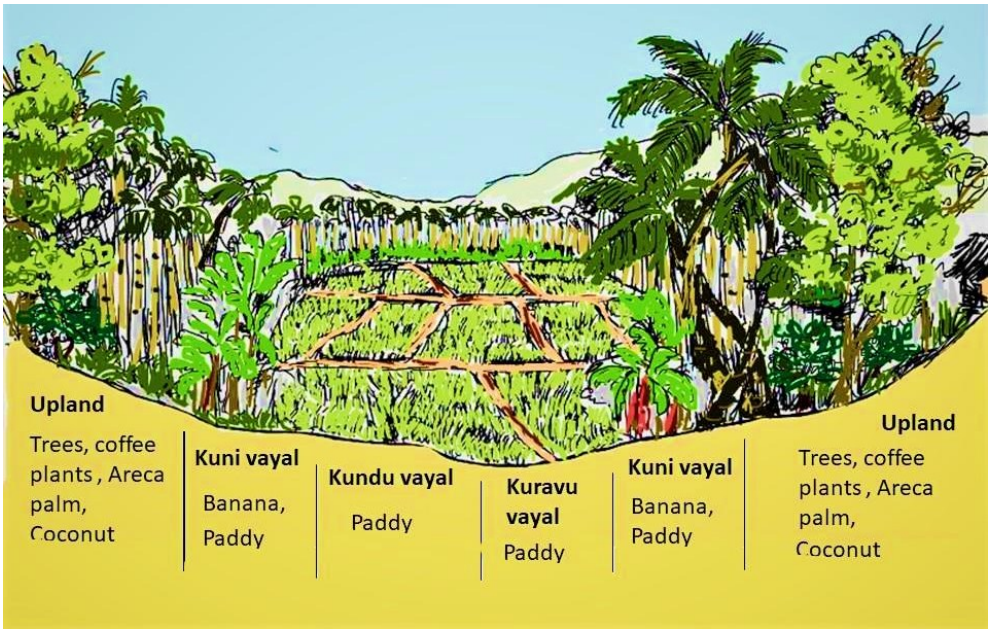
include rolling lands interspersed with small valleys between the western coastal plain and the eastern foothills and hills. The elevation range is 30 to 300 m, and the zone covers 10.56.385 hectares (27.18%) (KSHIS, 2019).

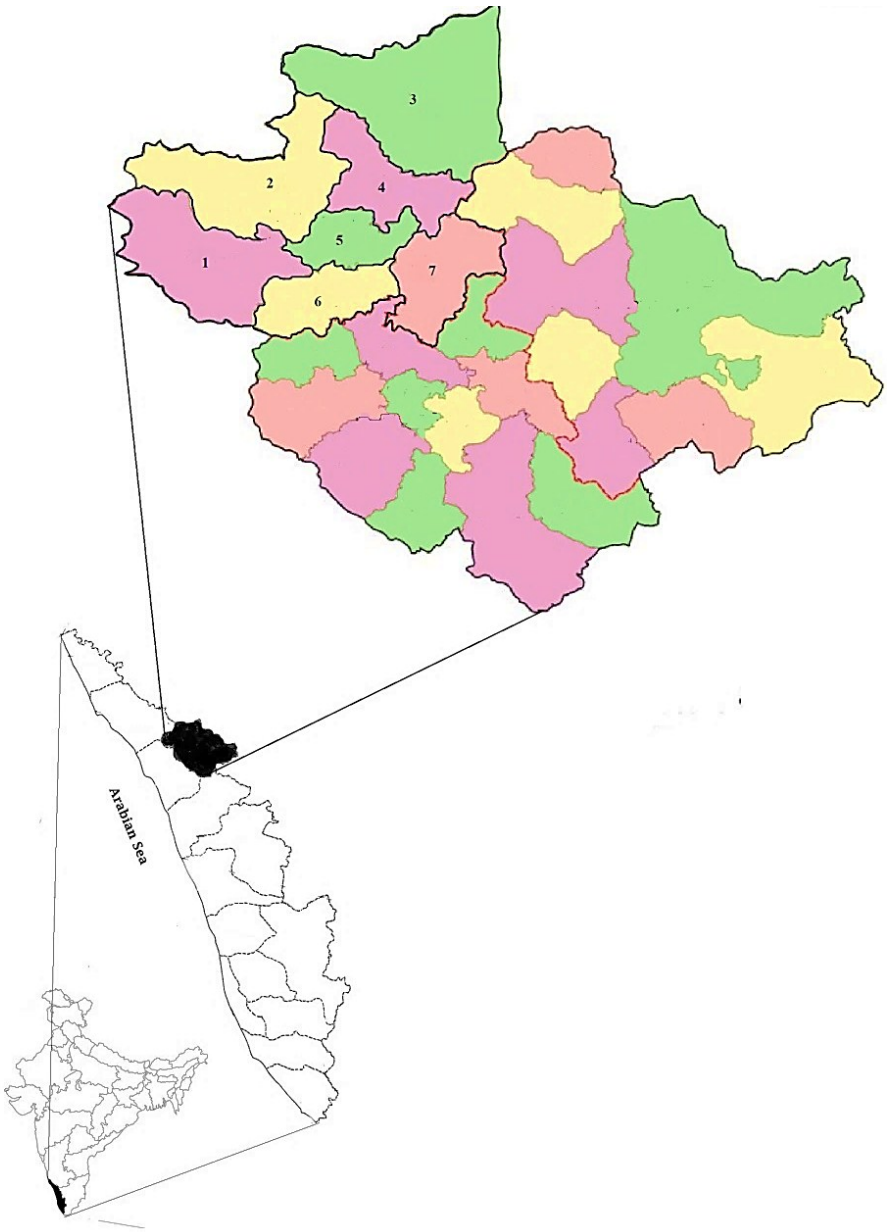
The Wayanad district of Kerala was the focus of study for traditional rice varieties. To reduce the variation in agro-climatic conditions, studies on the ranking of 49 traditional varieties based on the pest index were conducted in the North region of Wayanad, particularly in the neighboring panchayats such as Thondernadu (11.7710°N, 75.8418° E), Thavinhal (11.8488° N, 75.9521° E), Thirunelli (11.9081° N, 75.9971° E), Mananthavady (11.8014° N, 76.0044° E), Edavaka (11.7715° N, 75.9637° E), Vellamunda (11.7341° N, 75.9376° E), and Panamaram (11.7381° N, 76.0740° E).

The yellow stem borer susceptible aromatic rice varieties were tested in the rice fields of Edavaka and Panamaram Panchayat. The Western Ghats, a mountain range that stretches from North to south along the West Indian coast, includes the Wayanad district (Fig. 3.2), which is situated in North Kerala, South India. Many names, including Wayanad (elevated plateau), Vayalnadu (land of rice fields), and Vananad (land of trees), give rise to the name Wayanad (Nair, 1911). Between 700 and 2100 meters AMSL, with 11°26' to 12°00' in the North and 75°75' to 76°56' in the east, are the elevation ranges. The eastern border is delineated by the Tamil Nadu districts of Mysore and Nilgiris; to the North, it is bounded by the Coorg district of Karnataka; to the south, by the Malappuram district; and to the west, by the Kozhikode and Kannur districts of Kerala. With a total area of around 2136 km^2 and elevations ranging from 700 to 2100 meters AMSL, Wayanad has a tropical climate with an average annual rainfall of 2250 mm (Kumar and Srinath, 2011). Adivasis, a term used to refer to all of India's tribal residents, is Wayanad's indigenous population (Rath, 2006). The largest Adivasi population in Kerala is found in Wayanad (Chathukulam and John, 2006). Low-range undulating valleys are a common feature of Wayanad rice fields. Mainly four factors—water accessibility, soil composition, soil fertility, and the field's location—are used by the Kurichiyas, an ethnic group from Wayanad, to categorize vayals. The Kurichiyas may use

Vayal's conventional classification system to help them decide which crops to grow, use relevant information, and plan their work. Three types of vayals are distinguished by soil texture, mud composition, percolation, and water fertility retention (Fig. 3.1). A gentle incline in the foothills called Kunivayal leads to low, level terrain. The flat valley bottom fields are known as "Kundu vayals." Koravu Vayal is a swampy, uncommon variation of Kundu Vayal. This area is not the best place to stand or stroll because of the serious risk of falling into a deep swamp. Animal plowing is not feasible in this location because of the swampy terrain. In Kunivayal, types such as Pal thondi, Mara thondi, Thonnuram thondi, Urunikayama, Navara, Kochuvithu, and Kalladiyaran are grown that can withstand short-term droughts. Medium-duration cultivars (such as Gandhakasala, Mullan channa, Poothadi Kayama, Jeerakasala, Chennellu, and Chomala) are cultivated in Kundu vayal. On the other hand, cultivars that can withstand flooding and last a long time are grown in Koravu vayal, including Chettu veliyan, Pal veliyan, Mundon, Chenthadi, and Adukkan (Gopi et al., 2004).

Fig. 3.1 Paddy landscape of Wayanad, North Kerala (Adapted from Gopi et al., 2004).





Map 3. Panchayats selected for the sampling in traditional rice varieties of Wayanad 1 Thondernadu; 2- Thavinhal; 3- Thirunelli; 4- Mananthavady; 5- Edavaka; 6- Vellamunda; 7- Panamaram

Materials and method

Existing traditional pest management practices in North Kerala

Three hundred forty-eight farmers cultivating traditional (n=111) and high-yield rice varieties (n=237) were surveyed, with 86 being interviewed to know about traditional pest management practices.

Fig. 3.2 Farmer survey; a-farm walk, b-focus group discussion, and c-interviewing farmers.



For the survey, we interviewed tribal and non-tribal rice farmers practicing traditional pest management practices. The data was collected through personal interviews, farm walks, and a focus group discussion (Fig. 3.2).

Influence of rice varietal differences on pest infestation

Farmers cultivating traditional varieties were identified from the MS Swaminathan Research Foundation's (MSSRF) Farmer's Address Book and a pilot survey of farmers who attended the Biodiversity Congress and Seed Fest programs.

Two hundred and three traditional rice farmers in Wayanad, cultivating traditional varieties (n=65) or high-yield varieties (n=92) or both traditional and high-yield varieties (n=46), were interviewed. This group included both tribal (n=26) and non-tribal farmers (n=177). Among the interviewed farmers, 19 traditional farmers' plots were selected for insect pest sampling. The sampling was done from 2017 to 2019 in the booting and ripening stages of the paddy (July to October). A transect measuring 5 m x 2 m was laid on the rice field's four sides and covered on foot. Handpicking and sweep netting were done to collect the rice insect pests. Parasitized and unparasitized caterpillars were handpicked from the rice field and reared for the possible emergence of parasitoids and adult insects at 28°C and 70–80% relative humidity. The emerging parasitoids were counted, preserved in 70% alcohol, processed using hexamethyldisilazane (HMDS), later card mounted, and identified up to species level according to the morphological characteristics of adults using the available taxonomic keys from the available literature and help of experts.

Calculation of Pest Species Impact Index (P-Index)

This protocol evaluates, categorizes, and lists pest-resistant traditional rice cultivars in a given ecological zone based on their susceptibility to pest attacks. The goal is to use qualitative and quantitative methods to evaluate and monitor pest resistance in traditional varieties. A set of questions and documentation of the scientific data was utilized to rank each species. Three quantitative data sets (pest density, pest abundance, and percentage parasitism) make up the Pest Resistance Assessment Protocol. The Pest Species Impact Index (P-Index) is comparable to the Important Value Index (IVI) (e.g., Nguyen et al., 2014), which is calculated using quantitative data from field observation for each rice variety in a specific region of interest. Each of these values represents a percentage that ranges from 0 to 100.

Table 3.1. Equations to calculate Pest Index (PI) of pest species in traditional rice varieties of Wayanad.

Index	Equation
Pest Species Impact Index (Pi)	$\frac{D + Ab + P}{300}$
Pest density (D)	$\frac{\text{Number of pest species present in a variety}}{\text{Total number of pest species present in all varieties}} \times 100$
Pest abundance (Ab)	$\frac{\text{Number of individual pests in a variety}}{\text{Total number of individual pests of all species in a variety}} \times 100$
Percentage parasitism (P)	$\frac{\text{Number of parasitized pest}}{\text{Total number of pests in each variety}} \times 100$

Yellow stem borer susceptible aromatic rice varieties

Study organism

The yellow stem borer (YSB), scientifically known as *Scirpophaga incertulas* (Walker), is recognized as the primary stem borer species impacting rice cultivation in India. This pest, which feeds exclusively on rice hosts, poses a significant threat throughout all stages of rice plant growth, spanning from nursery to harvest. In India, the YSB exhibits multiple generations annually, with reports documenting 4–5 generations. Larvae of the YSB emerge from egg masses laid on the leaf laminae, employing silky threads to descend to the base of tillers, where they penetrate the stem by creating minute openings just above the water level, subsequently consuming the developing stem primordia. Upon infiltration of the tillers by the larvae, resulting damage typically presents as either a dead heart or a white ear head, contingent upon the crop's developmental stage. The associated yield losses attributed to YSB infestation have been estimated to vary between 38 to 80 percent (Padmakumari et al., 2017).

Sampling

Because yellow stem borer (YSB) infests rice throughout its vegetative, booting, and ripening phases, we monitored pest damage (white ear heads) and egg clutches throughout the rice cultivating season, June-December, from 2018 and 2019. To sample the traditional and high-yield varieties for yellow stem borer

incidence, quadrats measuring 25 × 2m^2 were arranged at the four corners of the field (e.g., Rajesh et al., 2021). To test the effect of plant morphological traits on the yellow stemborer infestation (white ear heads and the number of egg masses laid), we selected three aromatic rice varieties, viz., Chomala, Gandhakasala, and Jeerakasala, and four high-yield varieties, viz., Aathira, Aiswarya, Kanchana, and Uma. The plant characteristics, such as the panicle length (cm), culm length (cm), cultivar duration (days), number of tillers, culm width (mm), and leaf width at egg mass laid (cm), were compared with the number of white year heads per plot, the number of eggs in clutches, and the area of the egg mass (mm).

Among the pest susceptible aromatic varieties, Gandhakasala was selected to compare the YSB incidence with the main crop. The main crop (high yield) chosen for the study was Uma, a locally popular variety among farmers. The quadrate sampling method was employed in the main crop, Uma (a high-yielding variety), and the insect pest susceptible aromatic traditional variety, Gandhakasala. Gandhakasala, with a growth period of 150–175 days and a booting stage occurring 6–7 days before the main crop, was planted for each plot of the main crop, preferably in an adjacent plot. Yellow stem borer susceptibility was checked in 1) Uma variety alone, 2) Uma variety with Gandhakasala, and 3) Gandhakasala alone. The duration of the Uma variety ranged from 120 to 135 days. Observations on the number of dead hearts were recorded in the booting stage (95 days after transplanting (DAT)). Quadrats measuring 25 × 2m^2 were positioned at the four corners of the field to sample the Uma and Gandhakasala rice varieties (e.g., Rajesh et al., 2021). Five plots per site (four sites) were sampled for yellow stem borer infestation. We sampled the egg masses and white ear heads in all sampling units on the high-yield variety (Uma) and traditional rice variety (Gandhakasala). Visual observation was made to count the number of white earheads in the rice fields. Egg masses were taken into the laboratory, and counted the clutch size.

Data analysis

A Pearson correlation matrix was created to determine the trend (rice morphological features versus yellow stem borer infestation) in the high hill region

of North Kerala. In addition, the principal component analysis (PCA) biplot of the rice plant morphological characters that measure the susceptibility of yellow stem borer infestation in traditional and high-yield rice was carried out. In addition, the principal component analysis (PCA) biplot of the rice plant morphological characters that measure the susceptibility of yellow stem borer infestation in traditional and high-yield rice was carried out. A t-test was done to compare the clutch size, area of egg mass, and the number of white ear heads formed in the Uma and Gandhakasala rice varieties in the mixed plot of Uma (high yield) and Gandhakasala (traditional) rice varieties, the main crop (Uma rice variety) in the presence or absence of Gandhakasala, and the Gandhakasala rice variety in the presence of Uma variety crop and as a monocrop. PCA analysis was done in PAST 3.0 software, and all other tests were carried out in R-4.2.2 software.

Farmers knowledge on rice pests, natural enemies, and pest management

Farmer survey instruments and procedures

Surveys were conducted from 2018 to 2020 in the high hill, foothill, and midland laterite agro-ecological zones of North Kerala. A total of 340 farmers were selected for the study. In each zone, the owner farmers of the study site and farmers of different padasekharams under the Krishi Bhavan in different panchayats were randomly selected. A semi-structured questionnaire with open-ended questions was employed. The questionnaire was revised four times by subject-matter specialists and extension workers in the MS Swaminathan Research Foundation and agricultural officers to avoid ambiguity, redundancy, and bias. In a nearby village, the questionnaire was pre-checked before use in the study area. The master plan for data collection was adapted from Sinzogan et al. (2004) (Fig. 3.3).

Person-to-person interviews, including phone calls and farm walks, were used to conduct the surveys, which took 30–60 minutes per interviewee.

The survey framework is created for a variety of objectives. The information gathered included data about each farmer's socioeconomic and demographic background. In the following section, we discussed farmers' knowledge of rice pests

and their natural enemies. We asked farmers to list the rice pests and natural enemies they know. Farmers have been encouraged to evaluate the damage the rice insect pests have caused. To assess farmers' level of knowledge in these areas, we asked them to list the characteristics of insects they knew to be pests or natural enemies and rate them on a four-point scale adapted from (Midega et al., 2012; Okonya and Kroschel, 2016; Munyuli et al., 2017) (Table 3.2). The third section examined how farmers perceived controlling rice pests, whereas the fourth segment focused on pest management information sources and knowledge transmission. The subsequent sections also covered farmers' pest tolerance levels and gaps in pest management domains (Table 3.3).

Fig. 3.3 Master plan for data collection (Adapted from Sinzogan et al., 2004).

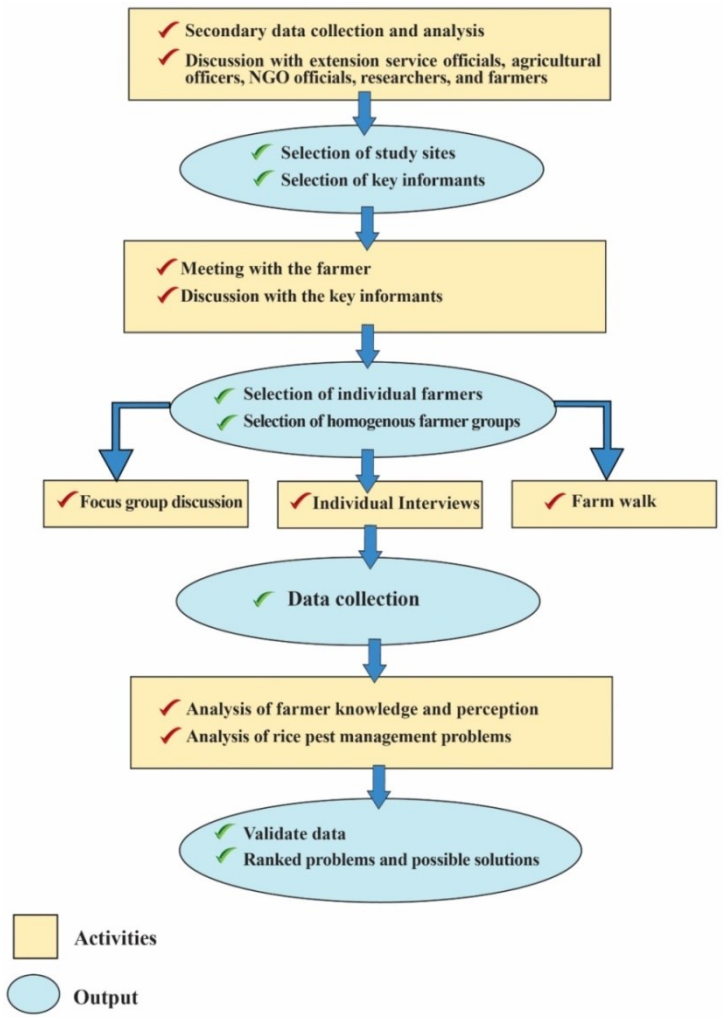


Table 3.2. Scoring criteria utilized to assess farmers' understanding of insect pests (adapted from Okonya and Kroschel, 2016)

Score	Knowledge level	Criteria
0	No	Unable to identify a rice pest or natural enemy by name, description, or type of damage caused.
1	Low	Identified one pest or natural enemy, provided one feature, and described one type of damage caused.
2	Medium	Identified two pests or natural enemies, described at least one feature of each, and described at least one type of damage caused by each.
3	High	Identified three or more pests or natural enemies, provided descriptions of one or more features of each, and described at least one type of damage caused by each.

Table 3.3. Questionnaire structure employed to evaluate agro-ecological knowledge and pest management practices among rice farmer communities in North Kerala (e.g., Wyckhuys and O'neil, 2007a)

Sl. No.	Survey section	Section component
1	Examination of socio-economic status	• Analysis of demographic factors such as age, sex, education, community, and experience. • Investigation into primary occupation, income levels, land size, and the purpose behind rice production. • Evaluation of income distribution and its relation to participation in pest management training
2	Insight into farmers' understanding of rice pests and natural enemies	• Assessment of farmers' perceptions and the perceived incidence of rice pests and their natural enemies. • Identification of rice pests through direct observation of specimens or damage. • Exploration of interconnections between knowledge of rice pests, natural enemies, damage perception, and socio-economic factors of farmers
3	Farmer's perspectives on rice pest management	• Examination of diverse pest management practices within rice cultivation. • Analysis of pest management strategies employing chemical pesticides.

		• Identification of commonly used chemical insecticides
4	Role of opinion leadership, social connectedness, and information sources	• Identification of sources informing the rate of pesticide application. • Exploration of the relationship between farmers' pest management behavior, knowledge, and information sources. • Availability of information sources for chemical pesticide alternatives. • Comparison of knowledge and pest management practices between trained and untrained farmers. • Investigation into the relationship between farmers' socio-economic characteristics and their knowledge level. • Identification of factors influencing the perception of rice plant damage. • Mapping of socio-ecological knowledge networks among traditional and high-yield rice farmers.
5	Assessment of crop loss tolerance in diverse farmer communities	• Evaluation of insect pest tolerance across different farmer communities. • Examination of the impact of farmers' socio-economic variables on their tolerance level for pest infestation.
6	Identifying gaps in rice pest management and proposing solutions	• Identification of knowledge gaps, farmer participation in training, government policy adoption, traditional knowledge incorporation, and extension services involvement

Color photographs of every potential rice insect pest and the natural enemy were displayed to farmers in all three agro-ecological zones, viz., the high hill, foothill, and midland laterite zones, and the perceived incidence of rice insect pests and natural enemies were calculated. They were then asked to rate the damage caused by each pest discovered to gauge their perspective on the severity of insect pest damage. The evaluation of damage inflicted by individual pests was conducted utilizing a five-point scale. This scale was structured to represent varying degrees of perceived damage, with ratings ranging from 1 to 5; 1 denoting very little damage, 2

indicating little damage, 3 representing moderate damage, 4 signifying severe damage, and 5 reflecting very severe damage (Okonya and Kroschel (2016).

The Likert scale techniques (Rutsaert et al., 2013) were used to collect data on the efficacy of rice pest management practices among farmers who had used at least one of the management practices. The Likert scale employed in this study has been delineated with the following labels: 1 representing totally ineffective, 2 denoting ineffective, 3 indicating relatively ineffective, 4 signifying indifference, 5 representing relatively effective, 6 indicating effective, and 7 denoting totally effective (e.g., Bažok, 2022)

To make the best pest management decisions, farmers were asked to select their top information sources, both within (for example, friends and family) and outside (e.g., agricultural officers, pesticide sellers) of their community. "Opinion leadership" refers to the degree to which others turn to a person for knowledge and advice about certain advances (Rogers, 1995). The categorization of farmers identified as sources for pest management guidance as opinion leaders, as established by Wyckhuys and O'Neil (2007b). We interviewed farmers who had discussed or used non-chemical approaches to managing rice pest insects to learn about these techniques. Farmers from high hill (n=150), foothill (n=85), and midland laterite Communities (n=105) were chosen randomly to determine the farmers' degree of connectedness. To do this, we asked every farmer to mention the number of other farmers they communicated regularly with for rice pest management (e.g., Wyckhuys and O'Neil, 2007b).

Survey of extension officers and agricultural experts

To gather comprehensive insights into the capacity development and training needs of agricultural extension agents for effectively disseminating pest management information to smallholder farmers, a mixed methods approach was employed. This approach incorporated telephone interviews, questionnaire surveys, and expert consultations. Thirty agricultural extension agents from the districts of North Kerala were given a questionnaire to complete. The study included questions on knowledge to better identify the capacity-building requirements of agricultural

extension agents to help farmers manage the infestation of rice pests. Extension agents were interviewed on their knowledge of effective pest management techniques and the kinds of instruction they get. Expert interviews were undertaken to learn more about the obstacles to effective extension services in managing pest infestations. Fifteen expert interviews were performed between January 2019 and December 2020. Experts were specifically chosen based on their extensive and in-depth expertise in the control of rice pests.

Construction of socio-economic web

The food webs used in ecology to investigate trophic interactions or food connections are comparable to the social-economic web. The main idea behind food webs is to map linkages between different species that reside in a particular area to reveal the structure of a community. Food webs vary in complexity, importance, and breadth depending on the examined system and the intended result (Sunderland et al., 2005). Similar to how organisms in an ecosystem interact, the elements of an agricultural system are interconnected. Because of this, we employed the economic framework of food webs to examine the qualitative data, replacing the organisms with social and ecologic aspects (e.g., socio-economic status, farmer's knowledge, information sources, and rice pest management practices). The complex social-economic system was designed to be represented to identify relationships among its many elements. The components of the observable system are identified to create a social-economic knowledge web. Information from the data analysis, components gathered via participatory techniques, and qualitative interview data from both disciplinary perspectives were combined to determine significant categories relevant to the original study goals and interests. The objective was to identify the components of the social-economic system (the dots in the figures). We identified connections between the components using several analyses (the lines in the figures). We found that the interview data provided direct relationships (component A influences component B or vice versa).

Additionally, there were indirect associations (component C affects component A through component B). The action for these links was then specified

using arrowheads (Betz et al., 2014). The activity's direction and direct and indirect relations with other factors showed the effect of farmers' knowledge of traditional and modern agricultural systems.

Data analysis

The perceived incidence of pests and natural enemies, the influence of rice pest management information sources on specific pest management practices other than chemical pesticides, and pesticide application rates for the management of rice pests in three agro-ecological zones (high hill, foothill, and midland laterite) in North Kerala, as well as the chemical pesticide alternatives for the management of pests, were all analyzed using a chi-square analysis. Using a Spearman rank correlation, the associations between farmers' socio-economic status, knowledge of natural enemies, perception of pest-induced crop damage, and knowledge of rice pests were examined. A Spearman correlation matrix examined the association between farmers' socio-economic traits and their knowledge of pests, natural enemies, and perception of pest damage.

Akaike's Information Criterion (AIC) model (Akaike, 1973) was used to compare the various models (Sileshi, 2006). In this study, AIC was used to select logistic regression models for the perception of rice pest damage in North Kerala rice ecosystems. The model exhibiting the lowest Akaike Information Criterion (AIC), and consequently, the highest parsimony, was selected as the optimal model to depict the association between the perception of crop damage by pests and various variables. These variables encompassed knowledge of natural enemies (KWN), knowledge of pests (KWP), participation in training (T), engagement with local institutions (LI), identification as opinion leaders (OL), level of connectedness (DC), farmer age (A), agricultural experience (E), and landholding size (L).

In a logistic regression model, multicollinearity is a statistical phenomenon caused by highly correlated predictor variables. Collinearity causes the variances of parameter estimates to increase, which leads to inaccurate conclusions about the relationships between the explanatory and response variables. Employing a fusion of linear regression alongside option tolerance, Variance Inflation Factor (VIF),

condition indices, and variance proportions enhances diagnostic accuracy. Eliminating one of the correlated variables was entirely adequate in reducing multicollinearity for moderate to large sample sizes (Midi and Bagheri, 2010). Model variables selected for the collinearity tests are KWN—knowledge of natural enemies; KWP—knowledge of pests; T—training; LI—local institution involvement; OL—opinion leadership; DC—degree of connectedness; A—age of the farmer; Exp—experience in agriculture; and L—land size.

The generalized linear models (GLMs) (Nelder and Wedderburn, 1972) consist of a broad class of models that predict the outcome of a response variable as a linear function of a set of predictors, with linear regression as a special case (Mandal, 2014). This study used the GLM to predict the factors that influenced the farmer's perception of rice plant damage in North Kerala, India. Model variables: KWN—knowledge of natural enemies; KWP—knowledge of pests, T—training; LI—local institution involvement; OL—opinion leadership; A—age of the farmer; Exp—experience in agriculture; and L—land size.

By incorporating a heterogeneity parameter Tau^2 that explicitly accounts for across-study variation, random effects methods enable the modeling of differences between studies (Biggerstaff and Tweedie, 1997). An analysis of the random effect model and heterogeneity statistics were performed to determine the significance of insect pest tolerance in the high hill, foothill, and midland laterite farmer communities.

The forest plot is a particularly effective tool in meta-analysis since it quickly visualizes overall effect estimates and study heterogeneity (Israel and Richter, 2011; Verhagen and Ferreira, 2014). Each study's estimate is shown, with the line of no impact represented by the vertical line. The weight assigned to the study is indicated by the size of the squares, with bigger squares signifying more weight. The weight assigned to each study is automatically determined depending on the estimate's accuracy (more accurate estimations are given greater weight). The next step is to statistically combine all individual estimates into a single estimate using meta-analysis. A black diamond represents this visually, with the overall

estimate located in the center and the confidence interval located along its breadth. The pooled estimate also has a numerical display (Verhagen and Ferreira, 2014). In this study, we used forest plots to show the effect of different socio-economic variables on the pest infestation tolerance level of the high hill, foothill, and midland laterite farmer communities. Summary estimates were analyzed using a random-effects model (RE model).

Results

Existing traditional pest management practices in North Kerala

Management of insect pests

The most noticeable insect pests were controlled by sweeping, using "muram" (a winnower made of bamboo) or nets, and handpicking. The handpicking method was used to remove immature stages of the lepidopteran pests. The sweeping method was employed in the morning and was used to capture adult flying insect pests and larval pests. The branches of thorny plants such as *Ficus hispida* and *Artemisia vulgaris* were swayed to injure the larvae of concealed defoliators such as *Cnaphalocrocis medinalis*, *Helcystogramma arotraeum*, and *Leptispa pygmaea*. The lemongrass oil leaves (*Cymbopogon citratus*) were chopped and swung, causing the caterpillars of *C. medinalis* to be wounded because of the silica and bristles in the leaves and eventually killed or consumed by birds. The farmers employed *Cycas circinalis* flowers and dried sardine in the field as deterrent to drive away rice bugs. When armyworm infestations are severe, farmers tend to flood the fields. Alternatively, farmers drain the water to control rice case worms in the vegetative stage of the paddy and brown planthopper infestations. Stemborers were primarily exterminated by uprooting the damaged parts of the rice plant. Mainly, nocturnal adults of rice insect pests were managed using light traps. Weed eradication and bund shaving were commonly used to control pests that use weeds and bund plants as alternate host plants (Table 3.4) (Fig. 3.6).

Table 3.4. Existing cultural and mechanical insect pest management practices in North Kerala rice fields.

Scientific name of the pest	Local name of the pest		Management practices
	Farmer version	Vernacular name	
Ampittia dioscorides	Pacha puzhu	Ponthachadan	• Hand picking • sweeping
Cnaphalocrocis medinalis	Ila churutti puzhu Olappuzhu	Ila churutti puzhu	• Swaying branches of plants such as "Paarakam" (*Ficus hispida*) or "Kattukarpooram" (*Artemisia nilagarica*) to injure the larvae as well as insects in the field • Bund shaving • Swaying with lemongrass oil leaves (*Cymbopogon citratus*) • Light trap to capture adults
Dicladispa armigera	Vandu	Kaara vandu	• Sweeping using sweep net
Helcystogramma arotraeum	Ila churutti puzhu	Ila churutti puzhu	• Swaying branches of plants such as "Paarakam" (*Ficus hispida*) or "Kattukarpooram" (*Artemisia nilagarica*) to injure the larvae
Hieroglyphus banian	Pachathullan Pulchaadi Pachakuthira	Pachathullan Pulchaadi Pachakuthira	• Sweeping using sweep net • Bund shaving
Leptispa pygmaea	Ila churutti puzhu	Ela churutti vandu	• Swaying branches of plants such as "Paarakam" (*Ficus hispida*) or "Kattukarpooram" (*Artemisia nilagarica*)
Leptocorisa acuta	Chaazhi Munja	Chaazhi	• Flowers of "Eenth" (*Cycas circinalis*) are used as a deterrent • Swaying with "muram" • Hanging a fish in a cloth attached to a stick erected in the field • Keep the field and bunds free of weeds and

			grasses • Spraying of diluted buttermilk in the field • Light trap to capture adults
Melanitis leda ismene	Pacha puzhu	Pacha komban puzhu	• Hand picking, sweeping using muram
Mythimna separata	Pattala puzhu	Pattala puzhu	• Flood the field as soon as the caterpillars are noticed
Naranga aenescence	Pacha puzhu	Pacha puzhu	• Hand picking, sweeping using muram
Nilaparvata lugens	Chaazhi Munja	Munja	• Draining the field
Oxya hyla	Pachathullan Pulchaadi Pachakuthira	Pachathullan Pulchaadi Pachakuthira	• Sweeping using sweep net, bund shaving
Orsotriaena medus	Vella puzhu	Vellakkarumban	• Hand picking • Sweeping using muram
Parapoynx stagnalis	Kuzhal puzhu Ila churutti Muzhipanni	Kuzhal puzhu	• Drain away the water from the fields • Light trap to capture adults
Parnara bada	Ila churutti Pacha puzhu	Ila madakki	• Hand picking • Sweeping using muram
Pelopidas agna	Ila churutti Pacha puzhu	Ila madakki	• Hand picking • Sweeping using muram
Pelopidas mathias	Ila churutti Pacha puzhu	Ila madakki	• Hand picking • Sweeping using muram
Scirpophaga incertulas	Thandu thurappan Chaazhi	Thandu thurappan	• Uprooting the affected parts (roguing) • Burn rice stubble • Light trap to capture adults
Scirpophaga innotata	Thandu thurappan Chaazhi	Thandu thurappan	• Uprooting the affected parts (roguing) • Burn rice stubble • Handpicking of eggmasses. • Light trap to capture adults
Spodoptera litura	Pattala puzhu Karutha puzhu	Pattala puzhu	• Sweeping using muram • Planting of *Colocasia* as a trap crop.
Spodoptera mauritia	Pattala puzhu	Pattala puzhu	• Flood the field as soon as the caterpillars are noticed.
Tetrix subulata	Thavittu Pulchaadi	Pulchaadi	• Sweeping using sweep net

To combat rice insect pests, farmers in North Kerala mainly employed three plant products, namely neem oil emulsion, neem seed extract, and tobacco emulsion, as well as four animal products, namely diluted buttermilk, fish amino acids, panchagavya, and jeevamrutham. Of them, jeevamrutham and panchagavya strengthen the rice plant's defenses against pest infestation, while the others serve as insect pest repellents (Table 3.5).

Table 3.5. Plant and Animal products used to prepare the pesticide formulations to control rice insect pests in North Kerala.

Plant/ Animal product	Mode of preparation	Target pest
Diluted butter milk	Spraying of diluted butter milk in the field	*Leptocorisa acuta*
Fish aminoacid	Mix 1kg of finely cut fish with 1kg of jaggery and keep it in a tightly closed container. After ten days, there will be a liquid form. The fluid can be stored in a tightly closed container for 21 months. Take 1 ml of liquid from the vessel and add 1 liter of water to it. This diluted liquid can be sprayed into the field.	*Leptocorisa acuta*
Jeevamrutham	It is prepared with 200 liters of water, sufficient for 1 acre of land. The mixture consists of 3kg of soil, 2kg of jaggery solution (made by mixing 2kg of jaggery in water), 2kg of any pulse powder, 10kg of cow dung, and 4 liters of cow urine in the water. Fill a large container with cow urine solution. Add cow dung to the cow urine solution. Mix it thoroughly. Then add soil to it and mix it properly. The jaggery solution is then added, speeding up the pace at which bacteria reproduce. Now add flour to it and mix it. Pour the solution directly into a barrel and fill it with water. Then stir the solution clockwise and anti-clockwise. For 14 days, seal the barrel and stir the contents every morning while keeping it in a shady area. Before using it on the rice field, it may be further diluted. The mix can be used twice a month in the field.	Against all pests
Neem oil emulsion	Dissolve 60g of bar soap in a half liter of water. This solution is then mixed with 1 liter of neem oil. The solution can be sprayed on the field after adding 40-fold water to it.	Grasshoppers, thrips, and rice bugs
Neem seed extract	Dip the poultice of 30–80g of powdered neem seeds in a liter of water for twelve hours. The diluted solution can be used against pests.	Lepidopteran caterpillars, grasshoppers, and stemborers

Panchagavya	It is made of milk, curd, ghee, cow dung, and urine. First, thoroughly combine 4 kg of cow dung with 500g ghee. Add the necessary amounts of salt and yeast to 4kg of cow urine, 500g of milk, 500g of curd, and 50g of palm sugar. It is then maintained in a shaded area. In the morning, thoroughly mix. It will cause microorganisms to multiply more quickly. This mixture has a six-month shelf life. But it must consistently mix well. Add water to the mixture if it starts to dry out. This mixture improves the plant's resistance to pest attack.	Against all pests
Tobacco emulsion	Cut the 500g dried tobacco leaves into little pieces and boil them in 4 liters of water. After that, keep it for a day. Then, afterward, take the tobacco residue out of the solution. A bar of soap weighing 12g is chopped up into tiny pieces and dissolved in water. The tobacco solution is then mixed with this bar soap solution. The field may be sprayed with this solution after being watered seven times.	Lepidopteran caterpillars, mealy bug, scale insects etc. (against soft bodied pests)

Management of non-insect pests

Farmers frequently used electric and wooden fences to control large vertebrate pests such as deer, elephants, and wild boars. Deers are kept at bay by the sound produced by the hanging glass bottles and the metallic rod in the wind. The sound of fire crackers helps keep monkeys at a distance by frightening them. Physical barriers might assist in keeping peacocks away since they have been known to cause substantial grain loss. Rodents live in bunds in rice fields, and bund shaving makes it easier to trace them; later, the rat holes were dug out. Placing owl perches on coconut fronds in the paddy field also assists in reducing rodents. To limit grain loss during the ripening stages of the paddy, scarecrows and bird tape were employed to frighten the birds.

Tribal farmers used different methods to reduce the prevalence of avian pests. Jack fruit (*Artocarpus heterophyllus* Lam.) and fig (*Ficus racemosa* L.) tree latex are mixed and mashed into a thick paste. Latex is cooked with gingelly oil in a mud pot until it gets sticky and is then set aside as stock. To grip the bird, bamboo splinters are joined together (slightly thicker than a typical broomstick) to create a

sticky surface. To extend the life of the splinter, it is smoked. All the surfaces of the splinters are covered with gum, except for the handle. The gum-coated broomstick is put close to the field when there is a severe bird threat. The bird becomes tethered to the stick as soon as it touches it, losing its ability to fly. As a result, the birds are kept out of the rice field. They use other traditional techniques, such as catapult and human effigy, to frighten birds from eating the grains in the field (Table 3.6; Fig. 3.4).

Table 3.6. Existing cultural and mechanical management practices of non-insect pests in North Kerala rice fields.

Name of the pest	Management practices
Deer	Electric fencing, hanging glass bottle along with metallic rode in a tap
Elephant	Electric fencing, fire crackers
Monkey	Fire crackers
Peacock	Physical barriers
Rodents	Bund shaving, placing bird (for owl) perches in paddy field
Small Birds	Bird tape, jack fruit latex, fig latex, catapult, human effigy
Wild boar	Electric fencing, wood fencing

Traditional rice varieties are mainly cultivated in the high hill region of North Kerala. The majority of these rice varieties take six months to harvest. Traditional pest management practices were employed primarily by tribal farmers. We constructed a traditional pest management calendar from the surveyed data for indigenous rice varieties. The twelve months in the calendar year are divided for field preparation, seed selection, seed treatment, basal application, seed broadcasting, letting the cattle into the field, weeding, and harvesting. Farmers performed traditional pest management and plant strengthening activities during every abovementioned phase to increase crop yield. Seed treatment was done by treating the seeds with cow dung slurry water to prevent pest attacks and for the plant strength. After harvest, indigenous farmers mixed dried neem leaves and the extracts of *Glycosmis pentaphylla* Retz, with the rice seeds to prevent the stored product pests (Fig. 3.4). They cultivated traditional rice varieties as part of their

culture. These indigenous groups carry out several rituals following their religious beliefs to reduce the insect infestation in rice fields (Table 3.7).

Fig. 3.4 Traditional pest management calendar for traditional rice varieties in the high hill region.

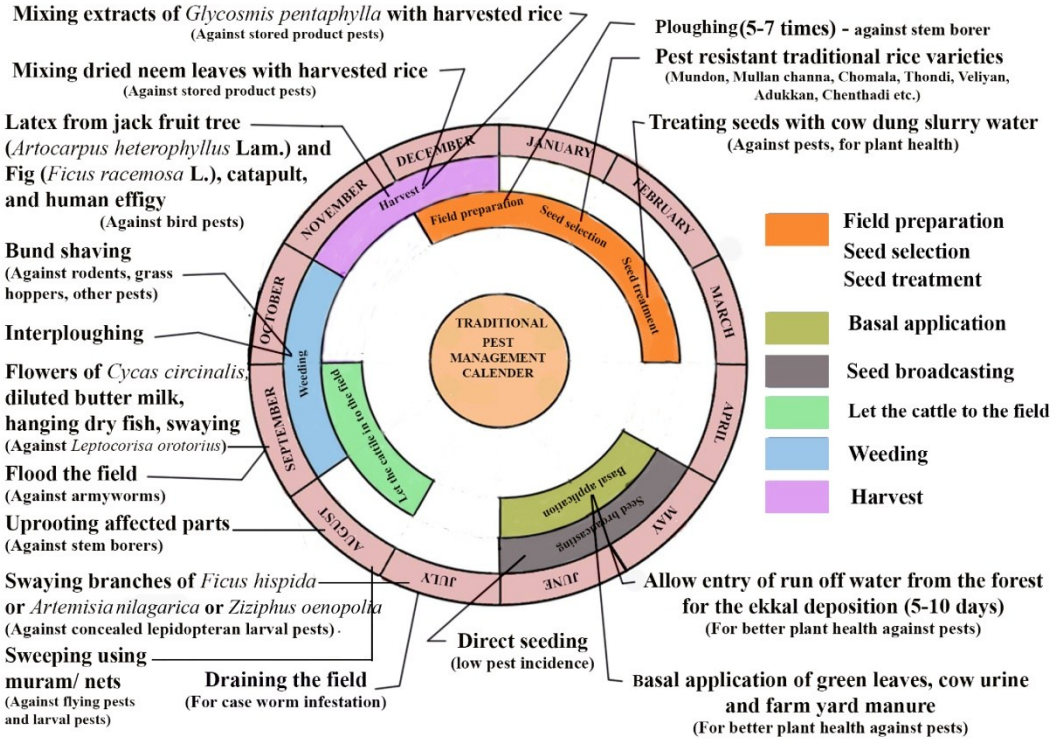


Table 3.7. Rice pest management belief/ceremony of tribal farmers in the high hill region of North Kerala.

Tribal group	Belief/ceremony	Target pests
Kuruchiyar	Mantras are recited while charcoal, turmeric powder, and lime are mixed in a coconut shell and placed at the edge of the rice field. They believe that pests will stay away because of the marked contrast between black and yellow.	Birds
Most tribal communities	To create an erect post called "vavu," they gather twigs from some of the common trees in the nearby forest and bundle them.	Against all pests and diseases
Wayanadan chetti	They offer a black fowl and fried rice to God during March and April on Uthradam nakshatra (auspicious day). The ceremony is called Vaikattu, Vaipoottal, or Panchakacham.	Birds, cattles, wild boar and other pests

Influence of rice varietal differences on pest infestation

Based on secondary data, field research was conducted to identify and examine pest resistance in several rice varieties. According to secondary data, the rice cultivars Adukkan, Chennellu, Chenthadi, Mundon, and Veliyan are resistant to pests, although field observations contradict this. Field observations revealed that the rice varieties Kanakam, Kunjuthi, Kunkumsali, Kunnumkulamban, Marathondi, Onachanna, Pal kayama, Thonnuram thondi, Uruthi kayama, and Velumbala were resistant to pests (Table 3.8).

Table 3.8. Comparison of pest resistance of both the traditional and high yield varieties based on the secondary information and the field observation. The bold texts represent significant results.

Type of rice variety	Name	Pest resistance (Based on secondary information)	Pest resistance (Based on field observation)
Traditional rice varieties	Adukkan	**Yes**	**No**
	Chembakam	No	No
	Chennel thondi	No	No
	Chennellu	**Yes**	**No**
	Chenthadi	**Yes**	**No**
	Chettu veliyan	No	No
	Chomala	No	No
	Chuvanna navara	No	No
	Gandhakasala	No	No
	Jeerakasala	No	No
	Kalladiyaryan	No	No
	Kanakam	**No**	**Yes**
	Kanni chennellu	No	No
	Karanjan	No	No
	Karimbadan	No	No
	Kayama	No	No
	Koduveliyan	No	No
	Kothambarikayama	No	No
	Kothandan	No	No
	Kovumbali	No	No
	Kunjikayama	No	No
	Kunjuthi	**No**	**Yes**

	Kunkumasali	**No**	**Yes**
	Kunnumkulamban	**No**	**Yes**
	Kuruva	No	No
	Marathondi	**No**	**Yes**
	Mundon	**Yes**	**No**
	Nasarbath	No	No
	Navara	No	No
	Okkapuncha	No	No
	Okkaveliyan	No	No
	Onachanna	**No**	**Yes**
	Onamottan	No	No
	Pal kayama	**No**	**Yes**
	Pal veliyan	No	No
	Palthondi	No	No
	Palthondi matta	No	No
	Punnaran thondi	No	No
	Raktasali	No	No
	Thavalakannan	No	No
	Thondi	Yes	Yes
	Thonnuram punja	No	No
	Thonnuran thondi	**No**	**Yes**
	Uruthi kayama	**No**	**Yes**
	Valichoori	No	No
	Veliyan	**Yes**	**No**
	Vellimuth	No	No
	Velumbala	**No**	**Yes**
	Vethandam	No	No
High yield rice varieties	Aathira	No	No
	Uma	No	No
	Kanjana	No	No
	IR 20	No	No

Only traditional rice varieties exhibited pest resistance in the study region, so those varieties were ranked according to their pest index. Among the forty-nine traditional rice varieties, the following were ranked first: Kanakam, Kayama, Kunjuthi, Kunkumasali, Kunnumkulamban, Marathondi, Onachanna, Pal Kayama, Raktasali, Thondi, Thonnuran Thondi, Uruthi Kayama, and Velumbala. The

Jeerakasala rice variety showed the least pest resistance in the study site, followed by Valichoori, Mundon, and Gandhakasala (Table 3.9).

Table 3.9. Ranking of pest resistance of traditional rice varieties based on pest index.

Sl No.	Rice variety	Pest index	Ranking based on pest resistance
1	Kanakam	0.00	1
2	Kayama	0.00	1
3	Kunjuthi	0.00	1
4	Kunkumasali	0.00	1
5	Kunnumkulamban	0.00	1
6	Marathondi	0.00	1
7	Onachanna	0.00	1
8	Pal kayama	0.00	1
9	Raktasali	0.00	1
10	Thondi	0.00	1
11	Thonnuran thondi	0.00	1
12	Uruthi kayama	0.00	1
13	Velumbala	0.00	1
14	Koduveliyan	1.79	2
15	Kalladiyaryan	1.85	3
16	Vethandam	1.97	4
17	Chuvanna navara	2.51	5
18	Okkan punja	2.46	6
19	Nasarbath	2.48	7
20	Kovumbali	2.70	8
21	Onamottan	2.71	9
22	Vellimuth	2.74	10
23	Kothambarikayama	2.75	11
24	Kuruva	2.82	12
25	Chembakam	3.17	13
26	Chennel thondi	3.63	14
27	Palthondi matta	3.69	15
28	Thonnuram punja	4.06	16
29	Chennellu	4.09	17
30	Kunjikayama	4.17	18
31	Karimbadan	4.23	19
32	Karanjan	4.69	20
33	Chenthadi	4.99	21
34	Punnaran thondi	5.20	22
35	Chomala	5.41	23
36	Palthondi	6.46	24
37	Okka veliyan	6.66	25
38	Kanni chennellu	6.72	26

39	Kothandan	6.80	27
40	Chettu veliyan	6.80	28
41	Veliyan	6.89	29
42	Adukkan	6.95	30
43	Navara	6.96	31
44	Thavalakannan	7.75	32
45	Pal veliyan	9.48	33
46	Gandhakasala	12.23	34
47	Mundon	14.19	35
48	Valichoori	14.27	36
49	Jeerakasala	16.27	37

Yellow stem borer susceptibility of rice varieties

Farmers grew high-yield rice varieties in the study area, mainly Aathira, Aiswarya, Kanchana, and Uma. The YSB (*Scirpophaga incertulas*) susceptibility of the traditional rice was examined by selecting aromatic varieties, including Jeerakasala, Gandhakasala, and Chomala. We analyzed the effect of plant biometric characters of high-yield and traditional varieties on YSB infestation. The Pearson correlation matrix revealed a significant difference between the average clutch size of *Scirpophaga incertulas* and the plant's biometric characteristics (culm length, culm width, cultivar duration, leaf width where egg mass of *S. incertulas* is laid, panicle length, and the number of tillers). Except for leaf width where the egg mass laid, the number of white ear heads also significantly differed from the other plant morphological characters (Table 3.10). The relationship was plotted between the number of white ear heads and average clutch size with the significant morphological characters of (culm length, culm width, cultivation duration, number of tillers, and panicle length) traditional and high-yield rice varieties (Figures 3.5 to 3.9). Plant biometric analyses of different rice varieties revealed that the YSB egg mass in the Gandhakasala rice variety has a larger clutch size and causes more white ear heads than the others (Figures 3.5 to 3.9).

Table 3.10. Pearson correlation matrix of trend (rice morphological features versus yellow stem borer infestation) in the high hill region of North Kerala.

	Panicle length	**Culm length**	**Cultivar duration**	**Number of tillers**	**Culm width**	**Leaf width at egg mass laid**	**Number of white ear head/plot**	**Average clutch size**
Panicle length	— —							
Culm length	0.398*** <0.001	— —						
Cultivar duration	0.282* 0.018	0.807*** <0.001	— —					
Number of tillers	-0.360** 0.002	-0.819*** <0.001	-0.737*** <0.001	— —				
Culm width	0.342** 0.004	0.791*** <0.001	0.966*** <0.001	-0.706*** <0.001	— —			
Leaf width at egg mass laid	0.267* 0.025	0.183 0.130	0.115 0.345	-0.084 0.488	0.130 0.285	— —		
Number of white ear head/plot	0.394*** <0.001	0.653*** <0.001	0.842*** <0.001	-0.555*** <0.001	0.909*** <0.001	0.116 0.337	— —	
Average clutch size	0.738*** <0.001	0.543*** <0.001	0.594*** <0.001	-0.511 <0.001	0.683*** <0.001	0.279*** <0.001	1.000*** <0.001	— —

Fig. 3.5 The relationship between the number of white ear heads (a) and average clutch size (b) with the culm length of traditional (Chomala, Gandhakasala, and Jeerakasala) and high-yield rice varieties (Aathira, Aiswarya, Kanchana, and Uma).

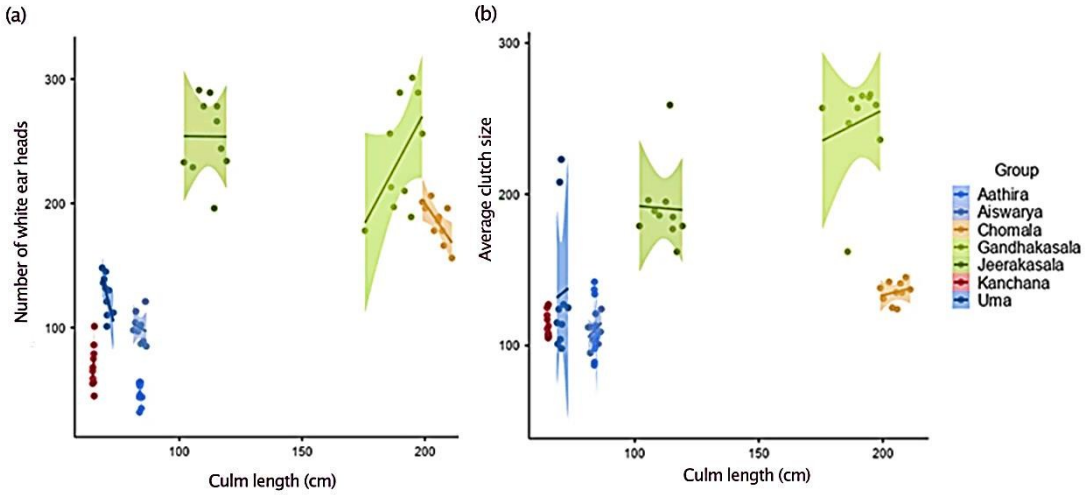


Fig. 3.6 The relationship between the number of white ear heads (a) and average clutch size (b) with the culm width of traditional (Chomala, Gandhakasala, and Jeerakasala) and high-yield rice varieties (Aathira, Aiswarya, Kanchana, and Uma).

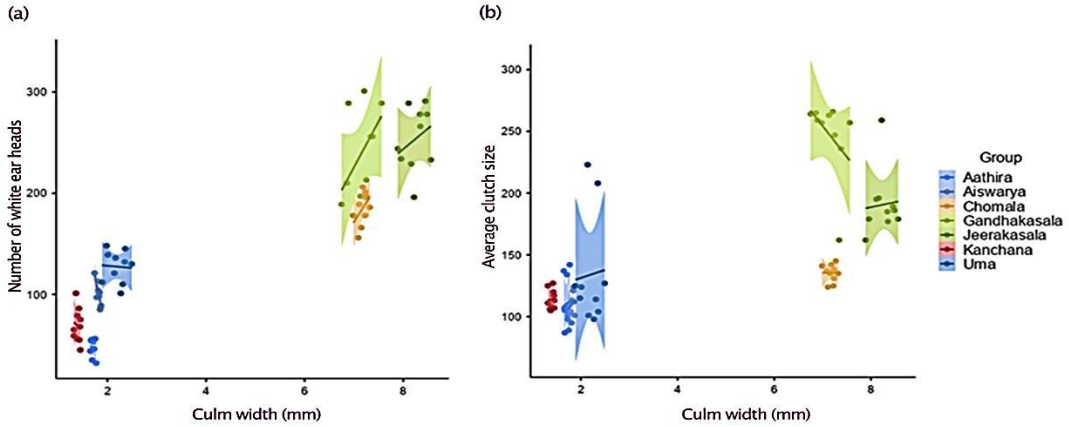


Fig. 3.7 The relationship between the number of white ear heads (a) and average clutch size (b) with the cultivar duration of traditional (Chomala, Gandhakasala, and Jeerakasala) and high-yield rice varieties (Aathira, Aiswarya, Kanchana, and Uma).

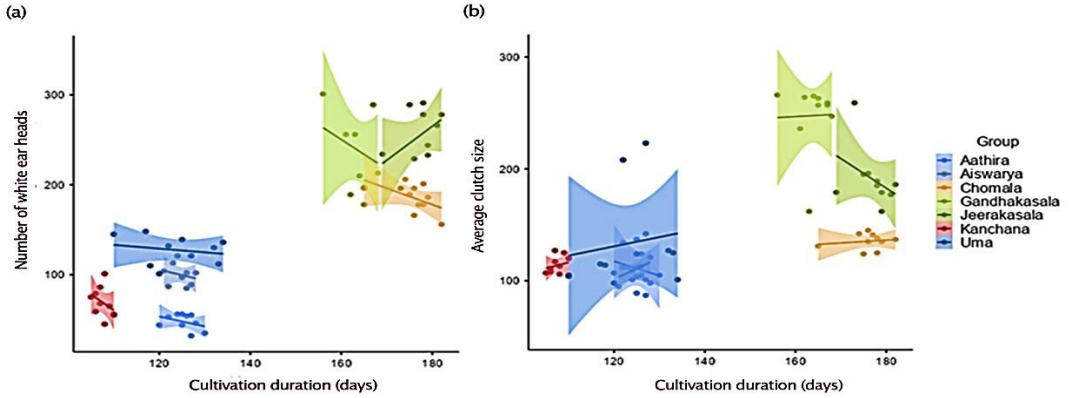


Fig. 3.8 The relationship between the number of white ear heads (a) and average clutch size (b) with the average tiller number per hill of traditional (Chomala, Gandhakasala, and Jeerakasala) and high-yield rice varieties (Aathira, Aiswarya, Kanchana, and Uma).

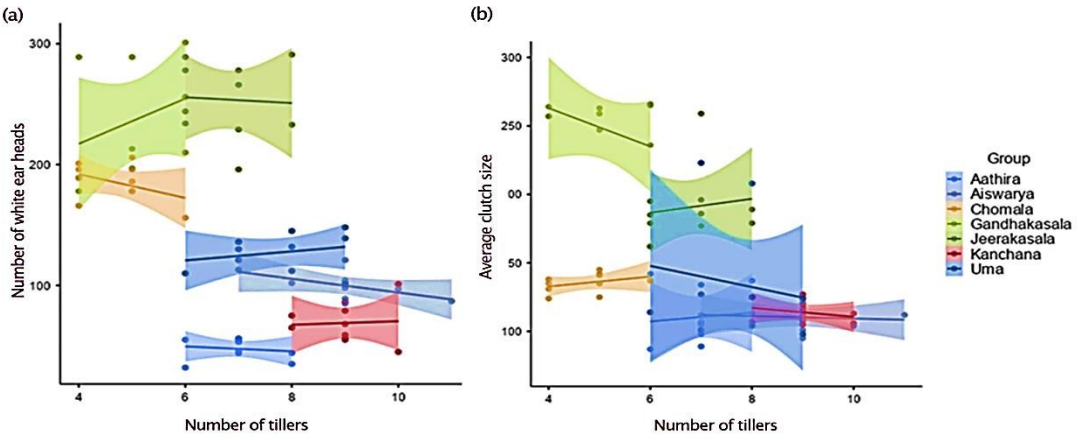


Fig. 3.9 The relationship between the number of white ear heads (a) and average clutch size (b) with the panicle length of traditional (Chomala, Gandhakasala, and Jeerakasala) and high-yield rice varieties (Aathira, Aiswarya, Kanchana, and Uma).

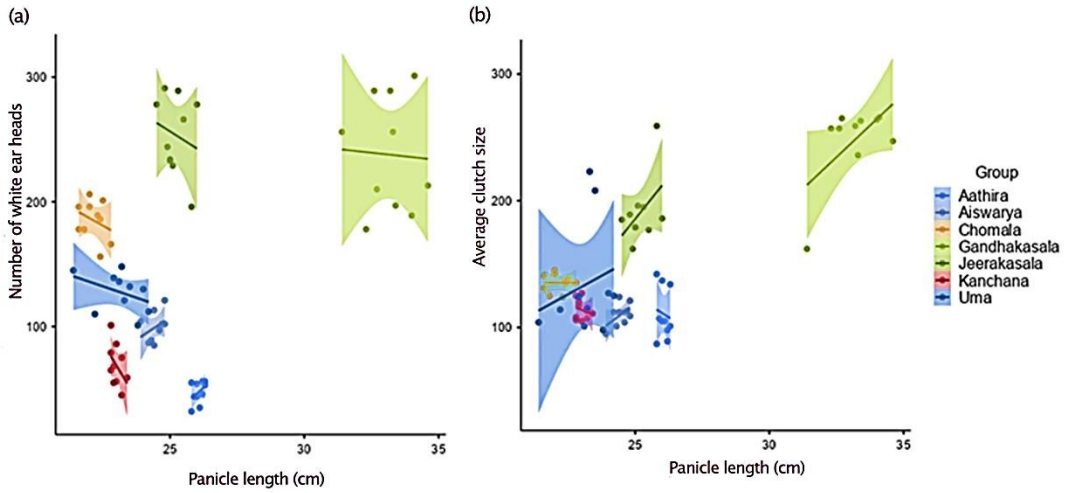
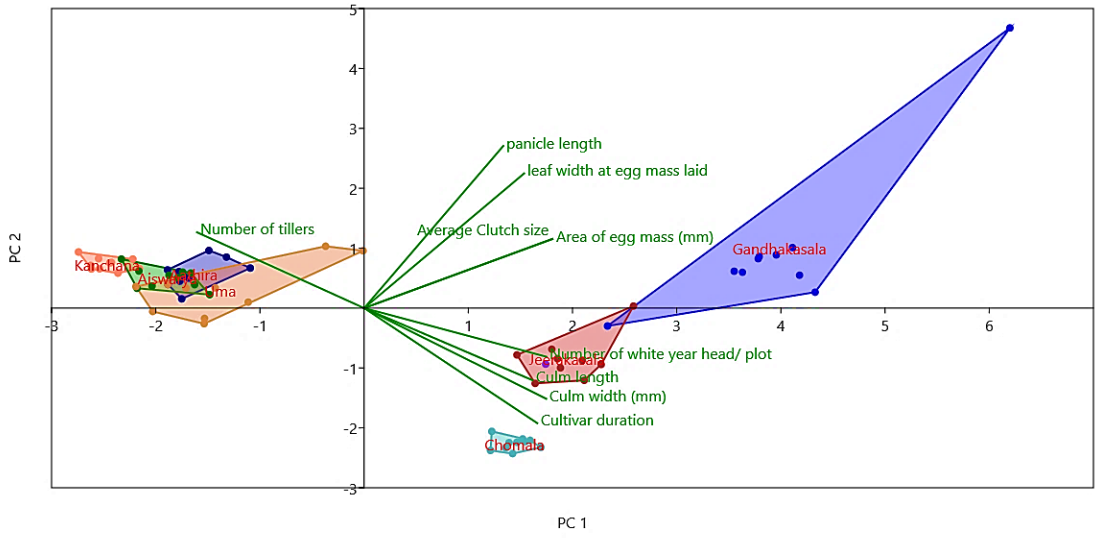


Fig. 3.10 Principal component analysis (PCA) biplot of the rice plant morphological characters that measure the susceptibility of yellow stem borer infestation in the traditional (Chomala, Gandhakasala, and Jeerakasala) and high-yield rice varieties (Aathira, Aiswarya, Kanchana, and Uma).



In Principal component analysis (PCA), components 1 (PC1) and 2 (PC2) together explain 90.69% of the variance, sufficient to explain the data (Table 3.11). The relationship between plant physical characteristics and yellow stem borer infestation in traditional and high-yield rice varieties varied. Traditional varieties such as Gandhakasala, Jeerakasala, and Chomala form one cluster, while high-yielding varieties (Aathira, Aiswarya, Kanchana, and Uma) form another, indicating

the distinctiveness in morphometric characters. The variables used to indicate the yellow stem borer infestation (clutch size, white ear heads, and area of egg mass) show a linear relation with panicle length, culm length, culm width, and cultivar duration. At the same time, the number of tillers negatively correlates with yellow stem borer infestation. The Jeerakasala and Gandhakasala varieties overlapped, indicating shared characteristics (Fig. 3.10).

Table 3.11. Loading scores of the principal component analysis (PCA) of the rice plant morphological characters (panicle length, culm length, cultivar duration, number of tillers, culm width, and leaf width at egg mass laid) that measure the susceptibility of yellow stem borer infestation (number of white ear heads per plot, average clutch size, and area of the egg mass) in the traditional (Chomala, Gandhakasala, and Jeerakasala) and high-yield (Aathira, Aiswarya, Kanchana, and Uma) rice varieties. Principal component 1 (PC1) captures the highest variation in the data, while Principal component 2 (PC2) accounts for the second-highest variation in the data.

	PC 1	**PC 2**
Eigen value	6.5894	1.57315
% variance	73.216	17.479
Panicle length	0.25988	0.51784
Culm length	0.35185	-0.23491
Cultivar duration	0.37209	-0.3199
Number of tillers	-0.32627	0.25975
Culm width (mm)	0.38833	-0.24568
Leaf width at egg mass laid	0.10781	0.44746
Number of white ear head/ plot	0.36843	-0.12981
Average Clutch size	0.36442	0.33866
Area of egg mass (mm)	0.36441	0.33873

A t-test was done to compare the clutch size, area of egg mass, and the number of white ear heads formed in the Uma and Gandhakasala rice varieties. The clutch size (203.8$\pm$20.35), egg mass area (28.76$\pm$2.86), and white ear heads (338$\pm$58.78) were higher in the Gandhakasala rice variety. The result showed a significant difference in stem borer infestation between the high-yield and traditional rice varieties if they grew together ($p<0.05$) (Table 3.12). There is a significant

difference in clutch size and the number of white ear heads in the mixed plot of Uma (high yield) and Gandhakasala (traditional) rice varieties. In the presence of the Gandhakasala variety, the Uma variety showed a decrease in YSB infestation (clutch size: 101.87±11.54; and the number of white ear heads: 43.9±8.83; Table 3.13 and Fig. 3.11). Similarly, Gandhakasala showed a significant difference in YSB infestation in the presence or absence of the high-yield variety. In the mixed plot, the number of white ear heads formed (338±58.78), the clutch size (203.8±20.35), and the egg area (28.76±2.86) are higher than as a mono-crop in Gandhakasala variety (Table 3.14 and Fig. 3.12).

Table 3.12. t-test for comparing yellow stem borer clutch size, area of egg mass, and the number of white ear heads in a mixed plot of Uma (high yield) and Gandhakasala (traditional) rice varieties. SD-Standard Deviation.

	Uma **Mean±SD**	Gandhakasala **Mean±SD**	t-test
Clutch size	101.8±11.54	203.8±20.35	$t(18)=13.78, p<0.05$
No. of white ear heads	43.9±8.83	338±58.78	$t(18)=15.645, p<0.05$

Table 3.13. t-test for comparing yellow stem borer clutch size, area of egg mass, and the number of white ear heads in the Uma rice variety in the presence or absence of Gandhakasala. SD-Standard Deviation.

	With Gandhakasala **Mean±SD**	Without Gandhakasala **Mean±SD**	t-test
Clutch size	101.87±11.54	237.8±45.8	$t(18)=9.09, p<0.05$
No. of white ear heads	43.9±8.83	247.6±31.47	$t(18)=19.703$, $p<0.05$

Table.3.14 t-test for comparing yellow stem borer clutch size, area of egg mass, and the number of white ear heads in Gandhakasala rice variety in the presence or absence of Uma. SD-Standard Deviation.

	With Uma **Mean±SD**	Without Uma **Mean±SD**	t-test
Clutch size	203.8±20.35	127.4±15.80	$t(18)=9.37, p<0.05$
No. of white ear heads	338±58.78	133.9±44.31	$t(18)=8.76, p<0.05$

Fig. 3.11 Comparison of clutch size of *Scirpophaga incertulas* in the high yield variety and traditional variety: (a) in the Uma rice variety (high yield variety) in the presence or absence of Gandhakasala, and (b) in the Gandhakasala rice variety as a mixed crop and a mono-crop.

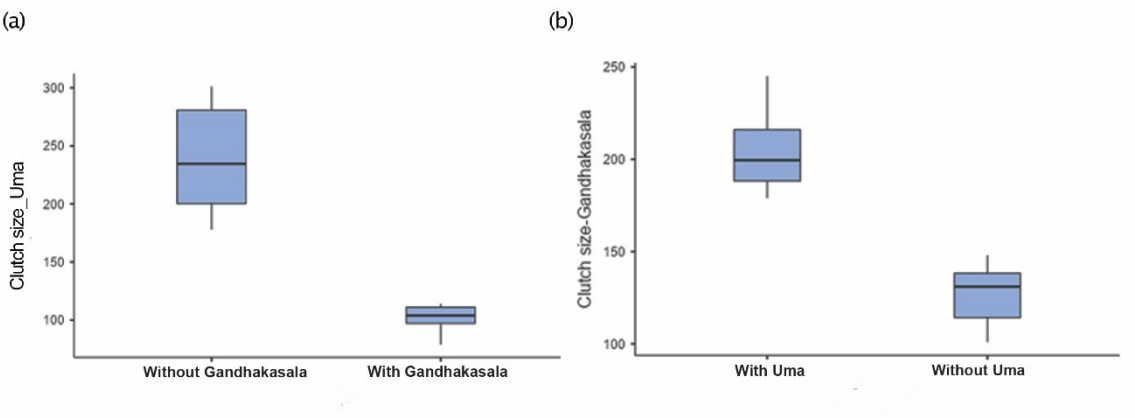
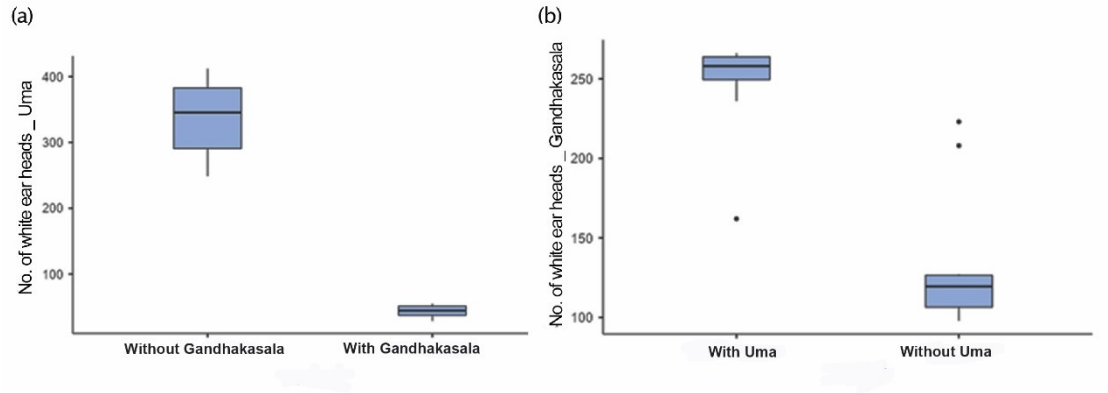


Fig. 3.12 Comparison of number of white ear heads formed in the high yield variety and traditional yield variety: (a) in the Uma rice variety (high yield variety) in the presence or absence of Gandhakasala, and (b) in the Gandhakasala rice variety in the presence Uma variety and a mono-crop.



Farmer's knowledge and perception on rice pest management

Farmer profile

The surveyed farmers in North Kerala were mainly men (82.9%). The majority of surveyed farmers (67.0%) fell within the above-middle age category (<60 years) across all three zones. Specifically, 31.2% were between 50 and 60 years old, while 1.7% were below 50. The family labor force was utilized by 50% of the farmers, and the highest utilization was in the high hill region (62.7%). In the survey, 79.9% of farmers were literate, while 21.0% were illiterate. Among the

literate, 38.2% had undergone elementary education (classes 1–7), while 40.6% of the respondents had high school and above education (classes 8–10 and above). The high hill region had a high level of elementary education (38.7%), while the foothill (44.7%) and midland laterite (41.9%) regions had a high level of high school or higher education. In the study region, 47.0% of farmers had 15 to 25 years of agricultural experience, 32.0% had more than 25 years of experience, and 20.9% had less than 15 years of farming experience. Most farmers in the high hill region had an average experience of over 25 years (41.3%), whereas it was between 15 and 25 years in the foothill (48.2%) and midland laterite regions (61.9%). The primary occupation of 58.8% of farmers was agriculture, and the percentage of farmers with agriculture as their occupation was high in the high hill region (72.7%). Most farmers consume the rice they produce (97.5%), which is 100% in the foothill and midland laterite regions. Only 19.3% of farmers sell their entire rice crop products and do not use them for consumption, which is in the high hill region. The primary source of income varied among farmers. Many depend on agriculture (58.5%). The income source for 21.7% of farmers is business, and 16.2% rely on the service sector. The 61.7% of the farmers surveyed possessed 1 to 2 acres of land. However, 87.9% of them used less than one acre for rice production. All farmers (100%) surveyed in the foothill region had less than 1 acre of land for rice production. The purpose of rice production for 33.8% of farmers was only for consumption; 8.5% sold the rice grains entirely, whereas 57.6% sold and consumed the rice. In the high hill region (58.0%) and the midland laterite region (96.2%), farmers mainly sell and consume rice grains. In contrast, most farmers in the foothill region consume rice (90.6%). 58.5% of farmers in North Kerala had no off-farm income, but 55.3% in the foothill region had off-farm income. The income from agriculture was less than 1 lakh for many farmers (57.1%), 32.9% had 1 lakh to 2 lakhs, and only 10% of farmers earned more than two lakhs per year. The percentage of farmers who attended the pest management training programs was significantly lower in all three zones, and only 25% participated in the training. Chemical pesticide applications were made by 40.6% of farmers. In the high hill region, pesticide application was made by most farmers surveyed (62.0%), which is much higher when compared to

application of pesticides by the farmers of the foothill and midland laterite zones (Table 3.15).

Table 3.15. Socio-economic characteristics of the respondents in three agro-ecological zones of North Kerala.

Variable	High hill (n=150)	Foothill (n=85)	Midland laterite (n=105)
	Frequency (% Response)	Frequency (% Response)	Frequency (% Response)
Gender			
Male	125 (83.3)	61 (71.8)	96 (91.4)
female	25 (16.7)	24 (28.2)	9 (8.7)
Age			
>50 years	3 (2.0)	2 (2.4)	1 (0.9)
From 50 to 60 years	48 (32.0)	20 (23.5)	39 (37.1)
<60 years	99 (66.0)	63 (74.1)	65 (61.9)
Family labor force			
Yes	94 (62.7)	34 (40.0)	42 (40.0)
No	56 (37.3)	51 (60.0)	63 (60.0)
Educational level			
Illiterate	36 (24.0)	16 (18.8)	20 (19.0)
Elementary	58 (38.7)	31 (36.5)	41 (39.0)
High school or above	56 (37.3)	38 (44.7)	44 (41.9)
Experience in agriculture			
>15 years	34 (22.7)	15 (17.6)	22 (21.0)
From 15 to 25 years	54 (36.0)	41 (48.2)	65 (61.9)
<25 years	62 (41.3)	29 (34.1)	18 (17.1)
Agriculture main occupation			
Yes	109 (72.7)	38 (44.7)	53 (50.5)
No	41 (27.3)	47 (55.3)	52 (49.5)
Self-consumption of product			
Yes	121 (80.7)	85 (100)	105 (100)
No	29 (19.3)	0	0
Source of Income			
Agriculture	108 (72.0)	38 (44.7)	53 (50.5)
Business	23 (15.3)	11 (12.9)	40 (38.0)

Service	16 (10.7)	27 (31.8)	12 (11.4)
Others	3 (2.0)	9 (10.6)	0
Total land size			
>1 acre	15 (10.0)	14 (16.5)	18 (17.1)
1 acre to 2 acre	94 (62.7)	48 (56.5)	66 (62.9)
<2 acre	41 (27.3)	23 (27.0)	21 (20.0)
Land for rice production			
>1 acre	111 (74.0)	85 (100)	103 (98.1)
1 acre to 2 acre	38 (25.3)	0	2 (1.9)
<2 acre	1 (0.7)	0	0
Purpose of rice production			
Consumption	34 (22.7)	77 (90.6)	4 (3.8)
Sell	29 (19.3)	0	0
both	87 (58.0)	8 (9.4)	101 (96.2)
Having off farm income			
Yes	42 (28.0)	47 (55.3)	52 (49.5)
No	108 (72.0)	38 (44.7)	53 (50.5)
Income from agriculture			
>1 lakh	72 (48.0)	65 (76.5)	57 (54.3)
1 lakh to 2.5 lakh	63 (42.0)	16 (18.8)	33 (31.4)
<2.5 lakh	15 (10.0)	4 (4.7)	15 (14.3)
Pest management training			
Yes	35 (23.3)	38 (44.7)	32 (30.5)
No	115 (76.7)	57 (67.0)	83 (79.0)
Pesticide treatment			
Yes	93 (62.0)	14 (16.5)	31 (29.5)
No	57 (38.0)	71 (83.5)	74 (70.5)

The understanding of farmers regarding rice pests and their natural enemies

Farmers generally referred to several insect pests known to infest rice crops using local terminology. Farmers cannot distinguish rice insect pests from their green-colored larval stages. They termed it “Pacha puzhu” (=Green Caterpillar) for six pests (*Ampittia dioscorides*, *Melanitis leda ismene*, *Parnara* sp., *Pelopidas agna*,

Pelopidas mathias, and *Naranga aenescence*). Three of them, *Parnara* sp., *P. agna*, and *P. mathias*, were also given the name "Ila churutti" (Leaf roller) rather than "Ila madakki." For rice pests with comparable symptoms of the damage, farmers use the same common name. For *Cnaphalocrocis medinalis*, *Helcystogramma arotraeum*, and *Leptispa pygmaea*, they called it "Ila churutti puzhu." In contrast, *Scirpophaga incertulas* and *Scirpophaga innotata*, were called "Thanduthurappan." *Mythimna seperata*, *Spodoptera litura*, and *Spodoptera mauritia* were named "Pattala puzhu." *Leptocorisa oratorius*, *S. incertulas*, *S. innotata*, and *Nilaparvata lugens* are together referred to as "chaazhi." In addition, grasshoppers such as *Hieroglyphus banian*, *Oxya hyla*, *Euscyrtus concinnus*, and *Tetrix subulata* were called "Pacha thullan/Pulchaadi/Pacha kuthira." Some farmers referred to the "Kuzhal puzhu" (*Parapoynx stagnalis*) as "Ila churutti." Nevertheless, all the farmers appropriately named "Ila churutti" the major pest of Kerala, the rice leaf folder *C. medinalis* (Table 5).

Table 3.16. Percentage of farmers citing various rice pests in three agro-ecological zones, viz., high hill (n=150), foothill (n=85), and midland laterites (n=105) of North Kerala during 2017–2019.

Rice pests	**Agro-ecological zones**		
	High hill	Foothill	Midland laterite
Deer	45	0	0
Elephant	57	0	0
Insects	54	100	100
Monkey	26	0	0
Peacock	31	0	0
Rodents	29	32	19
Small birds	17	11	24
Wild boars	79	35	0

Farmers mentioned more vertebrate pest species in the high hill area (n=7). Wild boars were considered a pest by 79% of the farmers, followed by elephants (57%) and insects (54%). According to the farmers in the high hill region, deer also caused substantial damage to the paddy (45%). On the other hand, insects were

recognized as serious paddy pests in the foothill and midland laterite zones (100%). According to farmers in the foothill region, rodents (35%) and wild boars (32% each) came in second and third, respectively. However, in the midland laterite region, small birds (24%) and rodents (19%) came in second and third positions, as cited by the farmers. The lowest number of pest categories mentioned was from the midland laterite region (n=3) (Table 3.16).

Farmers generally possessed limited to moderate knowledge regarding insect pests, with average scores ranging from 1.35 to 2.53. Typically, farmers could identify one or two insect pests and articulate at least one type of damage inflicted on rice by each identified pest. Farmers from the foothill region (score=2.53) had the highest knowledge of insect pests. In contrast, farmers from the midland laterite (score=1.35) had the lowest level of knowledge of insect pests (Fig. 3.13).

Fig. 3.13 Farmers' awareness of insect rice pests across three agro-ecological zones in North Kerala: high hill (n=150), foothill (n=85), and midland laterite (n=105). Scores ranged from 0 to 3, with 0 indicating no knowledge, 1 representing low knowledge, 2 denoting medium knowledge, and 3 indicating high knowledge.

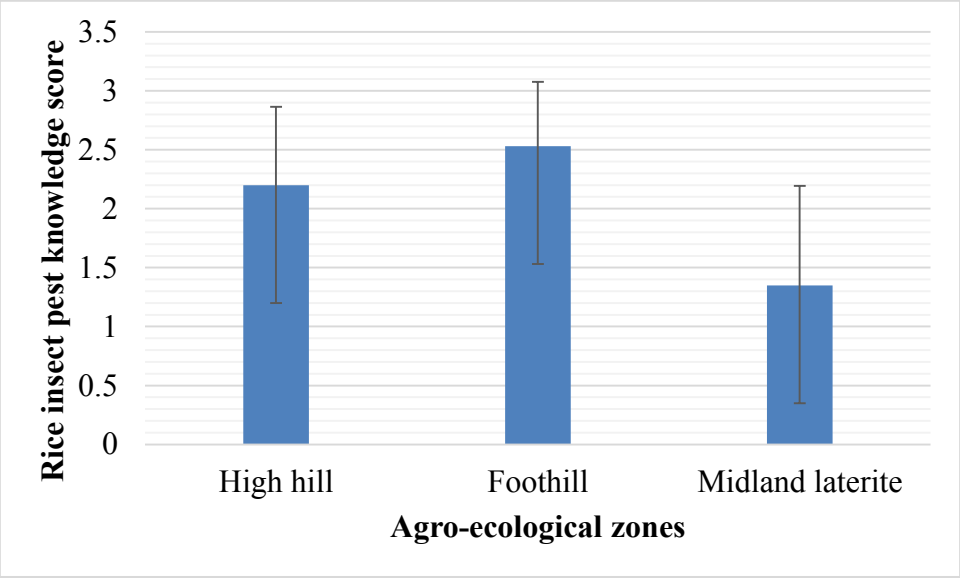
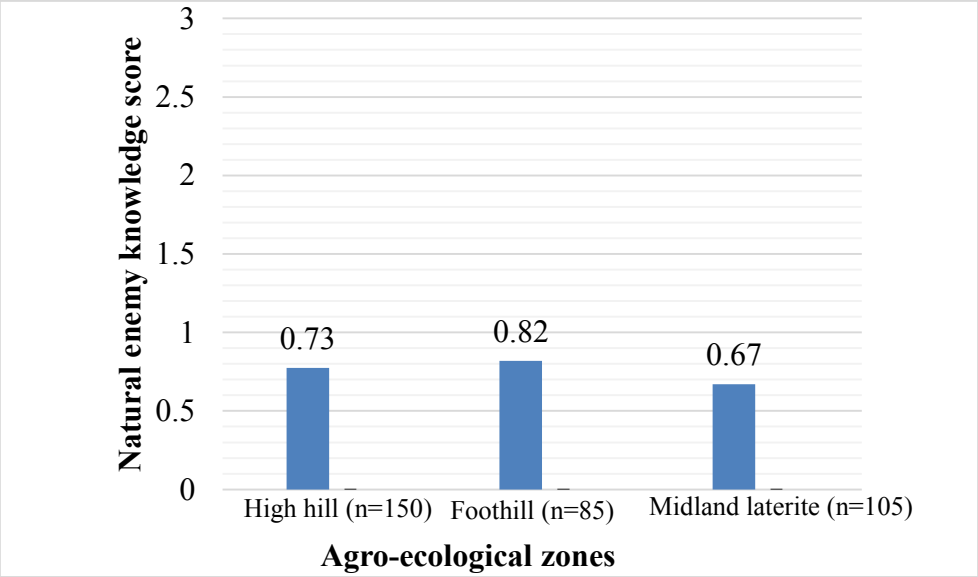


Fig. 3.14 Farmers' awareness of natural enemies across three agro-ecological zones in North Kerala: high hill (n=150), foothill (n=85), and midland laterite (n=105). Scores ranged from 0 to 3, with 0 indicating no knowledge, 1 representing low knowledge, 2 denoting medium knowledge, and 3 indicating high knowledge.



On average, farmers had very low knowledge of the natural enemies of rice pests (score, 0.67–0.82). Farmers named zero or one natural enemy and could not describe at least one feature of each natural enemy (Fig. 3.15). Farmers from the foothill region (score=0.82) had the highest knowledge of natural enemies. In contrast, farmers from the midland laterite (score=0.67) had the lowest understanding of natural enemies (Fig. 3.14).

All farmers surveyed (100%) recognized the damage caused by rice insect pests in their rice fields. Most identified the pest during its larval stage (87.64% of respondents). Farmers (72.05% of respondents) cited their personal experience as their primary source of pest knowledge, followed by information from their farmer peer groups (53.82%). For most farmers, rice plants were more vulnerable to pest attack in the booting stages of the paddy (82.94% of respondents), and 64.7% responded that pest severity was in the wet season (Table 3.17).

Table 3.17. Farmers' understanding and perceptions of rice insect pests.

Variables		**Numbers (respondents)**	**Frequency (%)**
Understanding the damage caused by rice insect pests		340	100.00
Knowledge of rice insect pest developmental stages	Egg	30	8.82
	Larva	298	87.64
	Pupa	15	4.41
	Adult	110	32.35
Farmer information sources of rice pests	Own observation in the field	245	72.05
	Extension officers	32	9.41
	Medias (radio/television/Magazines)	64	18.82
	Farmers peer group	183	53.82
	Friends/relatives	51	15.00
	No information on rice pests	11	3.23
farmers' perception of rice plant vulnerability across developmental stages	Vegetative	123	36.17
	Booting	282	82.94
	Ripening	198	58.23
Severe rice pest attack periods	Dry season	104	30.58
	Wet season	220	64.70
	Both seasons	16	4.70

Most farmers identified the leaf folder pests from the damaged leaves (68.2% of respondents), followed by discolored grains made by the rice bugs (42.4%). The white ear head formed by the attack of rice stem borers was the least identified (10.9% of respondents) (Table 3.18).

Table 3.18. Farmer's recognition of rice pests based on actual specimen or damage.

Recognition	% Response (N=340)
Cut off leaf tip from case worms	28.8
Defoliation from leaf feeder	25.0
Discolored grains by rice bug adult	42.4
Hopper burn	12.9
Leaf folder damaged leaves	68.2
Stem borer dead heart	20.9
White ear head by stem borers	10.0

After viewing the photographs, farmers responded in the interview to the presence or absence of insect pests in their rice fields. According to farmers, leaf folders (*Cnaphalocrocis medinalis*) were the most common insect pests in the three agro-ecological zones. They were reported by 58.5% of respondents, followed by rice bugs (*Leptocorisa oratorius*) (55.9% of respondents) and case worms (*Parapoynx stagnalis*) (third, 48.23% of respondents). Caseworms were reported as a severe pest in the high hill (62.7% of respondents) and foothill regions (77.6%). In contrast, leaf folders were the most severe pest in the midland laterite region (67.6%). The perceived incidence of armyworms, caseworms, and stemborers significantly differed in all three agro-ecological zones (Table 3.19).

Table 3.19. Perceived incidence of rice insect pests in three agro-ecological zones of North Kerala; percent respondents; n=340).

Insect pest	High hill	Foothill	Midland laterite	Overall	χ^2
Army worms	52.00	2.4	5.7	25.3	76.9^{***}
Case worms	62.7	77.6	3.8	48.2	63.4^{***}
Leaf folders	46.0	69.4	67.6	58.5	5.6^{ns}
Leaf rollers	20.7	28.2	27.6	24.7	1.4^{ns}
Rice bugs	58.7	67.1	42.9	55.9	5.4^{ns}
Stem borers	16.0	21.2	48.6	27.4	21.4^{***}

Note: Statistically significant at *P ≤0.05, **P ≤ 0.01, ***P ≤ 0.001; ns=not significant.

Only 26.8% of the surveyed farmers knew about biological control. The most cited natural enemies of rice pests were dragonflies (18.3% of respondents), followed by spiders (8.2%). Farmers had the least information about parasitoids as the natural enemies of rice pests (1.2%). Among the knowledgeable farmers, the sources of knowledge on natural enemies of rice pests were mainly the extension officers (6.2% of respondents) and farmer peer groups (5.6% of respondents) (Table 3.20).

Table 3.20. Farmers' knowledge and perceptions of natural enemies of rice pests (n=340).

Variables		**Numbers**	**Frequency (%)**
Knowledge of biological control		91	26.8
Knowledge of natural enemies of rice pests	Ants	22	6.5
	Birds	31	9.1
	Dragonflies	62	18.2
	Lady bird beetle	7	2.1
	Pathogens	5	1.5
	Parasitoids	4	1.2
	Spiders	28	8.2
	Wasps	11	3.2
Farmer primary information sources of natural enemies of rice pests	Own observation in the field	8	2.4
	Extension officers	21	6.2
	Media(radio/television/Magazines)	17	5.0
	Farmers peer group	19	5.6
	Friends/relatives	4	1.2

After seeing the photographs, the percentage of respondents on the presence of natural enemies has increased. 94.4% and 91.8% of the farmers mentioned spiders and dragonflies respectively as the most common natural enemies in the three agro-ecological zones. Interestingly, even after seeing the photographs, farmers in all three zones responded least to the presence of parasitic wasps (4.1%) (Table 3.21).

Table 3.21. Perceived incidence of natural enemies of rice pests in three agro-ecological zones of North Kerala; per cent respondents; n=340).

Natural enemies	High hill (n=150)	Foothill (n=85)	Midland laterite (n=105)	Overall	χ^2
Ants	16.0	42.4	29.5	26.8	11.9*
Birds	40.7	44.7	28.6	37.9	3.7
Dragonflies	89.3	91.8	95.2	91.8	0.19
Lady bird beetles	6.0	42.4	20.0	25.3	29.5*
Parasitoids	1.3	9.4	3.8	4.1	7.07
Spiders	88.0	100.0	99.0	94.4	0.92
Wasps	11.3	36.5	26.7	22.4	12.9*

∗ Means statistically different at P≤0.05

The farmers' agricultural experience and contact with research institutes or extension services influenced their knowledge of rice pests (Spearman rank correlation, $p<0.05$). There was a positive correlation between knowledge of rice pests, perception of pest damage, and farmers' contact with research institutes or extension services (Spearman rank correlation, $p<0.05$). Contrarily, there was no relationship between knowledge of natural enemies and the farmers' socio-economic characteristics in the study region (Table 3.22).

Table 3.22. Correlation Analysis: Spearman rank correlation values (r) and significance levels for relationships between farmer knowledge of rice pests, natural enemies, perception of damage, and socio-economic characteristics. The bold digits represent significant results.

Socio-Economic Characteristics	Knowledge of rice pests	Knowledge of natural enemies	Perception of rice pests damage
Age	-0.050 (0.354)	-0.039 (0.472)	-0.045 (0.407)
Education level	-0.002 (0.959)	-0.044 (0.414)	0.050 (0.352)
Experience in agriculture	0.136 **(0.011)**	0.038 (0.476)	0.094 (0.082)
Contact with research institute or extension services	0.464 **(<0.001)**	0.064 (0.234)	0.491 **(<0.001)**

Farmers' perception of rice pest management practices

Approximately 94.1% of the surveyed farmers employed at least one pest control method. The predominant management approach utilized was chemical pesticides, adopted by 78.0% of farmers. Additionally, 50.6% employed mechanical control methods, while 40.6% utilized synthetic biopesticides. The chemical pesticides used by farmers included Ekalux (Quinalphos), Fame (Flubendiamide), and Karate (Lambda-cyhalothrin). Farmers perceived synthetic pesticides as quite effective against rice insect pests, as indicated by the average effectiveness score of 6 out of 7 for all chemical pesticides. In addition, biological control has the highest average effectiveness score (7), but only 4.4% of farmers used biological control (Trichocard) for rice pest management. 5.9% of farmers did not use pest management practices, and the average effectiveness score was 3, indicating lesser effectiveness (Table 3.23).

Table 3.23. Rice pest management practices used by farmers (n=340).

Rice pest management Practices Used	Numbers	Frequency (%)	Average effectiveness score
Biological control	15	4.4	7
Botanicals	78	23.0	5
Chemical pesticides	265	78.0	6
Cultural practices	114	33.5	5
Mechanical control	172	50.6	4
Synthetic bio-pesticides	138	40.6	5
No management practices	20	5.9	3

The survey indicated that most farmers sprayed the crop with chemical pesticides (78%). Many farmers (55.2%) sprayed pesticides immediately (or shortly after) rice insect pests appeared. In contrast, only 22.6% of farmers adhered to the economic threshold level (ETL) set by the Agriculture Extension and Plant Protection Department when applying pesticides. 37.9% consulted pesticide sellers, and 17.3% followed the advice of their neighboring farmers to get knowledge of the pesticide application rate (Table 3.24).

Table 3.24. Farmers' pest management practices using chemical pesticides (n=265).

	Immediately spray insecticide	Spray at economic threshold level (ETL)	No consultation	Consult Agricultural officers and field assistants	Consult neighbors and fellow farmers	Consult Pesticide shop authorities
No. (% respondents)	188 (55.2)	77 (22.6)	28 (8.23)	56 (16.5)	72 (21.2)	129 (37.9)

The most commonly used chemical pesticides were pyrethroids (Karate, Lambda-cyhalothrin) in the high hill region (56.8%) and organophosphates (Ekalex, Quinalphos) in the foothill (91.7%) and midland laterite regions (87.5%) (Table 3.25).

Table 3.25. Common chemical insecticides used by rice farmers in the three agro-ecological zones of North Kerala (n=265).

Insecticides	High hill (n=125)		Foothill (n=60)		Midland laterite (n=80)	
	Number	% Response	Number	% Response	Number	% Response
Organophosphate Ekalux (Quinalphos)	40	32.0	55	91.7	70	87.5
Organoflourine Fame (Flubendiamide)	14	11.2	0	0	2	2.5
Pyrethroid Karate (Lambda cyhalothrin)	71	56.8	5	8.3	8	10.0

The influence of opinion leadership, social connectivity, and information sources on the dissemination of rice pest management knowledge

Farmers identified six sources of rice pest management information: the agricultural department; fellow farmers; friends or relatives; their own experience;

pesticide sellers; and referring labels on the pesticide bottles. Over half (201/340) of the farmers seek advice from other fellow farmers. Pesticide sellers (178/340), the agricultural department (44/340), and friends or relatives (17/340) were important sources of pest management advice outside of farmers' communities. In addition, 16.5% of farmers referred to labels on the pesticide bottles (56/340). A collective of farmers opted not to seek counsel from their community and instead relied solely on their own expertise (109/340).

In the case of farmers in the high hill and midland laterite regions, the primary source of information regarding the pesticide application rate was from the pesticide sellers (56% and 52%, respectively), followed by fellow farmers (44% and 48%, respectively). In contrast, most farmers referred to pesticide bottle labels in the foothill region to know about the pesticide application rate (50%). There was a significant difference in the pesticide application information from the agricultural department, pesticide sellers, and directions given on pesticide bottles in all three agro-ecological zones (Table 3.26).

Table 3.26. Information sources of the rate of pesticide application for the management of rice pests in three agro-ecological zone communities in the North Kerala. An equal number of farmers (n=50) were selected from each zone. A comparison is made between the proportions of farmers within a specific zone who relied on a particular information source across different sources of information.

Pesticide application information sources	Agro-ecological zone			χ^2, df=2
	High hill (%)	Foothill (%)	Midland laterite (%)	
Agricultural department	22.0	14.0	4.0	6.1*
Fellow farmers	44.0	36.0	48.0	0.87
Friends or relatives	4.0	6.0	0	2.8
Own experience	26.0	30.0	46.0	3.29
Pesticide sellers	56.0	44.0	52.0	7.96*
Referring labels in the pesticide bottle	18.0	50.0	8.0	19.0*

∗ Means statistically different at P≤0.05

The farmers in North Kerala consulted various sources to learn about rice pest management. Those farmers who interacted with agricultural officials, fellow

farmers, pesticide sellers, and farmers with their own experience identified spiders and dragonflies as the primary natural enemies of rice pests. In contrast, most farmers who gathered information from friends or relatives recognized birds as insect pests' major natural enemies (82.4%). In addition, the farmer community that referred to pesticide bottle labels for pest management considered dragonflies (69.6%) as the primary natural enemy of rice pests, followed by spiders (51.8%). Information about parasitoids and pathogens was mainly acquired by farmers who consulted agricultural institutes.

According to farmers who have consulted agricultural institutions (25.0%) and those with their own experience (28.1%), the major "natural enemy conservation" is the avoidance of chemical pesticide use. Farmers who sought pest management guidance from other farmers (23.4%), relatives or friends (17.6%), pesticide sellers (30.0%), and those who have referred to the labels on pesticide bottles (42.9%) reported that not killing natural enemies was their primary strategy of natural enemy conservation. Few farmers who received advice from other farmers (9.0%) and agricultural authorities (6.8%) planted flowering plants close to the rice field to conserve natural enemies (Table 3.27).

Farmers who sought information from various channels, including agricultural institutes, fellow farmers, friends or family, personal experience, and pesticide sellers, showed notably varied perspectives on alternatives to chemical pesticides (such as biological control agents, botanicals or bio-pesticides, cultural and mechanical control). Among the 340 surveyed farmers, 198 (58.2%) were aware of certain chemical pesticide alternatives. Within this group, 19.7% cited agricultural departments as their information source, 22.9% referred to fellow farmers, 3.5% mentioned friends or relatives, 26.5% relied on personal experience, and 16.1% turned to pesticide sellers. Farmers who sought advice from other farmers (41.2%), agricultural officials (31.8%), and friends or family members (50.0%) suggested using botanicals or biopesticides instead of chemical pesticides. Farmers, who relied heavily on the advice of pesticide suppliers (47.2%) and their personal experiences (47.5%), suggested cultural practices as alternatives to

chemical pest control. No farmers in the study area knew about nano pesticides (Table 3.28).

Table 3.27. Relationship between farmers' pest management practices, natural enemy awareness, pesticide alternatives, and conservation methods with primary information sources for rice pest management in North Kerala smallholder farmer communities (n=340).

	Information sources					
Farmer knowledge and pest management behavior	**Agricultural institute (%) (n=44)**	**Fellow farmers (%) (n=201)**	**Friends or relatives (%) (n=17)**	**Own experience (%) (n=109)**	**Pesticide Seller (%) (n=178)**	**Referring pesticide bottle Labels (%) (n=56)**
Natural enemies						
Ants	38.6	1.5	0.0	3.7	0.0	10.7
Birds	50.0	25.9	82.4	31.2	23.0	21.4
Dragon-flies	88.6	84.1	35.3	37.6	41.6	69.6
Lady bird	9.0	0.0	0.0	0.0	0.0	0.0
beetle	25.0	1.5	0.0	0.0	7.9	8.9
Pathogens	40.9	2.0	0.0	0.0	0.0	3.6
Parasitoids	100	97.0	58.8	72.5	46.1	51.8
Spiders	0.0	3.4	17.6	10.1	17.4	12.5
Pest management practices						
No action taken	9.0	0.0	0.0	6.4	0.0	0.0
Pesticide use	38.6	42.8	57.1	61.5	57.3	55.4
Mechanical and cultural control	6.8	16.9	42.9	71.6	10.1	19.6
Use of botanicals/ biopesticides	25.0	25.4	0.0	32.1	15.1	30.4
Natural enemy conservation						
No chemical pesticide usage	25.0	18.9	11.7	28.4	23.0	19.6
No killing of natural enemies	20.5	23.4	17.6	22.01 \	30.0	42.9
Planting flowering plants near the rice field	6.8	9.0	0.0	1.8	0.0	0.0

Table 3.28 Sources of information utilized by farmers to learn about alternative pest management techniques to chemical pesticides. Data were gathered through a survey of 340 farmers in smallholder communities in North Kerala. The table displays the number of farmers citing each information source. A comparison is made between the proportions of farmers relying on specific sources for information on alternative pest management techniques.

Chemical pesticide alternative	Sources of pest management information					χ^2, df=4
	Agricultural institute (%) (n=44)	Fellow farmers (%) (n=51)	Friends or relatives (%) (n=8)	Own experience (%) (n=59)	Pesticide Seller (%) (n=36)	
Biological control	15.9	15.7	0	0	0	22.7^{***}
Botanicals/ biopesticides	31.8	41.2	50.0	28.8	30.6	12.3^{*}
Cultural practices	25.0	25.5	25.0	47.5	47.2	25.3^{***}
Mechanical control	27.3	17.6	25.0	23.7	22.2	9.3^{ns}
Nano-pesticides	0	0	0	0	0	ns

Note: Statistically significant at *P ≤0.05, **P ≤ 0.01, ***P ≤ 0.001; ns=not significant.

Table 3.29. Information sources for the chemical pesticide alternative for managing rice pests in three agro-ecological zones in North Kerala. An equivalent number of farmers (n=50) were selected from each zone. The percentage of farmers within a specific zone who depended on a particular information source is compared across various sources of information.

Chemical pesticide alternative information sources	Agro-ecological zone			χ^2, df=2
	High hill (%)	Foothill (%)	Midland laterite (%)	
Agricultural department	44.0	32.0	12.0	8.9^{*}
Fellow farmers	54.0	30.0	18.0	1.9^{**}
Friends or relatives	0	2.0	14.0	10.8^{**}
Own experience	54.0	28.0	22.0	4.5^{ns}
Pesticide sellers	10.0	18.0	44.0	13.2^{**}

Note: Statistically significant at *P ≤0.05, **P ≤ 0.01; ns=not significant.

In the high hill area, most farmers (54.0%) learned about chemical pesticide alternatives from fellow farmers and through personal experience. Conversely, in the foothill region, a larger proportion (32.0%) sought information on pesticide alternatives from agricultural agencies. Meanwhile, in the midland laterite area, the primary source of information on pesticide alternatives was pesticide suppliers, as indicated by 44.0% of farmers. Chemical pesticide alternatives information sources differed significantly across agro-ecological zones (Table 3.29).

Table 3.30. Overview of pest management practices, natural enemy awareness, pesticide alternatives, and natural enemy conservation methods across farmer categories. Survey data from 340 farmers in North kerala, with percentages included.

Farmer understanding and practices in pest management	**Farmer category**			
	Pest management training recipient (n=71)	**Non trained, connected with other farmers (n=239)**	**Non trained, unconnected with other farmers (n=30)**	**Total non-trained farmers (n=269)**
Natural enemies				
Ants	47.9	36.0	6.7	32.7
Birds	59.2	54.8	26.7	51.7
Dragon-flies	88.7	75.7	36.7	71.4
Lady bird beetle	35.2	5.0	0	4.5
Pathogens	80.3	11.3	0	10.0
Parasitoids	76.1	8.8	0	7.8
Spiders	100.0	84.1	46.7	79.9
Pest management practices				
No action taken	11.3	71.1	10.0	7.4
Pesticide use	33.8	82.8	90.0	83.6
Mechanical and cultural control	71.8	59.0	46.7	57.6
Use of botanicals/biopesticides	59.2	30.1	20.0	29.0
Natural enemy conservation				
No chemical pesticide usage	63.4	88.3	26.7	81.4
No killing of natural enemies	73.2	59.4	6.7	53.5
Planting flowering plants near the field	69.0	25.5	3.3	23.0
Keeping flowering plants near the rice field	45.0	17.6	0	15.6

Two groups of people are involved in rice pest management: those who have received training and those who have not. Individuals who underwent training and those with an extensive network for acquiring rice pest management knowledge, exhibited awareness of various natural enemies involved in controlling rice pests. However, farmers who received training are more knowledgeable. Most trained farmers learned about spiders (100%), dragonflies (88.7%), parasitoids (76.1%), and pathogens (80.3%) as the major natural enemies of rice insect pests. Most trained farmers (71.8%) stated that mechanical and cultural methods were the best for managing pests. Contrarily, untrained farmers with pest management knowledge networks with other people (connections) (82.8%) and untrained farmers without connections (90.0%) considered pesticide application appropriate for managing rice insect pests. According to most pest management training recipients, natural enemy conservation means not killing natural enemies (73.2%). In contrast, for untrained but connected farmers, the natural enemy conservation was the stoppage of the use of chemical pesticides (88.3%) and for untrained but unconnected farmers it was 26.7%. However, the untrained, non-connected farmers knew the least about the significance of flowering plants in conserving natural enemies (Table 3.30).

A weak positive association was found between the knowledge of natural enemies and training in pest management and opinion leadership. Knowledge of pests is correlated with pest management training, opinion leadership, and knowledge of natural enemies. The perception of pest damage differed significantly from other variables such as pest management training, opinion leadership, knowledge of natural enemies, knowledge of pests, interaction with local institutions, and degree of connectedness. A strong association was found between perceived pest damage and agricultural pest management training (r=0.629) (Table 3.31).

Table.3.31. Spearman correlation matrix showing the relationship between farmers socio-economic characters (T-Training; OL-Opinion Leadership; L-Land size; Exp-Experience; LII-Local Institution Involvement; DC-Degree of Connectedness; A-Age) with the knowledge of pests (KW_P), knowledge of natural enemies (KW_N) and perception of pest damage (PD). The bold digits represent significant results.

	T	OL	L	Exp	KW_N	KW_P	LII	DC	A	PD
T	—									
	—									
OL	0.187	—								
	<0.001	—								
L	0.122	0.328	—							
	0.025	<0.001	—							
Exp	0.073	0.098	0.144	—						
	0.182	0.071	0.008	—						
KW_N	**0.247**	**0.376**	-0.086	0.039	—					
	<0.001	**<0.001**	0.115	0.476	—					
KW_P	**0.214**	**0.374**	-0.073	0.093	**0.141**	—				
	<0.001	**<0.001**	0.180	0.087	**0.009**	—				
LII	0.271	0.610	0.298	0.114	0.444	0.478	—			
	<0.001	<0.001	<0.001	0.035	<0.001	<.001	—			
DC	0.303	0.649	0.036	0.101	0.534	0.674	0.805	—		
	<0.001	<0.001	0.513	0.064	<0.001	<0.001	<0.001	—		
A	0.050	0.081	0.075	0.409	0.070	0.107	0.033	0.0850	—	
	0.356	0.137	0.170	<0.001	0.195	0.049	0.542	.117	—	
PD	0.629	0.162	-0.040	0.035	0.351	0.250	0.232	0.331	0.087	—
	<0 .001	0.003	0.467	0.519	<0.001	<0.001	<0.001	<0.001	0.109	—

We employed Akaike's Information Criterion (AIC) model selection to discern the most suitable model among a range of options describing the correlation between perception of damage, age, land size, experience, understanding of natural enemies and pests, training, local institutional engagement, opinion leadership, and level of connectedness. The first model is a combination model, significantly outperforming others, as it captures 61% of the cumulative model weight and exhibits the lowest AIC score (549.18). The model (PD~KWN+KWP+T+LI+OL+DC) comprises variables such as knowledge of natural enemies and pests, pest management training, local institutional involvement, opinion leadership, and degree of connectedness. The farmer's perspective on the crop damage brought on by insect pests is influenced by the combined effects of the above mentioned variables (Table 3.32).

The variation inflation factor (VIF) was used to avoid multicollinearity. A VIF value above five was removed from the model to prevent the multicollinearity

problem. As a result, the degree of connectedness factor was removed from the model (Table 3.33). We employed a generalized linear model (GLM) with a Poisson distribution and a log link function to identify the key factors influencing the perception of rice plant damage among farmers. Knowledge of natural enemies, pest knowledge, and pest management training positively and significantly influenced farmers' perceptions of insect pest-induced rice plant damage (Table 3.34).

Table.3.32. Akaike's Information Criterion (AIC) model selection was conducted using logistic regression models to analyze the perception of rice pest damage in North Kerala rice ecosystems. Criterion K represents the number of parameters in the model. ΔAICc indicates the absolute difference in Akaike's Information Criterion value adjusted for small sample sizes (AICc) between the best-fit model and the model under consideration. AICcWt represents the AICc weight, indicating the proportion of the total predictive power provided by the full set of models contained in the model being assessed. Cumulative. Wt represents the sum of the AICc weights. Log-likelihood (LL) is the value describing the likelihood of the model given the data. The AIC score is calculated from the LL and K. The "+" sign indicates a combination model. Model variables: perception of damage (PD), knowledge of natural enemies (KWN), knowledge of pests (KWP), training (T), local institution involvement (LI), opinion leadership (OL), degree of connectedness (DC), age of the farmer (A), experience in agriculture (E), and land size (L).

Model	**K**	**AICc**	**Δ AICc**	**AICcWt**	**Cum.Wt**	**Log Likelihood**
PD~KWN+ KWP +T+LI+OL+DC	8	549.18	0.00	0.61	0.61	-266.37
PD~ KWN + KWP +T+LI	6	551.50	2.31	0.19	0.80	-269.62
PD~ KWN + KWP +T+LI+OL	7	553.42	4.24	0.07	0.87	-269.54
PD~ KWN + KWP +T	5	553.45	4.27	0.07	0.95	-271.64
PD~ KWN + KWP +T+OL	6	554.04	4.86	0.05	1.00	-270.89
PD~ KWN + KWP +T	5	696.23	147.05	0.00	1.00	-343.03
PD~ KWN + KWP +LI	5	700.58	151.40	0.00	1.00	-345.20
PD + Exp +L	5	767.47	218.29	0.00	1.00	-378.64

Table.3.33. Collinearity Statistics to avoid multicollinearity. Model variables: KWN-knowledge of natural enemies, KWP-knowledge of pests, T-training, LI-local institution involvement, OL-opinion leadership, DC-degree of connectedness, A-age of the farmer, Exp-experience in agriculture, L-land size.

Variables	VIF	Tolerance
A	1.28	0.780
L	1.49	0.671
Exp	1.32	0.758
KWN	1.67	0.600
KWP	1.91	0.524
LI	3.24	0.309
DC	5.49	0.182
OL	2.16	0.463
T	1.17	0.853

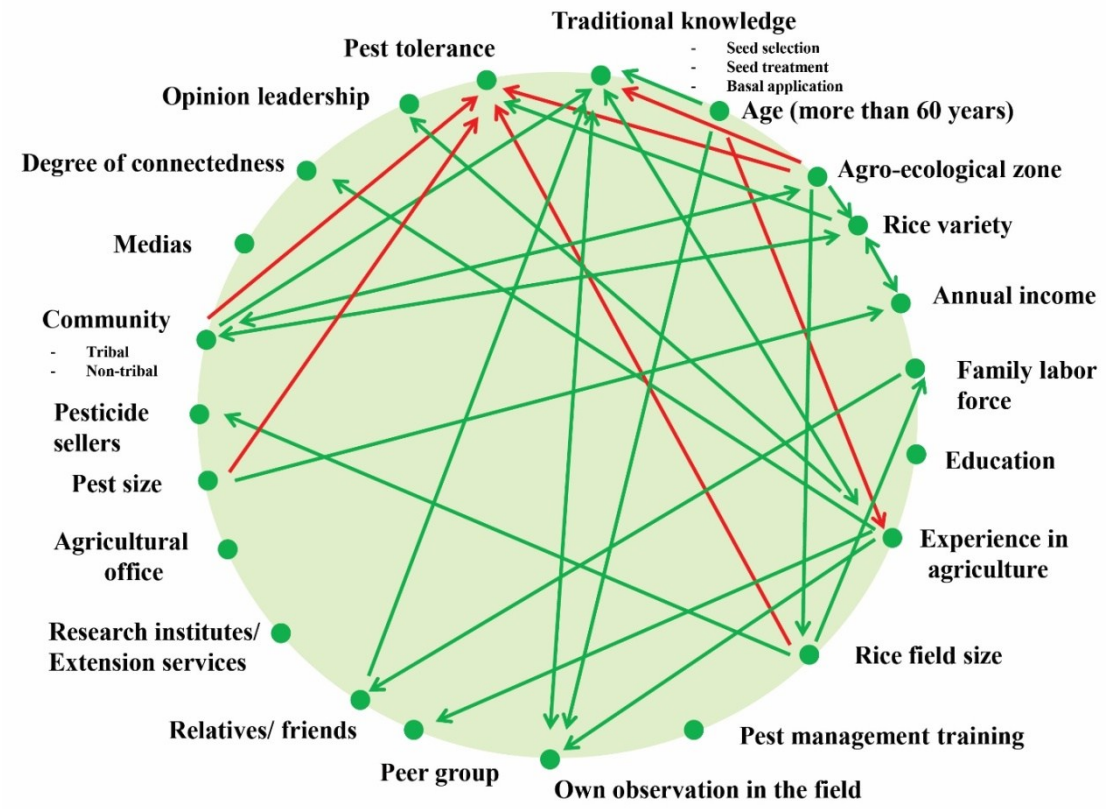
Table 3.34. Generalized linear model results for factors that influenced the perception of rice plant damage, North Kerala, India. Model variables: KWN-knowledge of natural enemies, KWP-knowledge of pests, T-training, LI-local institution involvement, OL-opinion leadership, A-age of the farmer, Exp-experience in agriculture, L-land size. The bold digits represent significant results.

Names	Estimate	SE	exp(B)	95% Exp(B) Confidence Interval		z	p
				Lower	Upper		
(Intercept)	0.3556	0.0205	1.427	1.370	1.49	17.2742	< .001
A	0.0043	0.0028	1.004	0.999	1.01	1.5110	0.132
L	-0.1094	0.0598	0.896	0.796	1.01	-1.8295	0.068
Exp	-0.0014	0.0020	0.999	0.994	1.00	-0.6963	0.487
KWN	**0.1690**	**0.0349**	**1.184**	**1.106**	**1.27**	**4.8436**	**<0.001**
KWP	**0.0724**	**0.0301**	**1.075**	**1.014**	**1.14**	**2.4009**	**0.017**
LI	-0.0316	0.0338	0.969	0.907	1.04	-0.9344	0.351
OL	-0.0021	0.0397	0.998	0.923	1.08	-0.0529	0.958
T	**0.5850**	**0.0453**	**1.795**	**1.642**	**1.96**	**12.8886**	**<0.001**

The structure of Socio-economic web that influence pest management decision in traditional and high-yield rice farmer communities

The socio-economic webs show the components that determine rice pest management decisions and are structured differently in traditional and high-yield rice farmer communities. Tribal farmer communities mainly practice traditional rice cultivation and traditional pest management methods.

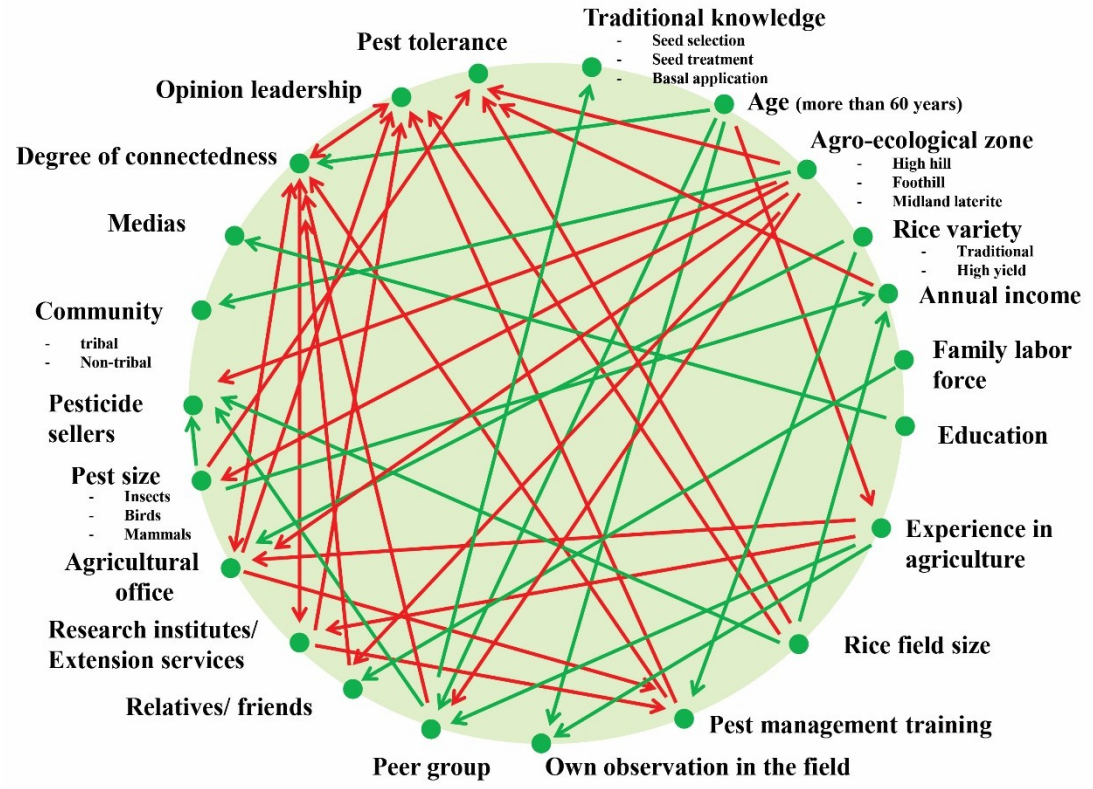
Fig. 3.15 Socio-economic web that influence pest management decision in traditional rice farmers. Dots: crucial system components derived from data. Green lines: direct interrelations based on participant information. Red lines: indirect interrelations identified through data interpretation. Arrows: direction of action indicating ongoing change processes.



The socio-economic system components (dots in the figures) are of varying importance for traditional and high-yield rice farmers learning about rice pest management. Moreover, the quantity of interrelationships (depicted as lines in the figures) among the components varies depending on the community. Using the number of interrelationships to indicate the magnitude of change, modern rice pest

management in high-yield rice varieties (40 interrelationships; Fig. 3.16) is changing more than traditional rice pest management in traditional rice varieties (26 interrelationships; Fig. 3.15). Modern rice pest management decisions were affected mainly by the degree of connectedness of a farmer's rice pest management knowledge, which was influenced by other web components such as local institution involvement (agricultural office, research institute, and extension services), relatives or friends, peer groups, pest management training, opinion leadership, and age. In addition, agricultural offices, pest management training, and opinion leadership also influence the pest management decisions of high-yield rice farmers.

Fig. 3.16 Socio-economic web that influence pest management decision in high-yield rice farmers. Dots: crucial system components derived from data. Green lines: direct interrelations based on participant information. Red lines: indirect interrelations identified through data interpretation. Arrows: direction of action indicating ongoing change processes.



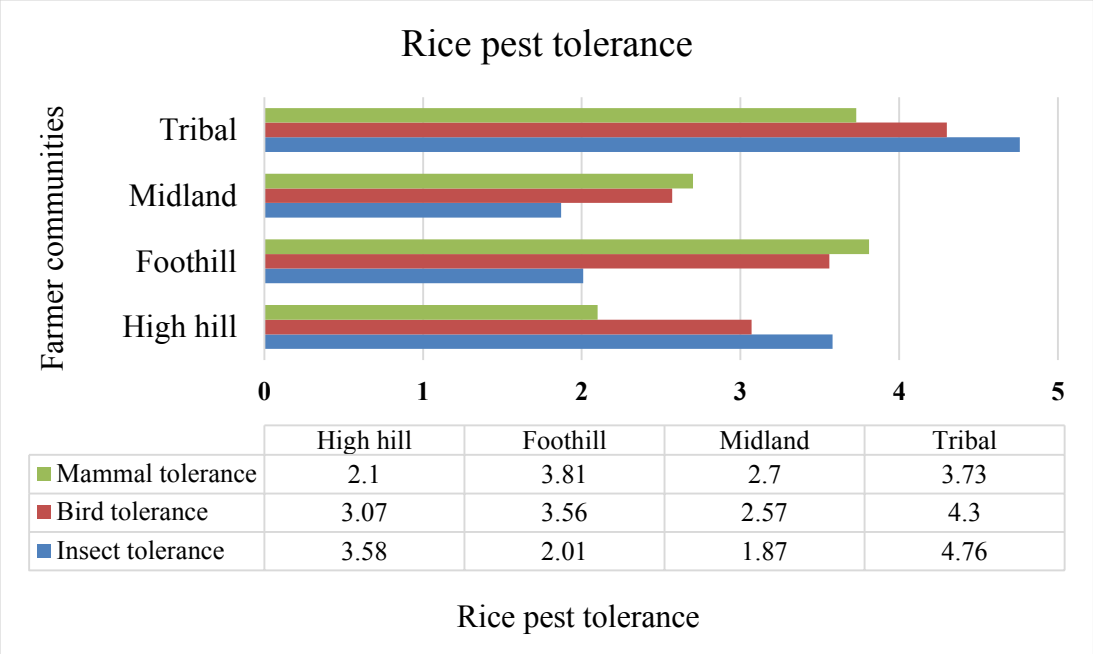
Unlike sources of non-traditional rice pest management knowledge, traditional knowledge was the primary source of knowledge for traditional rice pest management. It was strongly influenced by other web components such as

community, relatives or friends, own field observation, experience in agriculture, and age (Fig. 3.15). Furthermore, the traditional rice farmers who follow traditional rice pest management methods are independent of local institution involvement, media influence, and pest management training. The high-yield rice pest management system retains more social participation than the traditional one.

Tolerance of crop loss due to pest infestation in various farmer communities

In comparison to other farmer groups in North Kerala, tribal farmers (n=26) had a high tolerance for insect (4.30±0.47) and bird (4.76±0.42) pest infestations. In contrast, the farmers of the midland laterite region (n=105) had the lowest tolerance for insect pest attacks (1.87±0.75). The mammal tolerance level (3.81±0.64) was higher in the foothill region (n=85) than in other farmer communities. Crop damage by mammals was less tolerated among farmers in the high hill region (2.10±1.11) (Fig. 3.17).

Fig. 3.17 Tolerance scale of major rice pests causing crop loss in various farmer communities in North Kerala (tribal farmers, farmers in the high hill, foothill, and midland laterite regions). Rating Scale: 1—Minimal tolerance, 2—Limited tolerance, 3—Moderate tolerance, 4—Substantial tolerance, and 5—Extensive tolerance.



	High hill	Foothill	Midland	Tribal
Mammal tolerance	2.1	3.81	2.7	3.73
Bird tolerance	3.07	3.56	2.57	4.3
Insect tolerance	3.58	2.01	1.87	4.76

Of the 150 farmers surveyed in the high hill region, 60% showed high tolerance (scale=4 and 5), and only 24.6% showed low tolerance (scale=1 and 2) to

rice insect pest infestations. In contrast, most farmers in the foothill (72.3%, N=85) and Midland laterite regions (77.1%, N=105) showed low tolerance to insect pest infestations.

Analysis of insect pest tolerance in the high hill, foothill, and midland laterite farmer communities showed significant difference in the random effect model and heterogeneity statistics (Table 3.35).

Table 3.35. Analysis of insect pest tolerance level in various farmer communities (HH—high hill, FH—foothill, and ML—midland laterite) of North Kerala. Parameters: K—number of variables; SE—standard error; z—Fischer's z-score; CI—confidence interval; Tau^2—true heterogeneity variance; I^2—a measure of heterogeneity (percentage of variation not attributable to sampling error); H^2—heterogeneity statistics; df—degree of freedom; and Q—a measure of heterogeneity.

	K	Estimate	SE	z	CI Lower bound	CI Upper bound	Tau^2	I^2	H^2	df	Q
HH_high tolerance	36	0.640*	0.0335	19.1	0.574	0.706	0.0346 (SE=0.0095)	91.9%	12.333	35	552.420*
HH_low tolerance	36	0.214*	0.0260	8.21	0.163	0.265	0.0204 (SE=0.0057)	93.4%	15.053	35	472.063*
FH_low tolerance	30	0.780*	0.0261	29.9	0.729	0.831	0.014 (SE=0.0052)	81.1%	5.282	29	181.448*
ML_low tolerance	31	0.775*	0.0289	26.8	0.719	0.832	0.0196 (SE=0.0064)	90.9%	10.995	30	273.656*

Note. Tau² Estimator: Restricted Maximum-Likelihood. *$p \leq 0.01$

The forest plot for the effect of various socio-economic variables on the high tolerance level of rice insect pest infestation among the high hill farmer community showed that the tribal community (effect size: 0.98 [0.93, 1.03]), those who depend on the service sector for their primary income source (effect size: 0.97 [0.89, 1.05]), and those who do not spray pesticides in the field (effect size: 0.95 [0.89, 1.01]) showed high tolerance to pest infestations. The random effect model showed an overall effect size of 0.64 [0.57, 0.71] at a 95% confidence interval (Fig. 3.18).

The forest plot for the effect of various socio-economic variables on the low tolerance level to rice insect pest infestation among the high hill farmer community revealed that those with agricultural incomes greater than 2.5 lakhs and those who use pesticides in their rice fields both showed greater intolerance to pest infestations

(effect sizes: 0.80 [0.60, 1.00] and 0.40 [0.30, 0.50], respectively). At a 95% confidence level, the random effect model exhibited an overall effect size of 0.21 [0.16, 0.26] (Fig. 3.19).

Fig. 3.18 Forest plot showing the effect of different socio-economic variables on high tolerance level of high hill farmer community. Summary estimates were analyzed using a random-effects model (RE Model). CI, confidence interval.

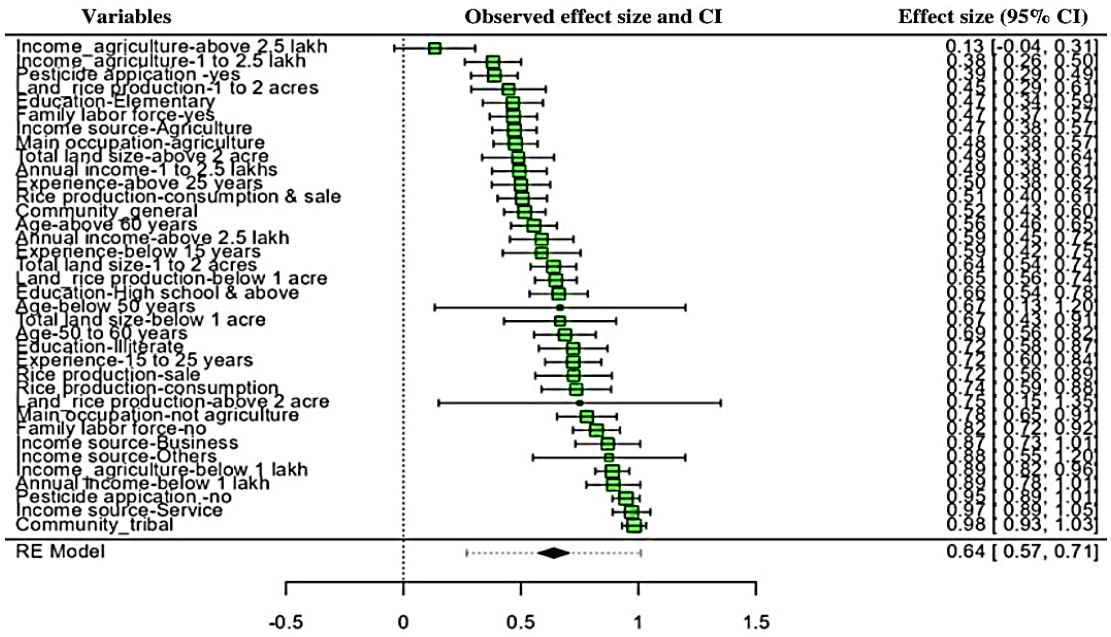
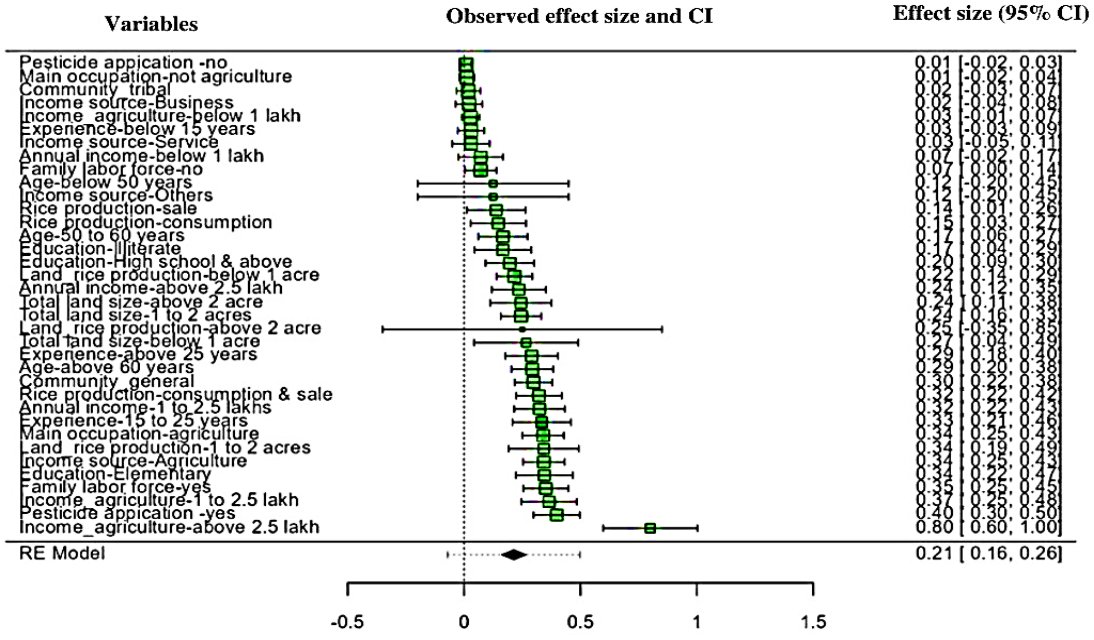
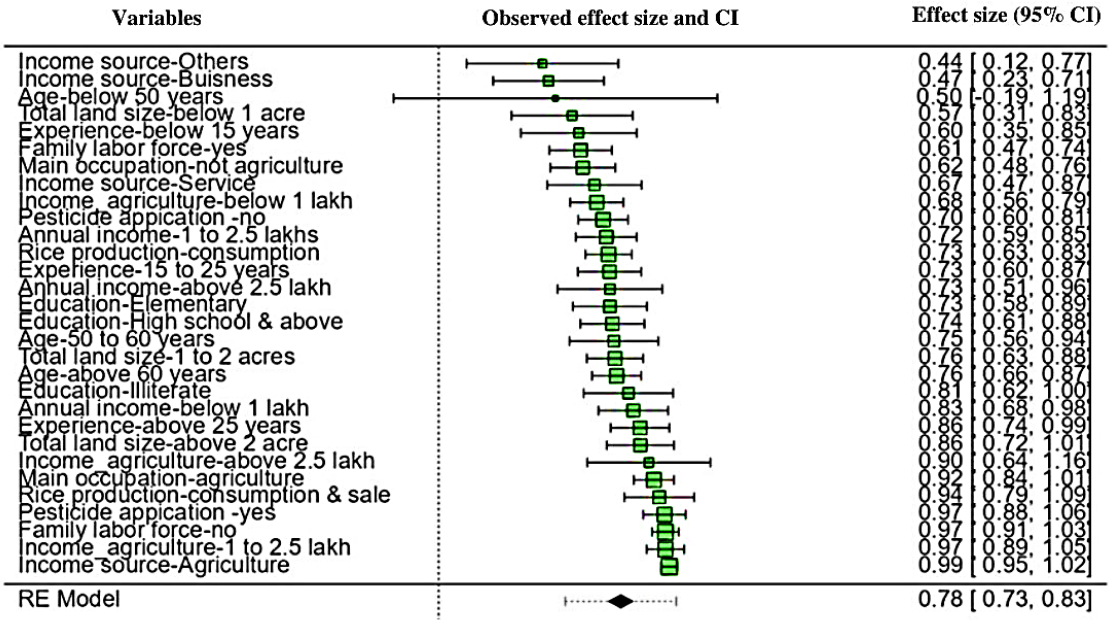


Fig. 3.19 Forest plot showing the effect of different socio-economic variables on low tolerance level of high hill farmer community. Summary estimates were analyzed using a random-effects model (RE Model). CI, confidence interval.



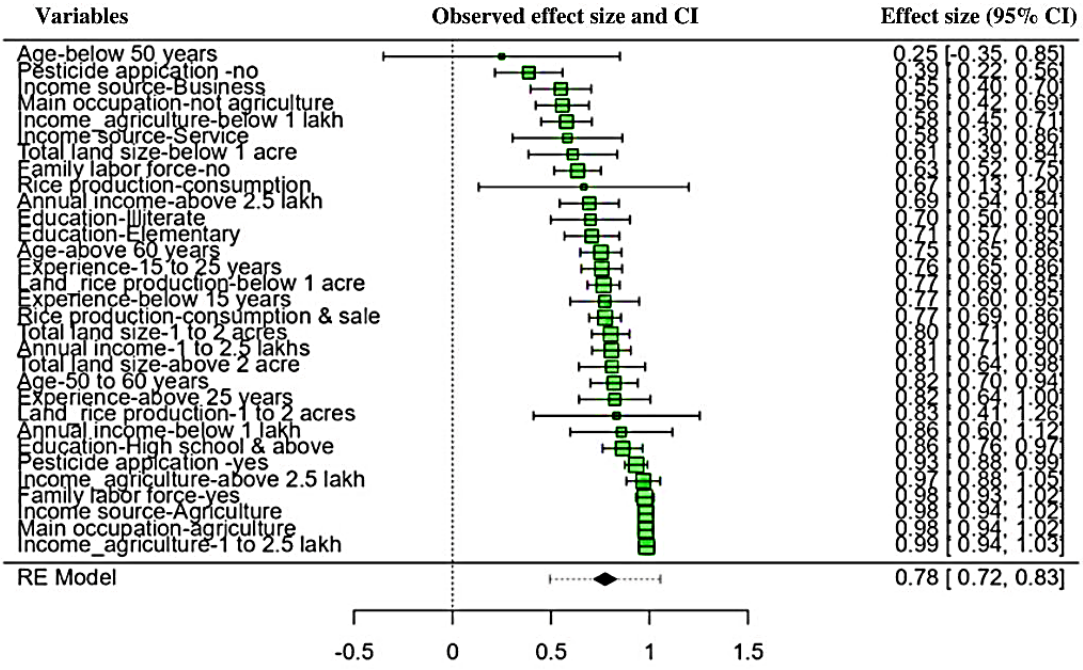
The forest plot for the effect of different socioeconomic variables on the low tolerance level to rice insect pest infestation among foothill farmers showed that those with agriculture as their primary source of income (effect size: 0.99 [0.95, 1.05]), agricultural income between one and two lakhs (effect size: 0.97 [0.89, 1.02]), no family labor utilization (effect size: 0.97 [0.91, 1.03]), and those who spray pesticides in their rice fields (effect size: 0.97 [0.88, 1.06]) showed high intolerance. The random effect model revealed an overall effect size of 0.78 [0.73, 0.83] (Fig. 3.20).

Fig. 3.20 Forest plot showing the effect of different socio-economic variables on low tolerance level of Foothill farmer community. Summary estimates were analyzed using a random-effects model (RE Model). CI, confidence interval.



The poor tolerance level to rice insect pest attacks among Midland laterite farmers revealed that those with incomes between Rs 1 lakh and Rs 2 lakhs (effect size: 0.99 [0.94], 1.03), agriculture as their primary occupation (effect size: 0.98 [0.94], 1.02), agriculture as their primary income source (effect size: 0.98 [0.94], 1.02), and family labor force (effect size: 0.98 [0.93], 1.02) demonstrated high intolerance. The random effect model determined a total effect size of 0.78 [0.72, 0.83] (Fig. 3.21).

Fig. 3.21 Forest plot showing the effect of different socio-economic variables on low tolerance level of Midland laterite farmer community. Summary estimates were analyzed using a random-effects model (RE Model). CI, confidence interval.

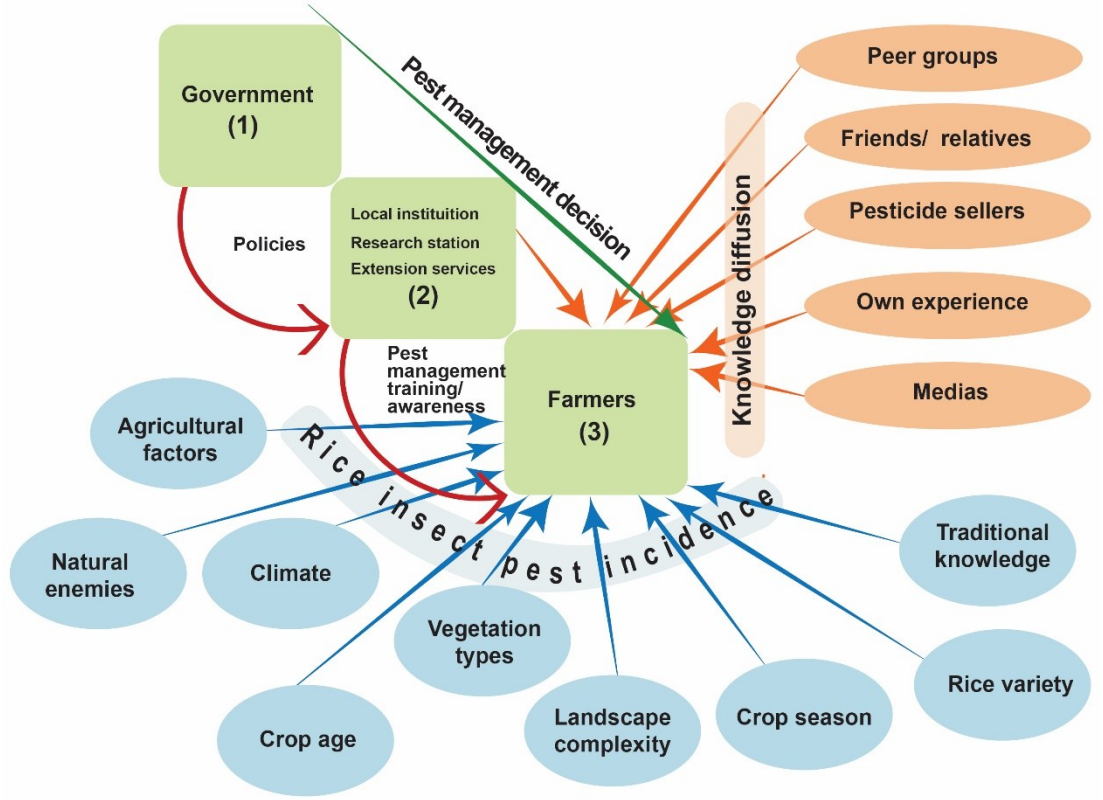


The gaps in rice pest management domains

In North Kerala, the government, agricultural-related organizations (agricultural offices, research stations, research institutes, etc.), and farmers are the three key domains that have a role in the farmer's choice of managing rice insect pests. However, the sources of the farmer's pest management knowledge (local institutions or extension services, farmer peer groups, friends or relatives, pesticide sellers, own experience, and media) and indirect influences (such as natural enemies, vegetation types, climate, crop age, landscape complexity, crop season, agricultural factors, rice varietal difference, and traditional knowledge) all influenced the farmer's choice regarding pest management (Fig. 3.22). Depending on the seasons and agro-ecological zones, some biotic and abiotic factors negatively influence the pest abundance in the rice field, which determines the farmer's choice of pest management in the North Kerala rice fields. They are parasitoids (high hill region: 83 species, N=4890; foothills: 91 species, N=3910; and the midland laterite: 61 species, N=3228); vegetation types (sparse vegetation and submerged vegetation); relative humidity (foothill, wet season; Spearman rank correlation, r=-0.633);

traditional pest management knowledge; traditional rice varieties and vegetative crop growth stage.

Fig. 3.22 Factors affecting farmer choice of rice pest management in North Kerala. Rice pest management has three domains: 1-government; 2-local institutions, or research stations or extension services; and 3-farmers. Orange arrows: the sources of knowledge diffusion and the components that directly affect farmers' pest management decisions; blue arrows: components that indirectly affect farmers' pest management decisions.

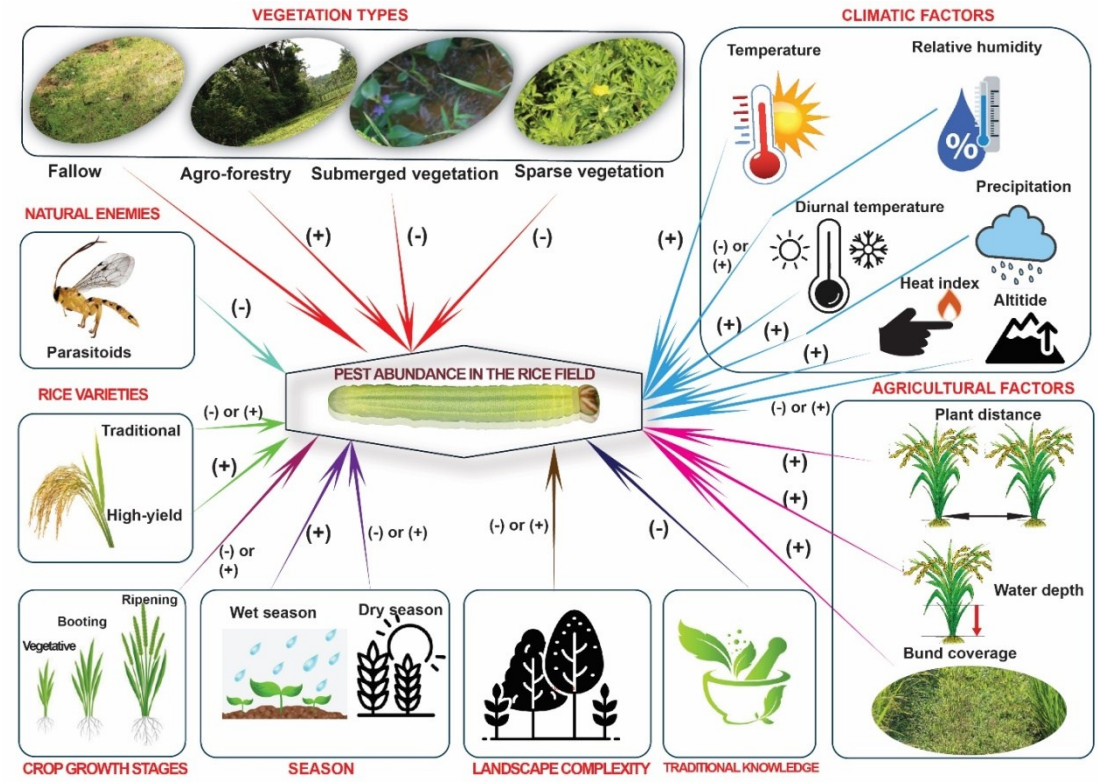


However, some factors positively influence the pest abundance, such as fallow and agro-forestry patches (r>0.5), the wet season (species richness and abundance were high), crop growth stages of the paddy (booting and ripening stages), mean temperature, maximum temperature, diurnal temperature, relative humidity, the heat index (foothill, dry season, r>0.5), and altitude (foothill, wet season, Spearman rank correlation, r=0.827). In addition, the landscape heterogeneity and some agricultural factors (high hill wet season, the plant distance: Spearman rank correlation, r=0.538, whereas in the dry season, water level, plant distance, and parasitoids: Spearman rank correlation, r>0.5; foothill wet and dry

seasons, water level, plant distance, bund weed coverage, parasitoids: Spearman rank correlation, r>0.5; midland laterite wet season, water depth, plant distance, and parasitoids; midland laterite dry season, plant distance) positively impact pest abundance in the study area (Table 2.23) (Fig. 3.23).

During the study, we found several gaps in the pest management domains. They include the farmers' knowledge gaps, farmer participation in pest management training, traditional knowledge adoption, extension services, and government policy adoption.

Fig. 3.23 Factors affecting pest abundance in the rice fields of North Kerala. (+) indicates the strong positive influence and the (-) depicts the strong negative influence.



Rice pest management knowledge gap

Farmers cannot identify rice insect pests by observing their green-colored larval stages (pest knowledge, score: 1.35–2.53). Pest recognition varies from zone to zone (foothill farmer community, highest knowledge, score=2.53, midland laterite farmer community, lowest knowledge, score=1.35). Similarly, farmers'

understanding of the natural enemies of rice pests varies from zone to zone. Knowledge of natural enemies is very low among North Kerala rice farmers (foothill region, highest score: score=0.82; high hill: score=0.73; and midland laterite, lowest score: score=0.67). Most identified the pest during its larval stage (87.64% of respondents), and they are least knowledgeable about the egg (8.82%) and pupal stages (4.41%) of the rice insect pests. Most farmers (72.05% of respondents) cited their personal experience as their primary source of pest knowledge, which indicates their fewer social connections with the research domain and agricultural officials. Most farmers identified leaf-folder pests (68.2%) and discoloured grains caused by rice bugs (42.4%) from damaged plant parts. However, they are least aware of the white ear head formation caused by the stemborers (10.9%) because they mistook the stemborer-induced damage for the rice bug attack. Farmers' pest identification expertise significantly differed with agro-ecological zones (Armyworms: χ^2=76.9; Case Worms: χ^2=63.4; Leaf Folders: χ^2=5.6; Leaf Rollers: χ^2=1.4; Rice Bugs: χ^2=5.4; Stem Borers: χ^2=21.4); and natural enemies (Ants: χ^2=11.9; Birds: χ^2=3.7; Dragonflies: χ^2=0.19). The results showed that the farmers' agricultural experience and contact with research institutes or extension services influenced their knowledge of rice pests and the perception of crop damage (Spearman rank correlation, $p<0.05$). The knowledge gap on the management of rice pests is seen among farmers in North Kerala, which includes the identification of the pests and their damage to the crop, the rate of pesticide application, and the alternatives to chemical pesticides.

Knowledge of natural enemies is mainly found in few farmers (6.2%) who approached extension officials. Overall, 73.2% of respondents in the baseline survey were not aware of biological control of rice pests. Although natural enemies such as lady beetles, parasitic wasps, and non-parasitic predatory wasps were abundant in their fields, most farmers could not distinguish them from insect pests. Most farmers (73.2%) did not recognize the beneficial insects, returned a "don't know" response, or provided incorrect identification. Interestingly, a few farmers in all three zones responded to the presence of parasitic wasps (4.1%). Furthermore, only 18.2% recognized dragonflies as the natural enemies of rice pests, and 8.2% responded that spiders were the natural enemies. Many responded positively to the presence of

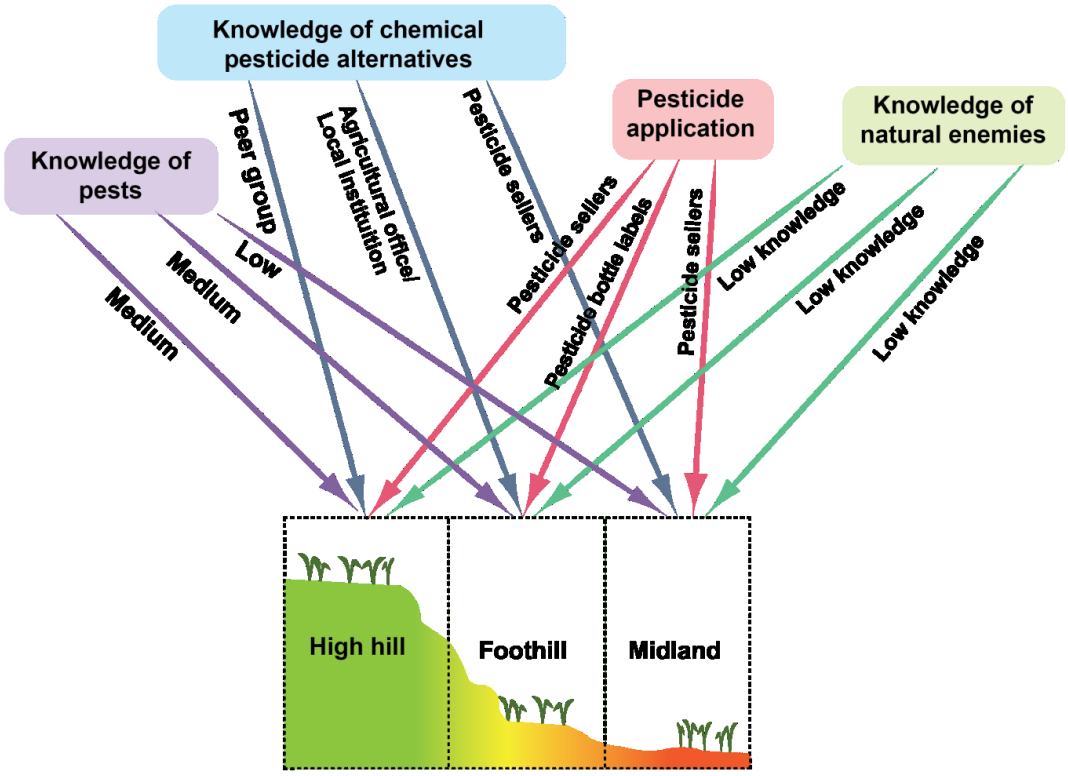
natural enemies in their rice fields only after seeing the photographs shown. According to them (n=340), spiders (94.4%) and dragonflies (91.8%) were the most common natural enemies.

There was a significant difference in the perceived incidence of ants, ladybird beetles, and wasps in all three agro-ecological zones. Interestingly, there was no relationship between knowledge of natural enemies and the farmers' socio-economic characteristics in the study region. According to knowledgeable farmers, biological control has the highest average effectiveness score (7), but only 4.4% of farmers used biological control (trichocard) for rice pest management. 5.9% of farmers did not use pest management practices; the average effectiveness score was 3, indicating lesser effectiveness. The survey revealed that among the 265 farmers surveyed, the majority employed various techniques to combat rice insect pests. Specifically, nearly all farmers utilized chemical pesticides, with a prevalence of 77.9% employing this method. Many farmers (55.2%) sprayed pesticides immediately (or shortly after) for the appearance of rice insect pests. The farmers believed synthetic pesticides were relatively effective against rice insect pests. The primary source of advice for chemical pesticide application rate varied across all three farmer communities belonging to different agro-ecological zones (56% in the high hill and 52% in the midland laterite regions: pesticide sellers; 50% in the foothill region: pesticide bottle labels). Farmers' perceptions of the natural enemy varied depending on the type of knowledge source they interacted with. Those who interacted with agricultural officials, fellow farmers, pesticide sellers, and farmers with their own experiences mainly identified arthropod pests such as spiders and dragonflies as the primary natural enemies of rice insect pests. In contrast, most farmers who gathered information from friends or relatives recognized avian pests (82.4%). In addition, the farmer community that referred to pesticide bottle labels also considered arthropod pests as the natural enemies of rice insect pests, which include dragonflies (69.6%) and spiders (51.8%).

Information about parasitoids and pathogens was mainly acquired by farmers who consulted agricultural institutes. The concept of natural enemy conservation to

reduce the rice pests in the field was found only in those who have contact with agricultural officials and those with several years of agriculture expertise. According to them, the primary "natural enemy conservation" strategy is avoiding chemical pesticide use and planting flowering plants near the rice field to conserve natural enemies.

Fig. 3.24 Farmer's knowledge and source of knowledge on rice pest management in three agro-ecological zones (high hill, foothill, and midland laterite zones) of North Kerala.



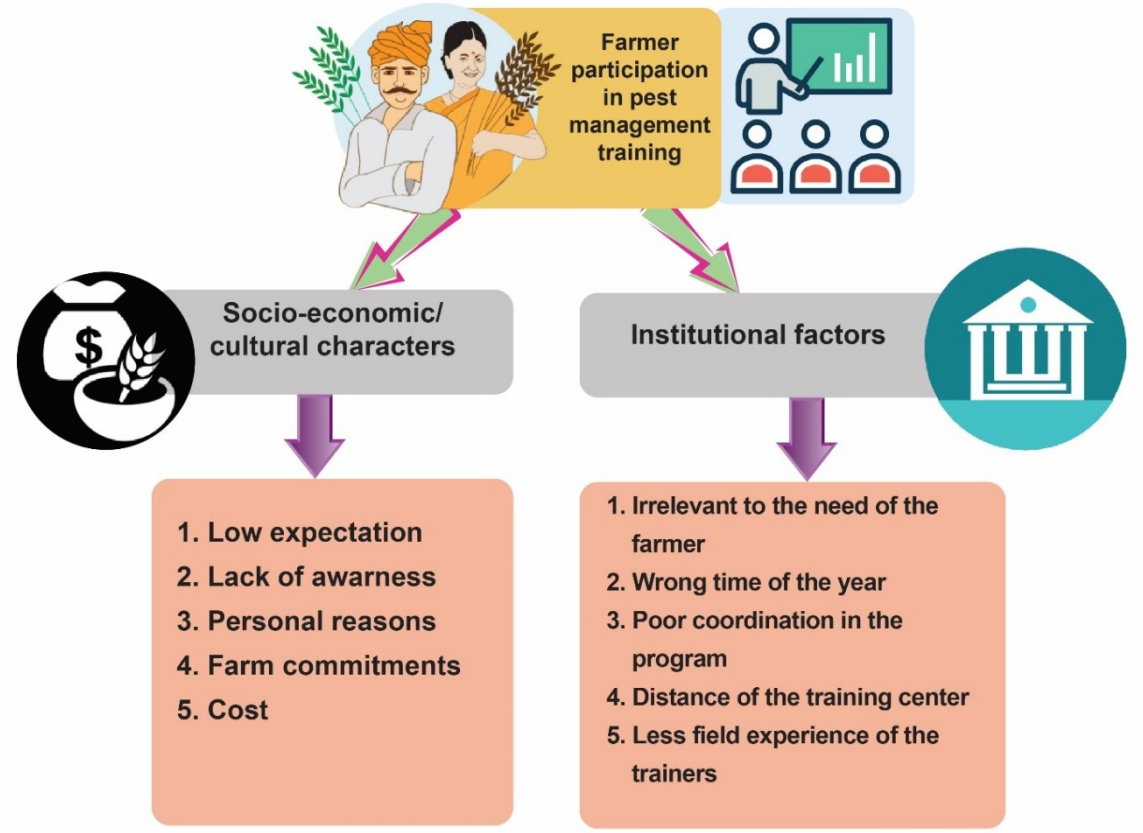
In contrast, the farmers who sought pest management guidance from other farmers (23.4%), relatives or friends (17.6%), pesticide sellers (30.0%), and those who had referred to the labels on pesticide bottles (42.9%) reported that not killing natural enemies was their primary strategy for natural enemy conservation. Farmers' perceptions of alternative chemical pesticides varied depending on the source of information. Only 58.2% (out of 340) knew of specific chemical pesticide alternatives (farmers who sought advice from other farmers, agricultural officials, and friends or family members suggested using botanicals or biopesticides; those

who consulted pesticide suppliers and their personal experiences considered using cultural practices; and no farmers knew about nano pesticides in the study area). Furthermore, the origin of farmers' knowledge regarding alternatives to chemical pesticides varies across different zones: in high hill areas, it predominantly comes from other farmers and personal experience; in foothill regions, it's primarily from agricultural agencies; while in midland laterite areas, the main source is pesticide suppliers. This result suggests the influence of various knowledge sources on the farmer's choice of rice pest management (Fig. 3.24).

Farmer participation gap in pest management training

Attending pest control training is more of a verbal than a practical activity in North Kerala. This study pinpointed the factors influencing rice farmers' participation in the training program. The ability of farmers to contribute positively to program development is sometimes underestimated. Most agricultural extension education programs, including pest management training, are designed without considering the situational or attitudinal obstacles of the target audience. The components influencing farmer participation in pest management training were compiled based on interactions with the farmers (n=340). The variables were divided into two categories: institutional and socio-cultural. Irrelevance to rice farmers' needs, a lack of awareness, poor facilitator coordination, the distance to the training center, and the trainers' lack of field experience would demotivate rice farmers' participation in pest management training. Institutional factors such as training at the right time of year, availability of facilities, and facilitators with good coordination and communication skills would motivate farmers to participate. Several socio-cultural factors influence low participation in training programs, including lack of awareness of farmers (80.9% of respondents), low expectations (82.4% of respondents), personal reasons (36.8% of respondents), farm commitments (55.6% of respondents), and travel costs (40.3% of respondents) (Fig. 3.25).

Fig. 3.25 Farmer participation gap in the pest management training in North Kerala.

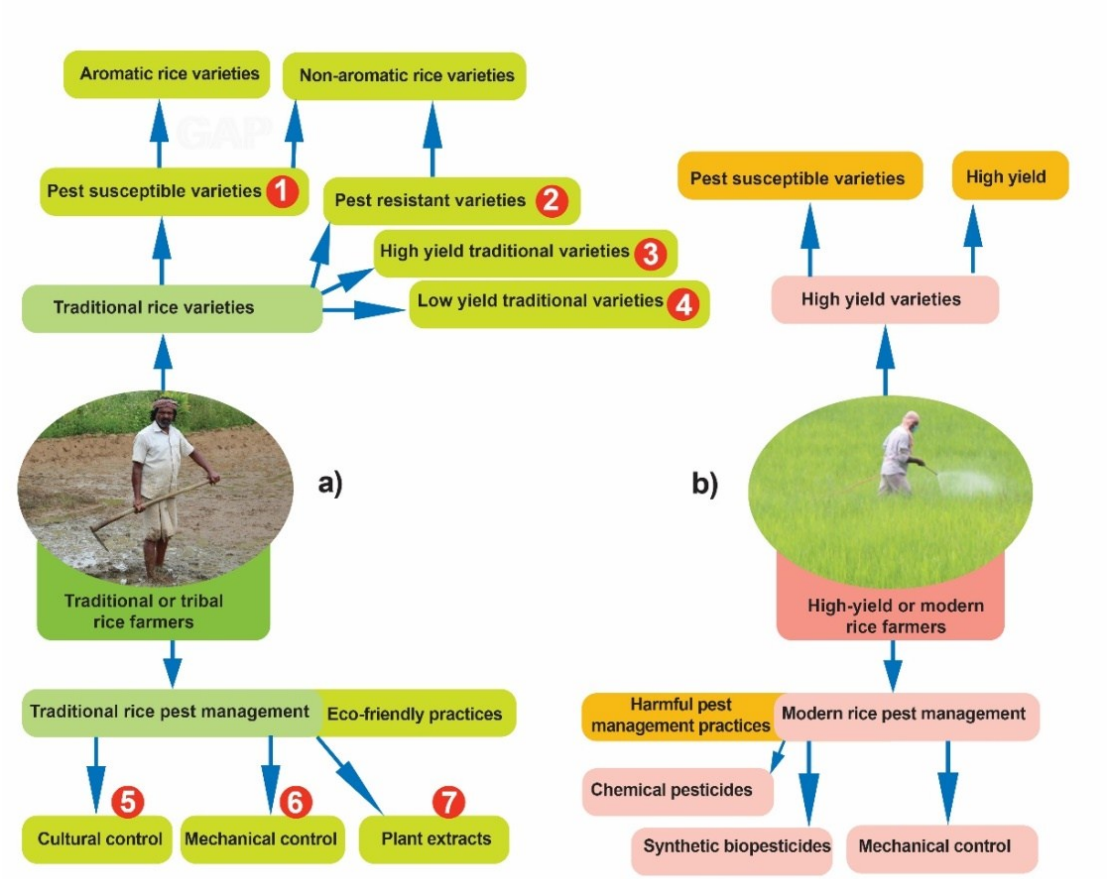


Gaps in traditional pest management adoption

In order to learn more about their pest control methods, traditional farmers (n=86), including tribal farmers (n=26), and high-yield or modern rice farmers (n=254) in North Kerala were surveyed. According to 86.0% of traditional farmers, traditional rice varieties are more pest-resistant than high-yield variants. However, 54.7% blamed traditional cultivars' for poor grain yields. Furthermore, 45.3% mentioned the availability of traditional types with excellent yields. Traditional rice varieties that are sensitive to pests were reported by 14% of traditional farmers. Gandhakasala, Chomala, and Jeerakasala were among the fragrant rice types grown by 69.8% of traditional rice farmers. Moreover, 8.1% of farmers cited high pest incidence in aromatic rice varieties. Mechanical pest control is used by 74.4% of traditional farmers and cultural control by 82.6%. 17.4% did not use pest management practices, realizing that traditional cultivars are pest-resistant enough to

withstand an infestation, and 57.0% employed plant extracts to control pests. Extension workers and experts (n=40), were surveyed to know about their validation of pest tolerant and pest susceptible traditional rice varieties, and the efficacy of traditional pest management practices in the field. But interestingly, no extension officials reported the validation. And 3.4% farmers requested us to validate their findings scientifically.

Fig. 3.26 Scientific validation gaps in traditional rice varieties (1–4) and traditional rice pest management practices (5–7) (a); and the types of modern rice pest management practices and the features of high-yield varieties (b).



Compared to traditional rice farmers, modern rice farmers depend the least on cultural (9.4% of respondents) and mechanical (33.8%) control practices. Chemical pesticides were the primary pest management method utilized by 92.1% of respondents. They also employed synthetic bio-pesticides (54.3%) rather than botanicals or plant extracts. 5.9% of modern farmers utilized biological control, while 7.8% did not use any pest control measures. The results indicate that modern

farmers had the least knowledge of traditional pest management practices. They all cited the high yields of modern varieties but also mentioned the high pest susceptibility of high-yield varieties (97.0% of respondents (Fig. 3.26).

Gaps in extension services

Every extension worker (N=30) was aware of at least one crop damage incident from insect pests. They all (100%) correctly recognized the discolored grain caused by adult rice bugs, and 96.7% managed to identify the caseworm attack and leaf-folder infestation in the field. However, no infestation of a rice pest has been identified with absolute confidence. Even though they are aware of multiple crop damages, they struggle to distinguish between damage brought on by various rice pests that are relatively similar. 83.3% of extension staff mistook the defoliation caused by the rice blue beetle for a leaf-folder infestation, even though they were familiar with the pest's name.

Likewise, 63.3% of extension workers incorrectly identified the rice field's cattle grazing appearance, attributed to armyworm infestation, as a situation involving case worm infestation. 33.3% of them recognized hopper burn as a disease brought on by the pathogen. 10% of respondents also identified stem borer dead heart as a disease. 26.7% of participants mistakenly thought the chaffy grain from the rice bug attack was the white ear heads caused by the stemborer (Table 3.36). In contrast to the response of extension workers, the experts (N=15) in the field of rice pest management recognized all the crop damage induced by rice insect pests (100% recognition).

Table 3.36. Extension workers recognition of rice pests based on actual specimen or damage.

Recognition	% Response (N=30)
Cut off leaf tip from case worms	96.7
Cattle grazing appearance in the field by armyworms	36.7
Defoliation from rice blue beetle	16.7
Discolored grains by rice bug adult	100
Hopper burn	66.7
Leaf folder damaged leaves	96.7
Stem borer dead heart	90
White ear head by stem borers	73.3

Every extension personnel was aware of the role played by birds, dragonflies, and spiders as natural predators of rice pests. However, only 33.3% possessed knowledge about ladybird beetles as natural enemies of rice insect pests. Even though most respondents are aware of ants (90%), parasitoids (90%), and pathogens (70%) as natural enemies of rice pests (Table 3.37). Extension workers who knew of parasitic wasps were asked to name the parasitoid, and many of them mentioned *Trichogramma* (70%) and Trichocard (100%). However, they did not know the classification of parasitoids as egg, larval, and pupal parasitoids or the name of parasitoids other than *Trichogramma*. Pathogens as natural enemies of rice pests were unknown to 30% of extension workers. Among the 70% of knowledgeable extension workers who knew pathogens as natural enemies, 52.9% suggested *Beauveria bassiana* as the major pathogen against rice pests, mainly rice leaf folders; others did not know to name the pathogen (47.1%).

Table 3.37. Extension worker knowledge on natural enemies of rice pests.

Extension worker knowledge and pest management behavior	**% of respondents (N=30)**
Natural enemies	
Ants	90.0
Birds	100
Dragon-flies	100
Lady bird beetle	33.3
Pathogens	70.0
Parasitoids	90.0
Spiders	100
Pest management practices	
No action taken	0.0
Pesticide use	96.7
Mechanical and cultural control	100
Use of botanicals/biopesticides	90.0
Natural enemy conservation	
No chemical pesticide usage	86.7
No killing of natural enemies	56.7
Planting new flowering plants near the field	46.7
Conserving existing flowering plants near the rice field	50.0

Extension workers emphasized active measures against pests. All surveyed extension officials (100%) highlighted the importance of including mechanical and cultural controls in pest management practices. A large majority, 86.7% of respondents, knew that protecting natural enemies meant avoiding the use of chemical pesticides in the field. On the flip side, 96.7% of all respondents still saw pesticides as a viable option for pest management. Additionally, only half of the extension workers understood the importance of having flowering plants near the field (Table 3.37).

100% of extension staff members mentioned mechanical and cultural methods as alternatives to pesticides. As alternatives to pesticides, however, every expert in this profession (100%) mentioned biological control, botanicals, cultural control, and mechanical control. However, 33.3% of specialists said that nano pesticides are alternatives to chemical pesticides, although no extension worker was aware of them (Table 3.38).

Table 3.38. Percentage of response to extension worker knowledge of chemical pesticide alternatives. Data were collected by surveying 30 extension workers in North Kerala.

Chemical pesticide alternative	% of respondants (Exension workers, N=30)	% of respondants (Experts, n=15)
Biological control	86.7	100
Botanicals/ biopesticides	96.7	100
Cultural practices	100	100
Mechanical control	100	100
Nano-pesticides	0.0	33.3

Experts and other agricultural extension personnel (n=40) cite several obstacles to the execution of effective pest control trainings. Insufficient funding (87.5% of respondents), a high farmer-to-extension officer ratio (97.5% of respondents), a lack of adequate transportation options (85.0% of respondents), farmers' unwillingness (92.5% of respondents), lack of sufficient extension materials (70.0% of respondents), and the workload of the office (97.5% of respondents) are the main issues. Most extension agents listed the pressure of office

work and the high farmer-extension officer ratio as the primary barriers to providing efficient extension services (Fig. 3.27).

Fig. 3.27 Challenges to effective extension services reported by the pest management experts of local agricultural institutions and research stations.

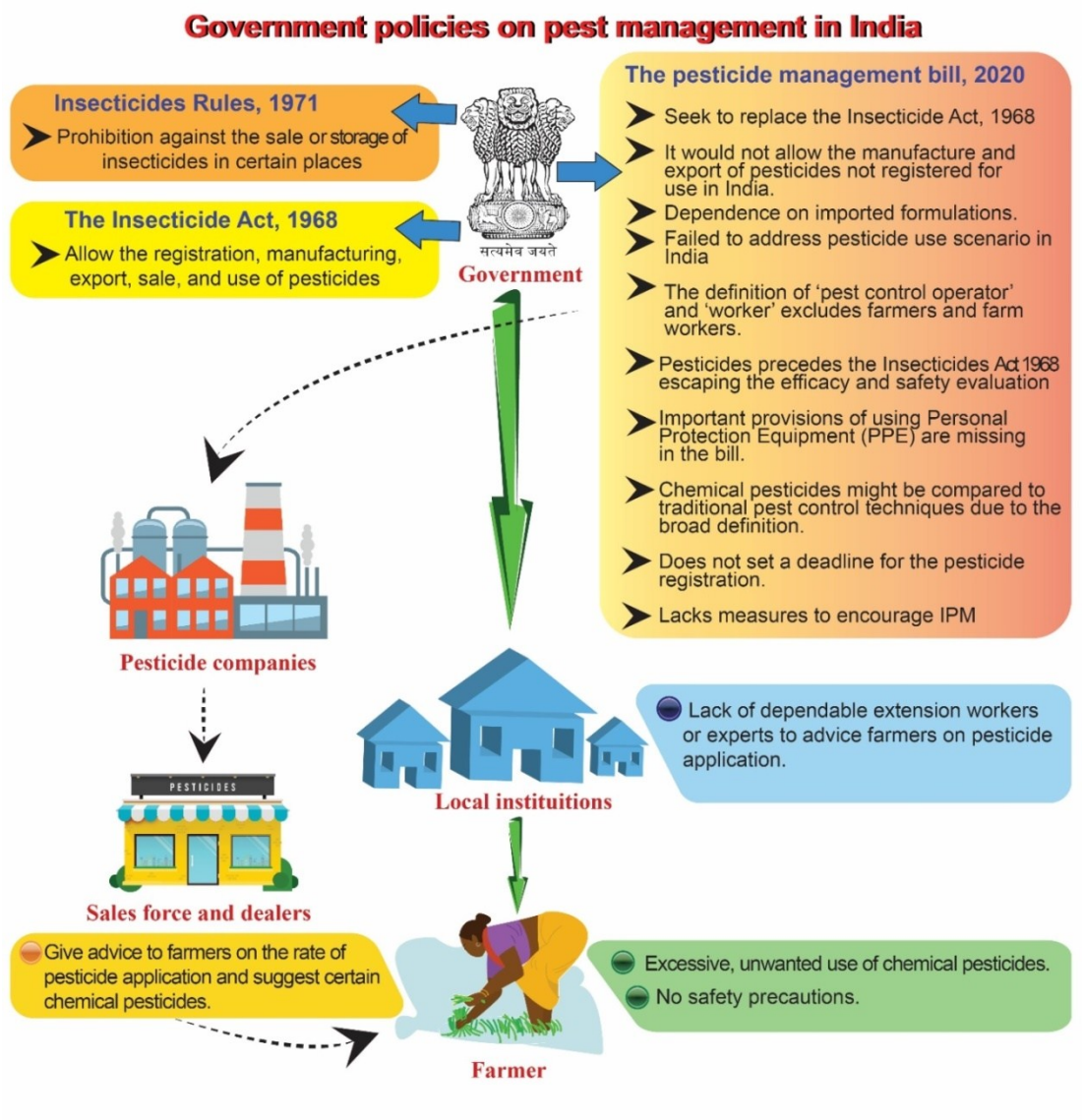


Gaps in government policies

Farmers (N=340) were interviewed to assess their understanding of government policy. The Insecticide Rule (1971), the Insecticide Act (1968), and the Pesticide Management Bill (PMB) 2020 were the three main policies on which the knowledge was tested (Fig. 3.29). None of the farmers surveyed knew the Insecticide Act of 1968 or the Insecticide Rule of 1971. However, only a few farmers (2.9%) knew the PMB 2020. Nevertheless, no one was aware of the PMB's 2020 report. On their understanding of government policies, 30 extension agents and 15 experts were interviewed. Only 40% of extension workers understood the

statements in the bill, even though 66.6% knew the bill by its name. All experts knew the bill, and 73.3% were familiar with its positive and negative aspects.

Fig. 3.28 The gap of government policies on pest management in India.



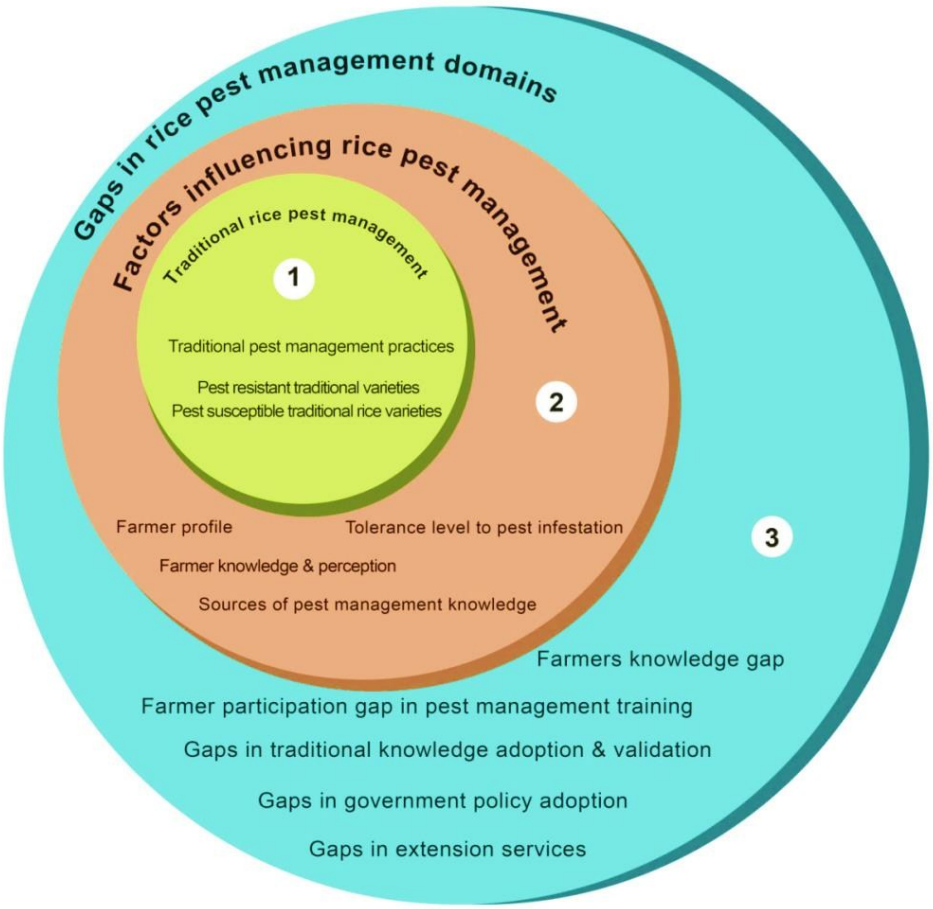
For rice pest management, 77.9% (n=340) of the farmers at the study site rely primarily on chemical pesticides. Only 12.9% of the farmers in the study region sought advice from extension agents or specialists about the pesticide application rate. Since 95.7% of extension workers or experts (n=40) cited office burden as one of the main obstacles to effective extension service, more than half of the farmers in the study site (52.3%) relied primarily on pesticide sellers for information on

pesticide application rates and the selection of pesticides. In a crop season, most farmers in the survey regions sprayed pesticides two to four times (77.9% of respondents). While applying pesticides, 87.0% of farmers took no precautions. Among them, 60.1% faced breathing problems, and 32.5% suffered from skin irritations.

Discussion

The study revolved around understanding how socio-ecological factors interact in the context of rice pest management. It analyzed traditional practices, considered human influences, highlighted shortcomings in current methods, and suggested solutions to enhance the management of rice pests in North Kerala (Fig. 3.29).

Fig. 3.29 The three aspects of the study carried out comprised (1) traditional rice pest management (2), factors influencing rice pest management (3), and the gaps in rice pest management domains in North Kerala.



Traditional rice pest management

Traditional pest management practices

The pest management strategies employed by small-scale Kerala farmers offer a multifaceted and resourceful approach to combat agricultural pests, deeply rooted in cultural, mechanical, and religious practices. These methods, evolved over generations, encompass diverse techniques ranging from manual interventions to the use of natural elements and traditional products derived from plants and animals. Manual interventions such as handpicking, sweeping, and using muram or nets effectively control visible insect pests. Specific methods, like swaying plant branches to injure concealed defoliators and using lemongrass oil to harm caterpillars, are innovative ways to combat pest infestations. In the present survey, we observed that farmers use unconventional items such as dried sardine fish and *Cycas circinalis* flowers to repel Gundhi bugs. According to previous reports, farmers frequently employ traditional methods such as dead, rotting frogs, crabs, and fish to manage Gundhi bugs (Das and Saikia, 2010; Majumder et al., 2013). Despite their effectiveness, the public display of these lures on bamboo sticks attracts more insects (Chandra et al., 2017). Furthermore, we observed that traditional rituals are performed by tribal farmers, guided by their cultural beliefs, viz., Mantras, placing erect posts called Vavu and Vaikattu, to minimize insect infestations in rice fields. Water management practices play a significant role in rice pest management strategies as noted by Fujisaka (1990). Lorenz et al. (2018) also reported a similar strategy. They claim that rice that has been submerged is substantially less vulnerable to armyworm damage. In the present study, farmers flood fields to wash away pests like armyworms, while drainage is employed to manage infestations of brown planthoppers and rice case worms. A similar report by Litsinger (1994) suggests field drainage against brown planthoppers and caseworms.

Additionally in our observations, methods like uprooting injured areas of rice plants (roughing) and cutting dead hearts are used to eliminate stemborers, although these may not eradicate all larvae effectively. Innovative approaches include light traps, weed removal, and bund shaving. Farmers utilize light traps to control

nocturnal pests, although criticisms exist regarding their cost (Li-Ying, 1982), inconsistent effectiveness (Litsinger, 1994), and impact on beneficial species (Kondo, 1917).

Weed management involves attracting pests for better extermination, while bund shaving aims to drown eggs and pupae of certain pests. Indigenous rodent control methods, such as owl perches and bund shaving, also reduce pest. Human-wildlife conflicts pose significant challenges for farmers in Kerala. To mitigate these conflicts, a diverse range of tactics is employed, including the use of electric and timber fences, scare tactics using fire crackers, and physical barriers to deter animals such as deer, elephants, monkeys, and wild boars. Moreover, specific crop protection measures have been developed to target pests like peacocks, deer, and rodents during both pre and post-harvest phases. Notably, these measures aim to safeguard crops from wildlife intrusion and damage. Furthermore, the integration of traditional pest management practices from tribal regions holds substantial significance. These age-old practices, refined and adopted across India, offer valuable insights into sustainable pest control methods. References to study by Sinha et al. (2007) underscore the credibility and acceptance of these traditional practices within the scientific community.

Using various plant and animal-based products for controlling rice insect pests is a prominent practice among farmers in North Kerala. Among the plant products utilized-neem oil emulsion, neem seed extract, and tobacco emulsion-alongside the animal products like diluted buttermilk, fish amino acids, panchagavya, and jeevamrutham, and panchagavya are specifically noted for their ability to bolster the rice plant's natural defenses against pest infestation. Conversely, the remaining products function primarily as insect pest repellents. Moreover, the development of bio-pesticides using traditional knowledge signifies a crucial link between age-old agricultural practices and their relevance in modern farming techniques (Panda et al., 2011). The documentation of these practices holds immense importance as it validates and integrates these traditional methods into scientific assessments and modern agricultural practices.

The traditional pest management calendar, designed for indigenous rice varieties, outlines a systematic approach, integrating pest control and plant strengthening activities at various stages of crop cultivation. Seed treatment using cow dung slurry water and post-harvest pest prevention techniques using neem leaves and *Glycosmis pentaphylla* Retz extracts exemplify these practices' incorporation into farmers' cultural traditions.

The multifaceted approach of traditional pest management methods among small-scale Kerala farmers reflects a holistic and resourceful way of combating agricultural pests. Drawing on cultural and mechanical practices, these methods showcase a rich repository of indigenous knowledge that has evolved. Integrating this traditional wisdom into modern scientific assessments and agricultural practices holds promise for sustainable and effective pest management in the future.

Pest resistant traditional varieties

The present study examines pest resistance across various rice varieties, employing both secondary data analysis and field research. While secondary data suggested pest resistance in rice cultivars like Adukkan, Chennellu, Chenthadi, Mundon, and Veliyan, on-field observations contradicted these findings. Field observations revealed a different set of rice varieties-Kanakam, Kunjuthi, Kunkumsali, Kunnumkulamban, Marathondi, Onachanna, Pal Kayama, Thonnuram Thondi, Uruthi Kayama, and Velumbala-as exhibiting resistance to pests. Intriguingly, only traditional rice varieties demonstrated pest resistance in the study area, leading to a ranking of these varieties based on their pest index. Among the forty-nine traditional rice varieties assessed, several, including Kanakam, Kayama, Kunjuthi, Kunkumasali, Kunnumkulamban, Marathondi, Onachanna, Pal Kayama, Raktasali, Thondi, Thonnuran Thondi, Uruthi Kayama, and Velumbala, emerged as the top-ranked in terms of pest resistance. Conversely, Jeerakasala exhibited the lowest pest resistance within the study site, followed by Valichoori, Mundon, and Gandhakasala. These traditional rice cultivars showcase remarkable resilience against pests and diseases while seamlessly integrating into current micro-farming systems.

A pivotal factor influencing the selection of rice varieties is their inherent resistance to diseases and pests, a trait predominantly observed in these indigenous varieties. Numerous studies underscore the role of secondary metabolites in conferring insect pest resistance in rice plants. Specific compounds like schaftoside and isoschaftoside, identified in rice leaves and phloem, have exhibited promising antifeedant properties against pests like the brown planthopper (Stevenson et al., 1996; Saito et al., 2008; Katsumata et al., 2018). However, despite advancements in this field, a comprehensive understanding of the mechanisms governing insect pest resistance in traditional rice plants remains elusive. This knowledge gap poses a barrier to developing effective pest-resistant varieties and innovative farming techniques as noted by Uawisetwathana et al. (2019).

The results call for further research to identify and comprehend potential secondary metabolites that could act as markers or bioactive compounds for sustainable solutions against insect pest infestation. It underscores the crucial role played by indigenous rice varieties possessing inherent resistance to pests, a fundamental aspect of the sustainability of agriculture. These traditional cultivars, esteemed for their adaptability and resilience against pests, are pivotal in addressing challenges associated with pests in agricultural contexts.

Pest susceptible traditional varieties

Typically, traditional varieties experience fewer pest attacks compared to modern cultivars (Muralikrishnan et al., 2021). Nevertheless, certain traditional varieties exhibit a notable abundance of specific pests (e.g., Padmakumari et al., 2017). This phenomenon could be attributed to the variability in volatile composition among different traditional varieties (e.g., Ashokkumar et al., 2020). The study thoroughly examines the traditional rice varieties susceptible to the yellow stem borer (YSB), *Scirpophaga incertulas*, in the context of cultivating high-yield rice varieties. Specifically, this investigation focuses on the aromatic varieties Jeerakasala, Gandhakasala, and Chomala, analyzing their efficacy in deterring YSB infestation. Several studies, exemplified by Prasad et al. (2013) and Padmakumari et

al. (2017), have investigated the potential of trap cropping as an ecologically sound alternative for pest management while preserving crop yields.

Biometric analyses of high-yield (Aathira, Aiswarya, Kanchana, and Uma) and traditional rice varieties (Jeerakasala, Gandhakasala, and Chomala) were conducted, revealing significant correlations between the biometric characteristics of the plants and YSB infestation. The Pearson correlation matrix showcased a substantial disparity between the average clutch size of *S. incertulas* and various plant morphological traits, such as culm length, culm width, cultivar duration, leaf width (where *S. incertulas* egg masses are laid), panicle length, and the number of tillers. Notably, the number of white ear heads displayed distinct differences among the plant morphological characters, indicating their relation with YSB infestation. For instance, the results indicate that tall rice varieties tend to attract increased oviposition by YSB, leading to a higher accumulation of egg masses. This observation aligns with study conducted by Patanakamjorn and Pathak (1967); however, it contradicts the study of Chavan and Patel (2018). Further analyses displayed a linear relationship between plant physical characteristics and YSB infestation, wherein variables like panicle length, culm length, culm width, and cultivar duration positively correlated with YSB indicators, while the number of tillers showed a negative correlation. For instance, longer panicle length, culm length, and culm width could provide favourable conditions for YSB infestation. These characteristics might offer more space and resources for YSB larvae to thrive, contributing to increased infestation levels. Conversely, a higher number of tillers might indicate a healthier or more robust plant that's less susceptible to infestation due to better nutrient distribution or resilience against pest attacks. In certain cases, higher tiller numbers may reduce pest infestation. When plants produce more tillers (side shoots), they may exhibit a "dilution effect." This effect means that the presence of more tillers spreads the impact of pest feeding across multiple shoots, reducing the damage to each individual tiller or plant as depicted by Ishii-Eiteman and Power (1997).

The Gandhakasala rice variety showed a significant difference in YSB infestation in the presence or absence of the high-yield variety (Uma). The attractiveness of different rice varieties to insect pests can be attributed to several factors. Firstly, rice varieties emit volatile compounds that can either attract or repel specific insect pests. These compounds play a crucial role in pest behavior, influencing their choices for mating, feeding, or oviposition (Han et al., 2023). Secondly, genetic variations among rice varieties significantly impact their susceptibility to insect pests. Certain varieties may possess genetic traits that make them more appealing or suitable hosts for particular pests, while others may exhibit traits that provide resistance or tolerance to pest attacks (Shah et al., 2022). Additionally, the physical characteristics of rice plants, such as leaf shape, stem structure, or the presence of trichomes, can influence their attractiveness to insect pests. Pests often exhibit preferences for plants with specific morphological traits that offer suitable feeding or oviposition sites (Bisen et al., 2019), which supports our findings.

The study compared the clutch size, egg mass area of yellow stem borer (YSB), and the number of white ear heads caused due to YSB infestation between the high-yield Uma variety and the traditional aromatic Gandhakasala rice varieties within a mixed plot. In the mixed plot, clutch size (203.8±20.35), egg mass area (28.76±2.86), and white ear heads (338±58.78) were higher in the Gandhakasala rice variety. The results underscored a significant disparity in stem borer infestation between these high-yield and traditional rice varieties when grown together. The findings revealed an increase in YSB infestation in the Gandhakasala variety when grown alongside Uma, which indicates the increased susceptibility of Gandhakasala. These differences suggest that Gandhakasala, when utilized in a mixed plot with Uma, exhibits certain attributes that attract or support a higher population of YSB, thereby potentially drawing the pest away from the high-yield Uma variety. This outcome hints at the consequence of cultivating Gandhakasala along with the Uma variety. The study has the potential to offer a more precise explanation for the higher prevalence of certain pests in traditional varieties. This may require a deeper investigation into the plant morphology and precise volatile compositions that attract

pests to these varieties. A comparative study on pest infestations in various rice varieties when grown in combinations and singly may help in devising better pest management strategies.

Factors influencing rice pest management in North Kerala

Farmers' knowledge of rice pests and natural enemies

The agricultural landscape in Kerala relies heavily on rice cultivation as a fundamental source of livelihood for many small-scale farmers. However, the persistent prevalence of rice insect pests and vertebrate pests poses substantial challenges, significantly impacting crop yield and the livelihoods of these farmers (Krishnaiah and Varma, 2011; Jena et al., 2018). Effectively managing these pests necessitates a profound understanding of farmers' knowledge, perceptions, and practices, which intricately influence pest identification, ecological comprehension, and pest management strategies.

Farmers in Kerala encounter considerable difficulty in distinguishing between various pest species, particularly during larval stages, owing to their morphological similarities. This challenge often leads to grouping multiple pest species under a single common name, hampering precise pest management strategies due to the lack of accurate pest identification as noted by Bentley (1989). Similar observations have been noted in Philippines, where Filipino farmers use generic terms such as "worms" to describe various pest species causing analogous damage (Litsinger et al., 1980). The complexities extend to categories like planthoppers and leafhoppers, where Filipino farmers perceive homopterans as defoliators, with only a minority aware of their sap-sucking behavior. The term "hoppers" encompasses not just planthoppers but also around four species of leafhoppers. Despite their significant impact, pests like brown planthoppers might be overlooked due to their small size and novelty in the ecosystem as identified by Heong (1984).

The existing knowledge gap regarding farmers' perceptions, understanding, and practices related to pest management poses a significant obstacle in developing

effective pest control approaches tailored to the needs of smallholder farmers in North Kerala. This lack of comprehensive information impedes the alignment of pest management strategies with farmers' observations and practices, hindering the success of pest control programs.

Assessing farmers' socioeconomic characteristics, knowledge of pests, current practices, and barriers to effective pest management is crucial in tailoring pest control strategies to regional needs (Damalas and Hashemi, 2010; Hashemi and Damalas, 2010). However, the present study indicates that farmers' knowledge about insect pests and their natural enemies is generally limited. They struggle to identify pests beyond the larval stage and often rely on visible signs of damage for pest identification.

Farmers' perspectives on the significance of pests in rice fields vary based on their visibility and impact on crops. While some pests like leaf folders, case worms, and rice bugs are commonly recognized as severe pests in different agro-ecological zones, the recognition of these pests varies across regions, influenced by their perceived importance and accessibility, which is consistent with Bentley's (1992a) results.

While farmers possess some knowledge about natural enemies like spiders and dragonflies, their awareness of other beneficial organisms, such as parasitic wasps and ladybird beetles, remains notably low. Farmers often lack understanding regarding the biological control of pests, leading to challenges in implementing integrated pest management (IPM) practices.

Farmers observe increased pest incidence during specific crop stages, such as the paddy's booting stages, and associate more severe pest problems with the wet season. Their knowledge about pests predominantly originates from personal experience and farmer peer groups. However, information from extension services and research institutes plays a minimal role in enhancing their understanding of pests and their management.

Farmers' limited knowledge about pests and their natural enemies highlights the need for educational programs to improve their understanding of pest biology, pest identification, and ecological interactions. Successful pest management strategies should integrate farmers' observations and practices, encourage farmer-to-farmer knowledge exchange, and promote the appreciation of natural enemies in pest control (Midega et al., 2012). Developing decision support tools within an IPM framework becomes imperative to facilitate the integration of various pest control solutions and guide farmers in making informed decisions. Efforts to bridge the knowledge gap and empower farmers with comprehensive pest management strategies must focus on enhancing their understanding of pest biology, natural enemies, and the ecological dynamics within agro-ecosystems.

The challenges faced by farmers in identifying and managing rice insect pests and vertebrate pests in Kerala underscore the necessity for tailored pest management strategies rooted in farmer knowledge and practices. Addressing the knowledge gap, providing accurate pest identification tools, and promoting the understanding of beneficial organisms are essential steps towards effective and sustainable pest management in rice cultivation. Collaborative efforts between farmers, researchers, and extension services can drive the development and adoption of holistic pest management approaches, ensuring crop protection and sustainable agricultural practices in Kerala.

Farmers' perception of rice pest management practices

Pest management is a critical aspect of agricultural practices, significantly impacting crop yields and farmer livelihoods. In the context of rice cultivation in Kerala, farmers employ various pest management strategies, primarily utilizing chemical pesticides, mechanical controls, synthetic biopesticides, biological control, and genetic resistance. However, the motivations behind these practices, decision-making processes, challenges, and opportunities warrant a comprehensive exploration to enhance sustainable and effective pest management strategies.

The decision-making processes of farmers in implementing pest management strategies reflect their perceptions, opinions, and available knowledge rather than an

objective assessment of field realities. Chemical pesticides emerge as the most frequently used pest management method, with farmers attributing high efficacy scores to these chemicals. However, the indiscriminate use of pesticides poses significant risks to human health and the environment. Pesticides like Karate have been found to cause harm to farmers' skin and eyes, underlining the detrimental effects of chemical applications (Balkrishna et al., 2021). The prevalence of moderately hazardous pesticides, such as pyrethroids and organophosphates, in different regions of Kerala indicates the need for greater awareness regarding the adverse impacts of these chemicals on human health and the ecosystem. The "three Rs" problem-resistance, resurgence of pests, and pesticide residues-illustrates the consequences of excessive pesticide use, leading to ecological imbalances and reduced efficacy over time (Bernard and David, 2001; Pontius et al., 2002). Farmers' tendency to spray pesticides immediately upon noticing pest emergence reflects a fear of pest outbreaks and crop damage, emphasizing the importance of educating farmers on the ecological dynamics of pest populations to prevent indiscriminate spraying.

While biological control methods receive high efficacy ratings from farmers, their adoption rates remain low, indicating a significant gap between perception and practice. Farmers primarily relying on organic practices exhibit lower efficacy in pest management, suggesting the need for diversified pest management approaches. Understanding farmers' attitudes towards natural enemies and their impact on pest management can help in promoting environmentally friendly pest control options (Litsinger, 1994). Positive attitudes towards natural enemies correlate with exploring alternative chemical pest management strategies, such as mechanical control, demonstrating the potential for promoting more sustainable practices by leveraging farmers' ecological understanding. Farmers' adherence to Economic Threshold Levels (ETLs) set by agricultural authorities, consultation with pesticide sellers, and reliance on neighboring farmers' advice depict the diverse sources of knowledge influencing pesticide application decisions. Integrating Integrated Pest Management (IPM) strategies based on appropriate ETLs could effectively manage pest insects (Abrol, 2014), emphasizing the importance of knowledge dissemination regarding

proper pesticide application rates and timing. This study points out that investigating pesticide use patterns, constraints in pest control, awareness of environmental pollution caused by pesticides, and alternatives to pesticide use are vital for developing more sustainable and effective pest management strategies.

In conclusion, addressing the motivations and decision-making processes behind farmers' pest management practices in Kerala involves leveraging their perceptions, improving ecological understanding, promoting sustainable alternatives, and fostering collaborative efforts among stakeholders. Encouraging diversified pest management strategies, including biological control, while emphasizing the judicious use of chemical pesticides can contribute to sustainable agriculture and reduce environmental risks associated with pest management practices. Efforts focused on comprehensive research, education, and knowledge dissemination tailored to the local context can pave the way for more sustainable and effective pest management practices in Kerala's agricultural landscape.

Role of opinion leadership, social connectedness and information sources in the diffusion of rice pest management knowledge

Integrated Pest Management (IPM) is pivotal for sustainable agricultural practices, particularly in rice cultivation, where pest management strategies significantly impact crop yields (Norton and Mumford, 1993). In North Kerala, understanding the sources and insights that farmers rely on is crucial for the effective development of IPM extension materials. The diverse information channels, perceptions, and influences guiding farmers' pest management decisions underscore the complexity of agricultural decision-making processes.

Farmers in the study area primarily gather knowledge about managing rice pests through interpersonal communication and pest management training. Key resources for pest management information include the agricultural department, fellow farmers, friends or family, personal experiences, pesticide merchants, and labels on pesticide bottles. The insights garnered from these sources influence farmers' pest control strategies and decision-making processes.

The trustworthiness of information sources significantly impacts farmers' pest control decisions. Various studies indicate a significant reliance on agricultural technicians, government advice, and radio programs in acquiring pest management information (Brunold, 1981; Tjornhom et al., 1997). Farmers' preferences for certain information sources differ across regions and are influenced by agro-ecological zones, peer influence, and perceived risks associated with pests and pesticides. The influence of prior experiences, perceived efficacy of pest control methods, and misconceptions about pest abundance and management strategies may also significantly impact farmers' decisions on pesticide application (Kenmore et al., 1985; Mumford and Norton, 1993; Heong and Escalada, 1997).

Farmers in North Kerala have varying perceptions of natural enemies, influenced by the sources of information they access. Identifying key natural enemies—spiders, dragonflies, birds, and parasitoids-varies among farmers relying on different information channels. Conservation strategies for natural enemies range from refraining from using chemical pesticides to planting flowering plants adjacent to rice fields.

Awareness of non-chemical pesticide alternatives among farmers is significant, with sources like agricultural extension agents, fellow farmers, and personal experiences playing a crucial role. Farmers exhibit varying knowledge and acceptance of alternative pest management methods such as botanicals, biopesticides, and cultural practices.

Farmers with IPM training demonstrate higher knowledge of arthropod natural enemies, pesticide alternatives, and natural enemy conservation techniques. The influence of social connections and opinion leaders significantly affects farmers' pest control knowledge and adoption of IPM practices.

Our study indicates that farmers with extensive farming experience who engage with fellow farmers and extension officials possess a greater awareness of pesticide alternatives and a deeper understanding of both appreciating natural enemies and seeking alternatives to chemical pesticides. These findings align with the discoveries of Wyckhuys and O'Neil (2007a), who affirm a direct relationship

between the range of recognized pesticide alternatives and the familiarity farmers have with arthropod natural enemies. This correlation underscores the importance of experience and interaction in shaping farmers' knowledge of pest management. Significant discrepancies exist across farmer communities concerning their comprehension of natural enemies, available pesticide alternatives, and conservation practices, particularly among different types of farmers-those trained, untrained but socially connected, and untrained without social connections. Farmers associated with social connections for rice pest management demonstrate a heightened awareness of various natural enemies, consistent with the conclusions drawn by Wyckhuys and O'Neil (2007a,b). Contrarily, those without training exhibit comparatively lower levels of knowledge in these domains. Training emerges as a crucial factor influencing farmers' awareness levels. Those who undergo training exhibit a more profound understanding of pesticide alternatives, appreciation of natural enemies, and strategies to circumvent reliance on chemical pesticides. This suggests that formal training significantly enhances farmers' comprehension of pest management strategies, emphasizing the pivotal role of education in improving their knowledge base.

Our study revealed varying perceptions of pest damage, influenced by factors like pest management training, opinion leadership, understanding of natural enemies and pests, involvement with local institutions, and social connections. Notably, a strong correlation existed between perceived pest damage and agricultural pest control training. This suggests that individuals with better training often held more acute perceptions of pest-related issues, emphasizing the impact of education on recognizing and assessing pest damage.

In the present study, the relationship between understanding natural enemies, training in pest control, and opinion leadership was found to have a weak positive correlation. This implies that the focus of pest control training in North Kerala likely emphasized pests more than their natural enemies. However, knowledge of pests exhibited a connection with pest management training, opinion leadership, and comprehension of natural enemies. This interrelation suggests that while training

may have concentrated more on pests, a comprehensive understanding was linked to broader factors such as pest management education, influential leadership, and familiarity with natural enemies. In alignment with Wyckhuys and O'Neil (2007b) observations, the opinion leaders and the sources of pest management information influenced the dissemination of Integrated Pest Management (IPM) knowledge. Opinion leaders, who were notably active within regional organizations, held larger farming lands and maintained stronger social networks, played a crucial role in spreading knowledge.

Moreover, individuals participating in pest control training exhibited strong social networks and frequently shared knowledge with their peers. Farmers who were socially linked to training participants showed enhanced awareness of natural enemies and occasionally demonstrated greater competence in various pest management approaches, including biological control methods (for example, Wyckhuys and O'Neil, 2010). These findings underscored the significant impact of social ties and influential figures in disseminating knowledge and fostering understanding among farmers regarding pest management techniques and natural enemies.

The study illuminates the multifaceted landscape of information sources, perceptions, and influences guiding pest management decisions among rice farmers in North Kerala. It underscores the importance of tailoring pest management extension programs to leverage local knowledge, enhance social capital, and disseminate contextually relevant agricultural technologies. This study may serve as a foundation for future research and developing targeted extension programs to foster sustainable pest management practices. Emphasizing education, community engagement, and integrating local knowledge with modern pest control techniques can facilitate the adoption of more effective and sustainable pest management strategies in rice cultivation across North Kerala. In conclusion, understanding farmers' information sources, perceptions, and decision-making processes in pest management is critical for developing contextually relevant and effective IPM strategies. Addressing misconceptions, promoting alternative pest management

methods, and leveraging social connections can significantly contribute to adopting sustainable agricultural practices in North Kerala.

The structure of Socio-economic web that influence pest management decision in traditional and high-yield rice farmer communities

The socio-economic webs within traditional and high-yield rice farming communities play a pivotal role in understanding rice pest control decisions. These webs, characterized by distinct structures, influence the variables shaping pest management approaches in different farmer groups in North Kerala. Tribal communities primarily engage in traditional pest control techniques and rice farming practices, whereas modern rice farming communities focus on high-yield varieties. The socio-economic components hold varying degrees of significance for traditional versus high-yield rice farmers in learning about rice pest control. Furthermore, the connections between these components vary based on the community type. The level of interconnectedness within a farmer's knowledge network significantly influences their decisions concerning modern rice pest management.

In traditional rice farming, knowledge is predominantly derived from traditional practices, contrasting sharply with modern rice pest management sources. Traditional agricultural practices, developed through extensive trial and error over centuries, are considered empirically efficient (Thurston, 1990). These systems often emulate natural ecosystems, known for their diversity and stability (Litsinger et al., 2009). In the present study, it was observed that various elements, like agro-ecological zones, pest tolerance, and agricultural experience, significantly influence traditional pest control systems. Notably, engagement with regional institutions, education, media influence, or pest control training less affected traditional pest control techniques. These methods usually require modest resources and entail minimal structural change in traditional communities.

Comparatively, modern rice pest management systems involve more social engagement, indicating a greater impact of socio-economic components on pest management decisions. Despite the efficiency of traditional methods, the risk of losing these practices as agriculture modernizes remains a concern, highlighting the

need for their preservation and thorough evaluation. However, quantifying the relative importance of different socio-economic components within the web remains challenging due to data limitations. Techniques like Net-Map activities, where participants rank the components' significance, could enhance this quantification (Schiffer, 2007; Schiffer and Hauck, 2010).

Additionally, participatory web development could improve the social-economic web technique by allowing farmers to depict relationships between proposed components and contribute to overlooked elements. Through this participatory method, changes in processes could be better illustrated, enabling a clearer representation of current and future socio-economic webs. Notably, this social-economic web concept draws parallels with methodologies employed in social sciences like Net-Maps or social network analysis, despite being initially inspired by food webs and ecology (Schiffer, 2007; Scott, 2000). This convergence supports the notion that economics and social sciences share comparable methodologies. The social-economic web serves as an interdisciplinary tool, facilitating ease of learning, application, and integrating information from multiple disciplines to address terminological challenges, ultimately functioning as a bridge concept in interdisciplinary studies as mentioned by Betz et al. (2014).

Farmer's tolerance levels to pest infestation

The relationship between farmers and the various species that affect their crops is intricate, influenced by multiple factors such as economic conditions, ecological zones, and traditional agricultural practices. Goodale et al. (2015) highlighted that the type of annoyance a species poses-damage or threat-significantly shapes farmers' tolerance levels. The present study delves into the nuanced dynamics of farmer tolerance towards insect and vertebrate pests, examining diverse agricultural settings and socio-economic factors influencing these relationships.

The tribal farmers in North Kerala display higher tolerance levels toward insect and bird pest infestations compared to other farmer groups in the region. This tolerance could be attributed to the resilience of indigenous cultivars against

diseases and pests (Singh et al., 2007), thereby reducing farming costs and enhancing benefits. Additionally, indigenous farmers possess cultural techniques to deter avian pests (Fahad et al., 2015), emphasizing their unique knowledge base in managing pest-related challenges.

The tolerance levels among farmers in different agro-ecological zones vary significantly. For instance, farmers in the high hill area exhibit lower tolerance towards crop damage caused by vertebrate pests like elephants, monkeys, deer, and pigs due to their proximity to forest regions. These animals, drawn to grain fields due to scarcity in the forest, cause substantial harm to rice plantations, impacting harvests as noted by Grist and Lever (1969) and Fujisaka et al. (1991). Conversely, the farmers of foothill region display greater tolerance towards mammals, possibly influenced by lesser susceptibility to mammalian rice pests. However, the farmers of the same region shows low tolerance for insect pest infestations, likely because of the prevalence of insect-related crop destruction.

Socio-economic factors also play a crucial role in determining tolerance levels. For example, individuals whose primary income source is the service sector or those not using pesticides exhibit higher tolerance for insect infestations in certain zones. Conversely, farmers relying solely on agriculture for income or employing pesticides tend to display lower tolerance levels towards pest infestations. Furthermore, the distinction between full-time and part-time farmers impacts their perception of pest-related risks. Full-time farmers, accustomed to coping with existing pest threats, are more concerned about damage. In contrast, part-time farmers may be less affected due to their smaller scale of cultivation or different primary sources of income, consistent with the results of Goodale et al. (2015). However, these findings might not be universally applicable due to diverse environmental and socio-economic factors influencing farmers' tolerance levels in different regions. Nieman et al. (2020) emphasize that tolerance levels might favor less common or elusive species. Thus, interventions to reduce farmer conflicts and crop damage should align with these nuanced insights, considering strategies to increase overall farmer tolerance and mitigate losses caused by various pest species.

In conclusion, understanding the intricate relationship between farmers and pest species is crucial in devising effective management strategies. Wang et al. (2006) suggests implementing measures to reduce both actual and perceived losses. This comprehensive understanding, considering socio-economic, cultural, and ecological nuances, will facilitate the development of targeted interventions to enhance agricultural productivity while minimizing conflicts arising from species annoyance. The relationship between farmers and the various species that affect their crops is intricate and influenced by multiple factors such as economic conditions, ecological zones, and traditional agricultural practices.

Gaps in pest management domains and the recommended solutions

Farmer's knowledge gap and solutions

Rice farming in North Kerala faces numerous challenges associated with pest management, highlighting critical gaps in farmers' knowledge, extension services, acceptance of traditional wisdom, and government policy implementation. Addressing these gaps is crucial to enhancing sustainable pest management practices and reducing dependency on chemical pesticides. This study examines the identified gaps, assesses their implications, and proposes strategies for effective knowledge dissemination and farmer empowerment in rice pest management.

The study identifies a lack of understanding among farmers regarding rice pest management, encompassing pest identification, damage assessment, pesticide application rates, and alternatives to chemical pesticides. Additionally, farmers' decisions in pest management are influenced by outbreaks in neighboring fields, as evidenced by the findings of Litsinger et al. (2009) and advice from peer groups like extension workers and pesticide sellers. This reliance on external information sources often leads to misidentification of pests and limited comprehension of pest biology and natural enemies.

The gap between research institutions and smallholder farmers contributes to the inadequate implementation of pest management practices. Limited access to external inputs prompts the necessity for pest management strategies like

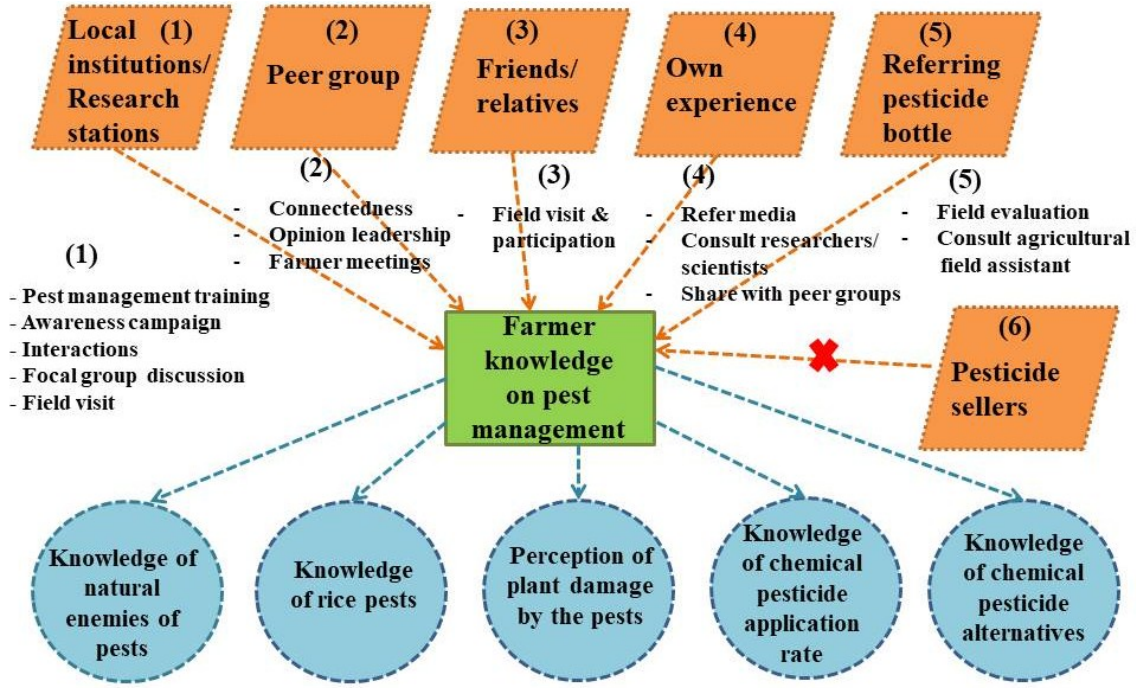
conservation biological control (CBC) that reduce output costs (Mkenda et al., 2017). However, farmers' awareness and acceptance of biological control are lacking due to insufficient knowledge dissemination. Agricultural institutions' failure to provide necessary pest management information exacerbates farmers' reliance on synthetic pesticides, further impeding sustainable pest management.

Farmers express dissatisfaction with the limited frequency of interactions with agricultural officers, leading to a lack of essential knowledge and guidance. While researchers are a significant knowledge source, the absence of follow-up interactions results in a lack of scaled-up and sustained application of research findings. Effective dissemination of agricultural information to farmers is crucial for successful pest management and sustainable farming practices. However, farmers often face challenges in accessing pertinent knowledge from research institutes, higher education institutions, and government agencies despite being the intended beneficiaries of this information. Addressing this issue requires innovative approaches such as Farmer Research Networks (FRN) and Farmer Field Schools (FFS) to enhance farmers' understanding and application of agricultural practices. FRNs, as proposed by Nelson et al. (2019), provide a platform for involving farmers in the research process, facilitating better information uptake. By collaborating and sharing experiences within these networks, farmers gain access to valuable knowledge, fostering a community-driven approach to learning and problem-solving in agriculture. Similarly, FFS, as suggested by Khatam et al. (2010), offers numerous benefits, including enhancing farmers' self-confidence, knowledge, and abilities through experiential learning. These schools also encourage using eco-friendly alternatives and can contribute to reducing pesticide usage while safeguarding the environment.

Integrated Pest Management (IPM) practitioners emphasize facts and the outcomes of farmer decisions (Meir et al., 2000). Williamson et al. (2003) stress the importance of regular field observations for informed decision-making in pest management. Effective extension programs and increased social engagement are critical in improving farmers' understanding of pesticide use and its implications for

health and the environment. This requires a systematic and coordinated approach involving closer cooperation between ecological and social scientists, as highlighted by Nagenthirarajah and Thiruchelvam (2008). Authorities are pivotal in improving the system and enhancing farmers' understanding of pest control. Strategies should encompass various knowledge sources, including pest management training, awareness campaigns, direct interaction with farmers, focus group discussions addressing pest management challenges, and frequent field visits by agricultural officials, researchers, and extension workers. Peer groups often serve as a significant source of pest management knowledge for farmers. Increasing connectedness within these groups and consulting experienced opinion leaders knowledgeable about eco-friendly pest management practices can significantly benefit farmers. Regular farmer meetings should be organized to facilitate group discussions, with the responsibility for meeting charges assigned to leaders of farming communities. Before seeking pest control advice, farmers should ensure that friends or family members have a comprehensive understanding of the field situation. Those with limited social ties should seek guidance from the media, researchers, and experts while engaging in discussions with peers to acquire diverse perspectives and additional information. It is crucial to explore alternatives to chemical pesticides due to their adverse effects on ecosystems and the natural enemies of pests. Farmers should avoid seeking advice solely from pesticide sellers, as their interests are often aligned with marketing pesticide products. In conclusion, addressing the knowledge gap in pest management among farmers necessitates implementing multifaceted strategies that involve farmer-centric approaches, collaborative research networks, experiential learning through field schools, and concerted efforts from authorities, researchers, and extension workers. Encouraging social engagement, promoting alternative pest management practices, and fostering a deeper understanding of the implications of pesticide use are essential for sustainable agricultural practices and improved pest control outcomes (Fig. 3.30).

Fig. 3.30 Recommended solutions for the improvement of farmer knowledge of rice pest management in North Kerala.



.**Farmer's participation gap in pest management training and solutions**

Understanding farmer engagement in training programs, especially pest management, is fundamental for sustainable agricultural development (Gboku and Lekoko, 2007). Various factors, such as institutional, socio-economic, and cultural barriers, significantly impact the participation of rice farmers in training initiatives. This study explores the underlying causes of these barriers and emphasizes the need to address them for effective farmer engagement and successful program implementation. In North Kerala, farmer involvement in pest control training programs is hindered by multiple challenges. These obstacles include factors such as lack of relevance to farmers' needs, unawareness, inadequate facilitator coordination, travel constraints, and trainers' insufficient field experience.

Additionally, socio-cultural factors like low expectations, limited awareness, personal commitments, and financial constraints further impede farmers' participation in these programs. Oakley (1991) categorizes participation barriers into structural, institutional, socio-economic, and cultural factors. These barriers manifest

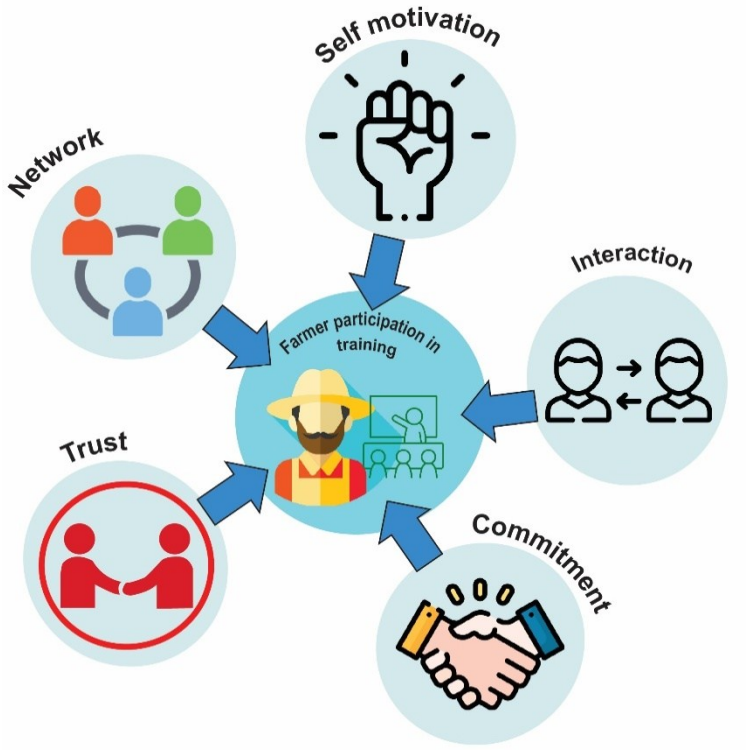
in various ways, affecting farmers' willingness and ability to engage in training initiatives. Lack of relevance, inadequate planning, poor management, and uninspired facilitators are institutional barriers that hamper farmer participation. Planning processes often fail to incorporate local insights, leading to programs not resonating with the farmers' needs and priorities. Effective coordination and planning are critical in engaging farmers, as Fasokun et al. (2005) highlighted. When organizations fail to plan adequately or involve local communities in program design, farmer participation dwindles. Institutional elements like inflexible provisions, inadequate duration, and poor adaptation to local requirements act as barriers that discourage farmer engagement.

Moreover, ineffective facilitators and insufficient training materials contribute to farmers' disinterest in training programs. Nafukho et al. (2005) emphasize the significance of accessible program materials and training center locations in fostering learner engagement. Institutions need competent and experienced facilitators with strong coordination skills to effectively engage farmers in these programs. Economic and social factors significantly influence farmer engagement, creating variations in attitudes, motivations, and situational barriers. Addressing these variations is crucial in designing programs that resonate with the target audience. Understanding socio-cultural, economic, and religious differences is essential to ensuring program designs that align with the diverse needs and perspectives of the farmers.

Additionally, it is pivotal to enhance the capabilities of facilitators through pre-service and in-field training to equip them with foundational education and facilitation techniques. Telayneh (2010) emphasizes the participatory extension strategy, advocating for the active participation of all stakeholders, especially farmers, throughout the process-from issue identification to evaluation. To enhance farmer engagement, addressing situational and attitudinal constraints is imperative. Improving awareness and networks among farmers will increase their commitment to training programs. Authorities must understand the obstacles faced by farmers and work collaboratively to build trust and foster commitment through meaningful

engagement. Prioritizing the resolution of institutional and socio-cultural barriers before program implementation is essential. By addressing low expectations, limited awareness, and other socio-economic challenges, agricultural extension programs can enhance their effectiveness and increase farmer participation in training initiatives. In conclusion, overcoming barriers to farmer engagement in training programs, especially pest management, requires a comprehensive approach. Effective coordination, community involvement in program design, competent facilitators, consideration of socio-cultural factors, and addressing institutional deficiencies are vital for successful and impactful farmer engagement in agricultural training initiatives (Fig. 3.31).

Fig. 3.31 Recommended solutions for the improvement of farmer participation of rice pest management training programs in North Kerala.



Gaps and solutions for traditional pest management knowledge adoption

The comparative study conducted between traditional and modern rice farmers in North Kerala provides valuable insights into the contrasting pest control methods and perceptions of rice cultivation. The survey outcomes reflect the

perspectives, practices, and challenges faced by both traditional and modern farmers in managing pests in their rice fields. Traditional farmers, constituting a significant portion of the surveyed population, expressed a prevailing belief in the higher pest resistance of traditional rice varieties compared to high-yield variants. Despite this perception, over half of them attributed poor grain yields to traditional cultivars. However, nearly half of these farmers acknowledged the availability of traditional rice types that exhibited excellent yields, indicating a nuanced understanding among traditional farmers regarding the performance of different varieties. The survey results revealed that certain traditional rice varieties, such as Gandhakasala, Chomala, and Jeerakasala, were cultivated by a majority of traditional rice farmers, particularly for their aromatic properties. However, a small percentage of farmers noted high pest incidence in aromatic rice varieties, suggesting that while these varieties possess desirable traits, they might be susceptible to pests. A notable observation from the survey was the prevalent utilization of mechanical and cultural pest control methods by traditional farmers. A significant portion did not employ specific pest management practices, relying on the inherent pest resistance of traditional cultivars.

Additionally, a substantial percentage of traditional farmers resorted to plant extracts for pest control purposes. Contrasting this, modern rice farmers were found to rely significantly on chemical pesticides as their primary pest management method. This highlights a substantial shift in pest control practices, with modern farmers using synthetic bio-pesticides and chemicals while employing mechanical and cultural control methods less frequently. An intriguing finding was the lack of validation reported by extension workers and experts regarding pest-tolerant and pest-susceptible traditional rice varieties. This gap in validation raises concerns about the scientific verification of these beliefs and practices among traditional farmers. Moreover, modern farmers demonstrated a substantial lack of awareness or utilization of traditional pest management practices. Despite acknowledging the high yields of modern varieties, a vast majority also recognized the high susceptibility of these high-yield variants to pests.

Most traditional farming approaches aim to mitigate crop pests rather than eradicate them, aligning with sustainable agricultural practices. However, there are challenges and gaps in understanding and validating traditional practices (Litsinger et al., 2009). Watson and Mahrita (1985) highlight the site-specific nature of indigenous crop protection methods, emphasizing the need for comprehensive scientific studies to validate the efficacy of pest-resistant traditional rice varieties. These gaps in scientific validation hint at the potential loss of invaluable traditional knowledge if it is not adequately documented and preserved. Social barriers between researchers and farmers complicate effective communication and knowledge transfer. Farmers, with their profound expertise and knowledge drawn from tradition and experience, often face resource constraints that limit their ability to innovate. This underscores the importance of collaborative efforts between researchers and farmers to bridge the farmer-scientist gap and incorporate farmers' knowledge into research and development initiatives. The adoption of modern agricultural practices, particularly by modern rice farmers relying heavily on chemical pesticides and synthetic bio-pesticides, starkly contrasts with the extensive use of traditional methods by their traditional counterparts. The potential disappearance of these traditional practices amid agricultural modernization underscores the urgent need to study, document, and preserve these methods before they vanish. In conclusion, traditional agricultural practices, deeply rooted in centuries of experience, offer a wealth of knowledge and sustainable pest and disease management methods. Collaborative efforts, recognizing farmers as experts, validating traditional practices, and documenting this invaluable knowledge are essential to preserving these time-tested methods and integrating them into modern agricultural frameworks.

Gaps in extension services and the recommended solution

The study aimed to enhance smallholder farmers' ability to tackle insect pest infestations by identifying the knowledge gaps and capacity-building needs of agricultural extension agents. Findings revealed that while extension agents were familiar with various crop-damaging pests, absolute confidence in identifying

specific rice pests was lacking. Recognizing distinctions between similar damages caused by rice pests posed a challenge.

In contrast, experts in rice pest management exhibited comprehensive recognition of agricultural damages caused by rice insect pests. While extension workers acknowledged birds, dragonflies, and spiders as natural predators of rice pests, awareness of the ladybird beetle's potential as a natural enemy was limited. Although most were aware of ants, parasitoids, and pathogens as natural enemies, identifying parasitoids such as *Trichogramma* and understanding their diverse classifications remained a gap.

Additionally, some extension staff lacked awareness regarding pathogens as rice pests' natural enemies. Extension workers universally advocated against inaction towards pests and suggested mechanical and cultural pest control methods as alternatives to chemical pesticides. However, conflicting advice was also given, recommending chemical pesticides foe pest control. Despite highlighting mechanical and cultural techniques as pesticide alternatives, the knowledge gap widened when comparing their awareness to that of professionals who identified a broader range of alternatives like biological, botanical, and nano pesticides. External impediments significantly hampered extension agents' ability to conduct efficient extension services, extending beyond capacity development and training alone. Barriers such as funding limitations, high farmer-to-officer ratios, transportation issues, farmer resistance, inadequate extension materials, and overwhelming office workloads hindered effective extension services. This scenario restricted extension workers from advising vulnerable populations, hindering efficient rice pest control. Consistent with prior studies, insufficient transportation, and materials inhibited extension agents from promoting modern agricultural methods (e.g., Belay and Abebaw, 2004; Baah et al., 2009).

The increased workload in regions susceptible to pest outbreaks posed challenges to skill development for effective extension delivery. Similarly, the ratios between extension workers and farmers impacted the frequency of farmer visits, hindering the dissemination of essential pest management methods. Improving

extension services necessitates enhancing extension agents' capabilities in identifying pests and their natural enemies, effective communication with farmers, innovative pest control strategies, and technical skill development.

Fig. 3.32 Recommended solutions for the effective extension services in rice pest management of North Kerala.



Capacity-building should encompass program planning, project evaluation, and the use of Information and Communications Technology (ICT) for pest infestation guidance. Additionally, farmer education and encouragement regarding innovative pest management technologies are crucial. Recommendations include regular capacity-building workshops on pest control, ICT utilization seminars, and thorough audio-visual communication training for extension professionals (e.g.,

Antwi-Agyei and Stringer, 2021). Addressing funding shortage, transportation, materials, and workload and conducting more field studies on rice pest control are essential for effective extension services benefiting smallholder farmers.

In conclusion, the study underscores the critical role of agricultural extension agents in facilitating effective pest management among smallholder farmers. Extension agents can better assist farmers in combating insect pest infestations by addressing knowledge gaps and overcoming barriers through targeted capacity-building initiatives, improved resources, and innovative communication strategies (Fig. 3.32). Ultimately, this will enhance agricultural productivity and sustainability, benefiting smallholder farmers and agricultural systems

Gaps in Government policy adoption

This study assesses the knowledge of farmers, agricultural authorities, and experts regarding government policies associated with pest management. The comprehensive evaluation of government policies concerning pest control and their influence on agricultural practices in North Kerala has unveiled critical gaps and implications that demand immediate attention. The stark reality of the study reveals an alarming scenario: the overwhelming use of chemical pesticides (77.9%) among farmers, combined with a meagre proportion (12.9%) seeking professional guidance, highlights a concerning reliance on pesticide suppliers for information and a lack of adherence to safety measures during application. The evident exploitation of policy gaps by pesticide companies, advocating high pesticide dosages without adequate farmer guidance, raises substantial concerns about environmental sustainability and public health. Farmers' limited understanding of key government policies, as observed through interviews regarding the Insecticide Rule (1971), Insecticide Act (1968), and Pesticide Management Bill (PMB) 2020, emphasizes a dire need for widespread education and awareness dissemination among farmers and extension workers. The disparities in understanding, observed among extension agents and specialists and the knowledge gap among farmers underscore a critical need for effective communication channels and training programs. Bridging the gap between policy enablers, agricultural experts, and farmers is imperative to counter the undue

influence exerted by chemical pesticide companies and to promote sustainable agricultural practices. Kumar and Reddy's (2021) analysis of PMB 2020 reveals both its strengths and significant shortcomings. While acknowledging its provisions for regulating the sector, monitoring pesticide toxicity, and compensating victims, the bill fails to address crucial challenges in efficient pesticide management. The enabling of unapproved pesticide uses despite authorized guidelines and the lack of clarity regarding pesticide usage permissions pose significant threats to human health and the environment. Recommendations highlighted the urgency of revising the PMB 2020, emphasizing the incorporation of crucial safety measures, such as personal protective equipment (PPE) regulations, and aligning authorized pesticide use with established recommendations. The study underscores the necessity of post-registration risk mitigation, user protection, community welfare, and environmental preservation as essential aspects to fortify within the bill to safeguard public health and the environment. Moving forward, this study strongly advocates for extensive awareness campaigns, training programs, and effective communication strategies to empower farmers with comprehensive knowledge of government policies and their implications. Bridging the communication gap between stakeholders, including government bodies, agricultural experts, extension agents, and farmers, is critical to reducing the undue influence of chemical pesticide firms and fostering sustainable agricultural practices. In conclusion, immediate revisions and comprehensive reforms within PMB 2020 are imperative to fortify pesticide regulations in India. Simultaneously, concerted efforts to educate, empower, and establish effective communication channels among stakeholders are crucial for transitioning towards sustainable agricultural practices that prioritize environmental preservation and public health.

CONCLUSIONS

CONCLUSIONS

The first part of this study provides significant insights into the species composition of rice insect pests and parasitoids, host-parasitoid associations, and anti-parasitoid defense strategies exhibited by rice insect pests in North Kerala's rice agro-ecosystems. The findings contribute to understanding the ecological interactions between insect pests and their parasitoids, which is crucial for developing sustainable pest management strategies.

1. **Species Composition of Rice Insect Pests**
    - Lepidoptera was the most species-rich and abundant order (n=20) across all agro-ecological zones, followed by Hemiptera (n=9), Orthoptera (n=4), and Coleoptera (n=2).
    - Pest abundance was higher during the wet season compared to the dry season.
    - Erebidae was the most species-rich family (n=5), while Hesperiidae dominated in numbers across both seasons.
    - Four Hesperiid species—*Ampittia dioscorides*, *Pelopidas agna*, *P. mathias*, and *Parnara* sp.—were common in rice fields.
    - Lepidopteran pests, such as *Cnaphalocrocis medinalis* and *Parapoynx stagnalis*, were more prevalent during the wet season.
2. **Parasitoid Composition and Seasonal Distribution**
    - Braconidae was the most abundant parasitoid family, comprising 35.18% in the dry season and 29.67% in the wet season, with microgastrine wasps (*Apanteles* sp.) being dominant.
    - Ichneumonidae was the second most abundant family, with *Casinaria ajanta* being particularly dominant in the foothill region.
    - Chalcididae showed substantial presence in the high hill region during the wet season, likely due to favourable climatic conditions.
    - Scelionidae was widely distributed across agro-ecological zones, particularly in midland laterite regions, with *Telenomus remus* being the dominant egg parasitoid.
3. **Host-Parasitoid Associations**
    - ***Egg Parasitoids:*** *Telenomus remus* emerged as a key egg parasitoid, effectively parasitizing eggs of six Lepidopteran pests:
        - *Mythimna separata*
        - *Spodoptera mauritia*
        - *Scirpophaga incertulas*
        - *Scirpophaga innotata*
        - *Psalis pennatula*
        - *Pelopidas agna* and *Pelopidas mathias*

- ***Larval Parasitoids:***
  - Koinobiont endoparasitism was the most frequent form, observed in Braconidae (n=8), Ichneumonidae (n=9), and Tachinidae (n=3).
  - Idiobiont ectoparasitism was more common in Eulophidae (n=5) and Bethylidae (n=3), with *Euplectrus* sp. preferring tubercle-covered or hairy caterpillars and *Sympiesis* targeting semi-exposed shelter-building caterpillars.
- ***Pupal Parasitoids:***
  - Ichneumonidae was the primary parasitoid family attacking pupae of rice insect pests, followed by Tachinidae.
  - Higher parasitization rates of *Pelopidas agna* pupae by Ichneumonidae were observed, correlating with its high abundance.
- ***Hyperparasitism and Parasitoid Overlap*:**
  - Braconidae and Ichneumonidae were highly susceptible to hyperparasitoids, with *Casinaria ajanta* (Ichneumonidae) and *Apanteles* sp. 2 (Braconidae) being especially vulnerable.
  - Higher overlap was observed among parasitoids targeting pests within the same genera, as seen in *Scirpophaga incertulas* and *S. innotata* sharing common egg parasitoids due to genus similarity.
  - *Pelopidas agna* shared several parasitoids with other pests during its larval and pupal stages.

4. Anti-Parasitoid Defense Strategies in Lepidopteran Pests

- ***Egg defense mechanisms influenced parasitism rates:***
  - A positive correlation was observed between clutch size and egg parasitism, with larger clutches experiencing higher parasitism rates.
  - A negative correlation between naked eggs and parasitism suggests that uncovered eggs were less prone to parasitoids.
  - Protective egg masses, despite offering some defense, were associated with increased parasitism.
- ***Larval defenses played a role in parasitism susceptibility:***
  - The effectiveness of larval hairs in deterring parasitoids remains unclear, but larval hair length and exposure had a more significant impact on parasitism than larval skin color.
  - Larvae with partial shelter had higher parasitism, while those in fully protective cases were largely unaffected, showing that full concealment helps avoid parasitoids.

Understanding the interactions between rice pests and their parasitoids provides crucial information for ecofriendly pest management strategies. The findings highlight the importance of conserving natural parasitoids and developing habitat management approaches to enhance biological control.

Second part of the study provides key insights into the community structure and spatio-temporal variation and the factors affecting the abundance of rice insect pests and their parasitoids across different agro-ecological zones in North Kerala. The major findings are:

1. **Pest and Parasitoid Community Structure**

- The foothill region had the highest insect pest abundance, comprising 32 species and 11,470 individuals.
- Parasitoid richness was highest in the foothill region, while parasitoid abundance peaked in the high hill area.
- The wet season showed the highest interaction among pests, primary parasitoids, and hyperparasitoids, fostering their persistence.
- The foothill region, acting as an ecotone, exhibited the most intense tri-trophic interactions, with 40 species of specialist parasitoids.
- Key parasitoids with highest interaction with rice insect pests included *Argyrophylax nigrotibialis* (Tachinidae) and *Charops bicolor* (Campopleginae), varying across seasons and zones.

2. **Pest Diversity with Crop Growth Stages**

- Pest diversity was higher during the booting stage than in the ripening of the paddy.

3. **Influence of Farming Practices and Environment**

- Pesticide untreated (PUT) rice fields had higher pest and parasitoid diversity than Pesticide treated (PT) fields across all zones and seasons except for the foothill wet season.
- There is a significant difference in parasitoid diversity between PT and PUT fields in high hill and midland laterite zones.
- However, no significant difference in parasitoid diversity between PT and PUT fields in the foothill region, possibly due to lower pesticide use and diverse landscape features.
- Lower pesticide uses in foothill areas (1.55±0.42 ml/liter of water) compared to other two zones might contribute to higher parasitoid survival.

4. **Environmental and Climatic Factors**

- ***Climatic factors influencing pests in the dry season (foothills)****:*
    - Mean temperature, maximum temperature, diurnal temperature, relative humidity, and heat index.
- ***Climatic factors influencing pests in the wet season (foothills)****:*
    - Relative humidity and altitude.
- ***Minimal climatic influence****:*
    - Heat index and precipitation had negligible effects on pest abundance in high hills and midlands during wet seasons.
    - Altitude had minimal impact on parasitoid abundance in all zones and seasons.
    - Diurnal temperature did not affect parasitoid abundance in midland wet and high hill dry seasons.
- ***Significant climatic factors influencing parasitoids****:*
    - Maximum and mean temperatures, heat index, precipitation, and relative humidity.

5. **Regression Model Insights**

- ***Key determinants of pest populations (dry and wet seasons):***
    - Plant distance, pesticide application frequency, parasitoids, and water depth.
- ***Key factors influencing parasitoid populations****:*
    - Water depth, pesticide application frequency, plant spacing, bund weed coverage, home gardens, and pest abundance.
- ***Negative correlation between pest populations and emergent aquatic vegetation***, suggesting that such vegetation may provide refuge for natural predators.
- ***Surrounding vegetation types (agroforestry, crop/grass, and sparse vegetation) influence rice production***, potentially competing with rice crops.

6. **Potential Pest Distribution**

- ***Temperature seasonality and fluctuations were major drivers*** *of pest distribution.*
- ***Different pests showed varying sensitivities to environmental factors:***
    - *Ampittia dioscorides*: Influenced by temperature annual range and temperature seasonality.
    - *Parnara bada*: Influenced by Isothermality and precipitation.

This study underscores the complex interplay between ecological zones, seasonal changes, farming practices, and climate in shaping rice pest and parasitoid populations. These findings contribute to sustainable pest management strategies by integrating ecological knowledge with farming practices.

Furthermore, the third part illuminates the rich tapestry of traditional pest management practices employed by small-scale farmers in North Kerala. Deeply rooted in cultural, mechanical, and religious traditions, these practices showcase remarkable ingenuity in combating agricultural pests. By integrating traditional wisdom with modern scientific assessments, farmers hold the key to developing sustainable and effective pest management strategies that ensure the resilience of agricultural ecosystems for generations to come.
The conclusions from the study reveal the major factors influencing rice pest management in North Kerala, encompassing socio-economic, cultural, and ecological dimensions. Here is a summary of the key findings and recommendations from each section:

Traditional Rice Pest Management

The traditional pest management practices in North Kerala, deeply rooted in cultural, mechanical, and religious traditions, provide invaluable insight into sustainable agricultural practices. These practices showcase the remarkable ingenuity of small-scale farmers in combating agricultural pests with minimal reliance on chemical inputs. The integration of these practices with modern scientific assessments can provide farmers with sustainable pest management strategies for resilient agricultural ecosystems.

Key Findings:

1. ***Manual and Physical Control Methods***

- Handpicking, sweeping, and the use of muram or nets are commonly employed for controlling visible insect pests.
- Farmers use innovative physical methods such as swaying plant branches to injure concealed defoliators and applying lemongrass oil to deter caterpillars.
- Unconventional methods like using dried sardine fish and *Cycas circinalis* flowers are employed to repel Gundhi bugs.

2. ***Cultural Practices and Rituals***

- Tribal farmers incorporate cultural rituals like chanting Mantras and placing Vavu and Vaikattu posts to reduce pest infestations, reflecting their deep-rooted cultural beliefs.
- Flooding fields is used to wash away pests such as armyworms, while drainage is employed to manage infestations of brown planthoppers and rice case worms.
- Practices like roughing (uprooting injured plants) and cutting dead hearts are used to reduce stemborers, though these methods may not fully eradicate larvae.

3. ***Innovative Approaches***

- Light traps are effectively used to attract nocturnal pests, and manage them.
- Bund shaving is utilized to drown eggs and pupae of pests that use weeds and bund plants as alternate host plants.
- Traditional methods of rodent control include the use of owl perches and bund shaving.

4. ***Mitigating Human-Wildlife Conflicts***

- Farmers face significant challenges from wildlife such as deer, elephants, monkeys, and wild boars. To mitigate these conflicts, they use a combination of electric and timber fences, scare tactics (e.g., firecrackers), and physical barriers.

5. ***Plant and Animal-Based Remedies***

- A variety of plant-based products such as neem oil emulsion, neem seed extract, and tobacco emulsion are utilized alongside animal-based products like diluted buttermilk, fish amino acids, panchagavya, and jeevamrutham to strengthen rice plants' natural defenses against pests.
- Seed treatment with cow dung slurry water and post-harvest pest prevention methods, such as using neem leaves and *Glycosmis pentaphylla* Retz extracts, are important practices rooted in cultural traditions.

6. ***Rice Varieties and Pest Resistance***

- Traditional rice varieties, such as Kanakam, Kunjuthi, Kunkumsali, and others, show varying levels of resistance to pests.

- Jeerakasala had the lowest pest resistance, followed by Valichoori, Mundon, and Gandhakasala.
- The study highlighted the susceptibility of traditional varieties like Jeerakasala, Gandhakasala, and Chomala to yellow stem borer (YSB) infestation, particularly in the context of high-yield rice varieties.

7. ***Influence of Rice Plant Morphology on Pest Infestation***

- The Pearson correlation matrix revealed significant relationships between YSB infestation and plant morphological traits such as culm length, culm width, leaf width, panicle length, and tiller number.
- Taller rice varieties attracted higher oviposition rates by YSB, leading to an increase in egg mass accumulation.
- Gandhakasala rice variety showed a significant increase in YSB infestation when grown alongside the high-yield variety Uma, indicating increased susceptibility when traditional and high-yield varieties are intercropped.

The third part of the study also delves into critical gaps in various pest management domains in North Kerala rice farming. It provides insightful recommendations to address these gaps. Here is a summary of the conclusions drawn from each section:

1. Lack of Understanding in Key Pest Management Areas

- **Gap**: Farmers struggle with pest identification, damage assessment, proper pesticide application rates, and understanding alternatives to chemical pesticides.
- **Recommended Solution**: Comprehensive training programs focused on pest identification, damage assessment, and the benefits of non-chemical pest management methods should be developed. Extension services should incorporate hands-on demonstrations and field-based training for practical learning.

2. ***Influence of External Factors on Pest Management Decisions***

- **Gap**: Farmers often base their pest management decisions on pest outbreaks in neighboring fields, leading to misidentification of pests and limited knowledge of pest biology and natural enemies.
- **Recommended Solution**: Strengthen local networks for sharing accurate pest management information, emphasizing the need for region-specific pest identification and management. Extension officers should actively engage with farmer groups to provide timely, tailored advice.

3. ***Limited Interaction with Agricultural Officers***

- **Gap**: Farmers are dissatisfied with the limited frequency of interactions with agricultural officers, leading to a lack of essential knowledge and guidance. Researchers' findings are often not scaled-up or sustained due to the absence of follow-up interactions.
- **Recommended Solution**: Increase the frequency of field visits by agricultural officers and researchers. Establish regular follow-up sessions to ensure research findings are effectively applied. Farmers should also be encouraged to participate in feedback loops to improve extension services.

4. ***Underutilization of Pest Control Training Programs***

- **Gap**: Low participation in pest control training programs due to factors such as irrelevance to farmers' needs, unawareness, logistical constraints, and socio-cultural barriers.
- **Recommended Solution**: Develop more relevant, farmer-centric training programs that address specific pest management issues in the region. Ensure that training sessions are convenient in terms of location and timing. Also, increase the engagement of local opinion leaders and agricultural stakeholders to drive awareness and participation.

5. ***Perceptions of Traditional Rice Varieties and Pest Resistance***

- **Gap**: Traditional farmers believe that traditional rice varieties have higher pest resistance, but many also attribute poor yields to these varieties. There is also limited validation of pest resistance for traditional varieties.
- **Recommended Solution**: Conduct research to validate and document the pest resistance of traditional rice varieties. Farmers should be provided with accurate information about the benefits and limitations of both traditional and high-yielding rice varieties.

6. ***Limited Knowledge of Natural Enemies Among Extension Workers***

- **Gap**: While extension workers acknowledge some natural predators like birds and dragonflies, they have limited knowledge of other natural enemies, particularly ladybird beetles and parasitoids.
- **Recommended Solution**: Extension workers should undergo specialized training on the identification and role of natural enemies in pest management. Collaboration with researchers and entomologists can help build a comprehensive understanding of beneficial organisms.

7. ***Conflicting Advice and Lack of Consensus Among Extension Workers***

- **Gap**: Extension workers often provide conflicting advice, with some recommending chemical pesticides while others suggest mechanical and cultural pest control methods.
- **Recommended Solution**: Establish clear, consistent pest management guidelines that emphasize integrated pest management (IPM) practices. Training sessions should focus on evidence-based, eco-friendly pest control strategies that align with sustainable agricultural practices.

8. ***Impediments to Effective Extension Services***

- **Gap**: Extension agents face significant external barriers, such as limited funding, high farmer-to-officer ratios, transportation issues, and inadequate extension materials, which hinder the delivery of effective pest management services.
- **Recommended Solution**: Strengthen the capacity of extension services by increasing funding, improving logistical support, and providing more relevant and engaging educational materials. A more structured approach to field visits and farmer engagement should be adopted to overcome these challenges.

9. ***Overreliance on Chemical Pesticides***

- **Gap**: A significant reliance on chemical pesticides (77.9%) is observed, with minimal use of professional guidance (12.9%) and inadequate adherence to safety measures during pesticide application.
- **Recommended Solution**: Develop and implement awareness campaigns on the risks of pesticide overuse and the importance of safety measures. Encourage the adoption of alternative pest control strategies, such as biological control, mechanical, and cultural methods, through practical demonstrations.

10. ***Exploitation of Policy Gaps by Pesticide Companies***

- **Gap**: Pesticide companies exploit policy gaps by recommending high pesticide dosages without providing adequate guidance to farmers. This practice aggravates environmental and public health concerns.
- **Recommended Solution**: Strengthen policy enforcement regarding pesticide use, ensuring that companies adhere to safety standards and provide proper guidance to farmers. Government agencies should improve farmers' awareness of the Insecticide Act (1968), Insecticide Rule (1971), and the

Pesticide Management Bill (PMB) 2020 through educational programs and outreach initiatives.

In conclusion, the study emphasizes the need for collaborative efforts involving farmers, researchers, extension agents, and policymakers to promote sustainable pest management practices, reduce dependency on chemical pesticides, and safeguard environmental and public health. Sustainable agricultural practices can be promoted by addressing knowledge gaps, enhancing farmer participation, preserving traditional knowledge, improving extension services, and reforming government policies, benefiting both farmers and the environment.

BIBILIOGRAPHY

Abedi, Z., Golizadeh, A., Hassanpour, M., & Soufbaf, M. (2020). Effect of pomegranate cultivars with varying levels of resistance to *Ectomyelois ceratoniae* on life history parameters of the parasitoid Venturia canescens. *BioControl*, *65*, 525–535.

Abraham. C. C., Mattew, K. P., & Das, N. M. (1973). Records of hymenopterous parasites of the rice leaf folder *Cnaphalocrocis medinalis* Guen in Kerala. *Agricultural Research Journal of Kerala*, *11*, 81.

Abrol, D. P. (Ed.). (2014). *Integrated pest management: Current concepts and ecological perspective*. San Diego, CA: Academic Press.

Adesina, A. A., Johnson, D. E., & Heinrichs, E. A. (1994). Rice pests in the Ivory Coast, West Africa: Farmers' perceptions and management strategies. *International Journal of Pest Management*, *40*(4), 293–299.

Agrawal, A. A., Ackerly, D. D., Adler, F., Arnold, A. E., Cáceres, C., Doak, D. F., Post, E., Hudson, P. J., Maron, J., Mooney, K. A., Power, M., Schemske, D., Stachowicz, J., Strauss, S., Turner, M. G., & Werner, E. (2007). Filling key gaps in population and community ecology. *Frontiers in Ecology and the Environment*, *5*(3), 145–152.

Ahmed, K. N., & Khatun, M. (1988). *Lasioderma serricorne* (F.), a possible alternate host of *Anisopteromalus calandrae* (Howard) (Hymenoptera: Pteromalidae) in Bangladesh. *Bangladesh Journal of Zoology*, *16*(2), 165–166.

Ahuja, U., Ahuja, S. C., Chaudhary, N., & Thakrar, R. (2007). Red rices–past, present and future. *Asian Agri–History*, *11*(4), 291–304.

Ahuja, U., Ahuja, S. C., Thakrar, R., & Rani, N. S. (2008). Scented rices of India. *Asian Agri–History*, *12*(4), 267–283.

Aiello., A., & Solis, M. A. (2003). Defense mechanisms in Pyralidae and Choreutidae: Fecal stalactites and escape holes, with remarks about cocoons, camouflage and aposematism. *Journal of the Lepidopterists' Society*, *57*(3), 168–175.

Akaike, H. (1973). Information theory and an extension of the maximum likelihood principle. In B. N. Petrov & F. Csaki (Eds.), *Proceedings of the 2nd International Symposium on Information Theory* (pp. 267–281). Budapest, Hungary: Akademiai Kiado.

Akbar, T. A., Hassan, Q. K., Ishaq, S., Batool, M., Butt, H. J., & Jabbar, H. (2019). Investigative spatial distribution and modelling of existing and future urban land changes and its impact on urbanization and economy. *Remote Sensing*, *11*(2), 105.

Alex, E. C., Ramesh, K. V., & Sridevi, H. (2017). Quantification and understanding the observed changes in land cover patterns in Bangalore. *International Journal of Civil Engineering and Technology*, *8*(4), 597–603.

Alfred, D. J., Ramaraju, K., Poorani, J., & Nikhil, K. (2019). Comparison of Eurytomidae and Eupelmidae (Hymenoptera: Chalcidoidea) diversity from three rice growing zones of Tamil Nadu. *Madras Agricultural Journal*, *106*(Special Issue), 242–248.

Ali, M. P., Huang, D., Nachman, G., Ahmed, N., Begum, M. A., & Rabbi, M. F. (2014). Will climate change affect outbreak patterns of planthoppers in Bangladesh? *PloS One*, *9*(3), 91678.

Ali, M. P., Kabir, M. M. M., Afrin, S., Nowrin, F., Haque, S. S., Haque, M. M., Hashem, A., Tabassum, B., Abd_Allah, E. F., & Pittendrigh, B. R. (2019). Increased temperature induces leaffolder outbreak in rice field. *Journal of Applied Entomology*, *143*(8), 867–874.

Ali, M. P., Kabir, M. M. M., Haque, S. S., Afrin, S., Ahmed, N., Pittendrigh, B., & Qin, X. (2020). Surrounding landscape influences the abundance of insect predators in rice field. *BMC Zoology*, *5*, 1–12.

Allen, W., & Jacobson, C. (2009). Learning about the social elements of adaptive management in the South Island tussock grasslands of New Zealand. In A. Allan & C. Jacobson (Eds.), *Adaptive environmental management: A practitioner's guide* (pp. 95–116). Dordrecht, Netherlands: Springer.

Allen, W., & Kilvington, M. (2005). Getting technical information into watershed decision-making. In *The farmers' decision: Balancing economically successful agriculture production and environmental quality* (pp. 45–46). Proceedings of the Soil and Water Conservation Society Annual Meeting. Iowa, USA: Soil and Water Conservation Society.

Allen, W., Bosch, O., Kilvington, M., Oliver, J., & Gilbert, M. (2001). Benefits of collaborative learning for environmental management: Applying the integrated systems for knowledge management approach to support animal pest control. *Environmental Management*, *27*, 215–223.

Allen, W., Fenemor, A., Kilvington, M., Harmsworth, G., Young, R. G., Deans, N., Horn, C., Phillips, C., Oca, O., Ataria, J., & Smith, R. (2011). Building collaboration and learning in integrated catchment management: The importance of social process and multiple engagement approaches. *New Zealand Journal of Marine and Freshwater Research*, *45*(3), 525–539.

Allen, W., Ogilvie, S., & Blackie, H. (2014). Bridging Disciplines, Knowledge Systems and Cultures in Pest Management. *Environmental Management*, *53*(2), 429–440.

Altieri, M. A. (1984). Developing pest management strategies for small farmers based on traditional knowledge. *Proceedings of the 20th Annual Meeting, October 21–26, St. Croix, US Virgin Islands*, *261555)*.

Altieri, M. A. (2004). Linking ecologists and traditional farmers in the search for sustainable agriculture. *Frontiers in Ecology and the Environment, 2*(1), 35–42.

Altieri, M. A., Francis, C. A., Schoonhoven, A., & Doll, J. D. (1978). A review of insect prevalence in maize (*Zea mays* L.) and bean (*Phaseolus vulgaris* L.) polycultural systems. *Field Crops Research*, *1*, 33–49.

Altieri, M. A., Todd, J. W., Hauser, E. W., Patterson, M., Buckman, G. A., & Walker, R. H. (1981). Some effects of weed management and row spacing on insect abundance in soybean fields. *Protection Ecology*, 3, 339–343.

Ambikadevi, D. (1998). Natural enemies of rice pests in Kuttanad, Kerala. *Insect Environment*, *4*(3), 81–82.

Ambikadevi, D., Bhasker, H. H., & Thomas, G. (1998). White backed plant hopper, *Sogatella furcifera* (Horvath) (Homoptera: Delphacidae): A major pest of rice in Kuttanad, Kerala. *Insect Environment*, *4*(2), 36.

Andow, D. (1983). The extent of monoculture and its effects on insect pest populations with particular reference to wheat and cotton. *Agriculture, Ecosystems & Environment*, *9*(1), 25–35.

Antwi-Agyei, P., & Stringer, L. C. (2021). Improving the effectiveness of agricultural extension services in supporting farmers to adapt to climate change: Insights from northeastern Ghana. *Climate Risk Management*, *32*, 100304.

Anu, A., Sabu, T. K., & PJ, V. (2009). Seasonality of litter insects and relationship with rainfall in a wet evergreen forest in south Western Ghats. *Journal of Insect Science*, *9*(1), 46.

Apgar, J. M., Argumedo, A., & Allen, W. (2009). Building transdisciplinarity for managing complexity: Lessons from indigenous practice. *International Journal of Interdisciplinary Social Sciences*, *4*(5), 255–270.

Appeaning-Addo, K. (2010). Urban and peri-urban agriculture in developing countries studied using remote sensing and in situ methods. *Remote Sensing*, *2*(2), 497–513.

Aranda, R., Peil, A., Rebello, N., Bordin, R. O., Souza, T. M. M. R., & Oliveira, V. T. N. (2021). Abundance and seasonality of insects in urban fragments of the Brazilian Cerrado. *EntomoBrasilis*, *14*, 933–933.

Arora, R., & Dhawan, A. (2013). Climate change and insect pest management. In *Integrated pest management* (pp. 44–60). Scientific Publisher.

Arora, S., Sehgal, M., Srivastava, D. S., Arora, S., & Sarkar, S. K. (2019). Rice pest management with reduced risk pesticides in India. *Environmental Monitoring and Assessment*, *191*(3), 241.

Arumugasamy, S., Jayashankar, N., Subramanian, K., Sridhar, S., & Vijayalakshmi, K. (2001). *Indigenous rice varieties*. Chennai, Tamil Nadu, India: Centre for Indian Knowledge Systems (CIKS).

Ashokkumar, K., Govindaraj, M., Vellaikumar, S., Shobhana, V. G., Karthikeyan, A., Akilan, M., & Sathishkumar, J. (2020). Comparative profiling of volatile compounds in popular south Indian traditional and modern rice varieties by gas chromatography–mass spectrometry analysis. *Frontiers in Nutrition, 7*, 599119.

Ashraf, A. M., & Lokanadan, S. (2017). A review of rice landraces in India and its inherent medicinal values–the nutritive food values for future. *International Journal of Current Microbiology and Applied Sciences*, *6*(12), 348–35.

Askew, R. R., & Shaw, M. R. (1986). Parasitoid communities: Their size, structure and development. In J. Waage & D. Greathead (Eds.), *Insect parasitoids* (pp. 225–264). Academic Press.

Ataev, Z. (2017). Foothill landscapes as the spatial-temporal ecotones (on the example of the North-Eastern Caucasus). In *Landscape Dimensions of Sustainable Development: Science – Planning – Governance* (pp. 31–32). Georgia.

Aubert, J. F. (1969). Ichneumonides non pétiolées inédites et révision partielle des genres Phytodietus Grav. et Netelia Gray. *Bulletin de la Société Entomologique de Mulhouse, 1968*, 93–103.

Baah, F., Anchirinah, V., & Badu–Yeboah, A. (2009). Perceptions of extension agents on information exchange with cocoa farmers in the Eastern region of Ghana. *Scientific Research and Essay*, *4*(7), 694–699.

Baer, C. S., & Marquis, R. J. (2020). Between predators and parasitoids: Complex interactions among shelter traits, predation and parasitism in a shelter- building caterpillar community. *Functional Ecology*, *34*(10), 2186–2198.

Bagheri, F., Goldansaz, S. H., & Soufbaf, S. M. (2020). Comparison between biological and two-sex life table parameters of two populations of parasitoid wasp *Venturia canescens* (Hym.: Ichneumonidae) of orchard and stored products under laboratory conditions. *Iranian Journal of Plant Protection Science*, *51*(1), 1–12.

Bakar, M. A., & Khan, M. M. H. (2016). Diversity of insect pests and natural enemies as influenced by growth stages and pest management practices in rice. *Bangladesh Journal of Agricultural Research*, *41*(3), 461–470.

Balasubramanian, A. (2017). *Kerala—At a glance*.

Balasubramanian, A. V., Vijaylakshmi, K., Sridhar, S., & Arumugasamy, S. (2002). Modern dilemmas and traditional insights. In B. Haverkort, K. Hooft, & W. Hiemstra (Eds.), *Ancient roots, new shoots–endogenous development in practice* (pp. 74–88). Leusden: Compas.

Balasubramanian, G., Sundarababu P. C., Venkatesan, S., & Gopalan, M. (1994). Evaluation of *Trichogramma japonicum* Ashmead against stem borer and *Trichogramma chilonis* against leaf folders in rice. *Pest Management and Economic Zoology, 2*(2), 97–100.

Bale, J. S., Masters, G. J., Hodkinson, I. D., Awmack, C., Bezemer, T. M., Brown, V. K., Butterfield, J., Buse, A., Coulson, J. C., Farrar, J., Good, J. E. G., Harrington, R., Hartley, S., Jones, T. H., Lindroth, R. L., Press, M. C., Symrnioudis, I., Watt, A. D., & Whittaker, J. B. (2002). Herbivory in global climate change research: Direct effects of rising temperature on insect herbivores. *Global Change Biology*, *8*(1), 1–16.

Balkrishna, A., Pandey, J. K., Tripathi, P. K., Joshi, R., & Arya, V. (2021). Chemical fertilizers and pesticides in Indian Agriculture: Effect on human health and environment. *Biological Forum – An International Journal*, *13*, 407–422.

Balvanera, P., Pfisterer, A. B., Buchmann, N., He, J. S., Nakashizuka, T., Raffaelli, D., & Schmid, B. (2006). Quantifying the evidence for biodiversity effects on ecosystem functioning and services. *Ecology Letters*, *9*(10), 1146–1156.

Bambaradeniya, C. N. B., & Amerasinghe, F. P. (2003). *Biodiversity associated with the rice field agroecosystem in Asian countries: A brief review* (Working Paper No. 63). Colombo, Sri Lanka: International Water Management Institute.

Bambaradeniya, C. N. B., & Edirisinghe, J. P. (2008). Composition, structure and dynamics of arthropod communities in agroecosystems. *Ceylon Journal of Science (Biological Sciences), 37*(1), 23–48.

Bambaradeniya, C. N. B., Edirisinghe, J. P., Silva, D. N., Gunatilleke, C. V. S., Ranawana, K. B., & Wijekoon, S. (2004). Biodiversity associated with an irrigated rice agro-ecosystem in Sri Lanka. *Biodiversity and Conservation*, *13*(9), 1715–1753.

Bandong, J. P., Canapi, B. L., Dela Cruz, C. G., & Litsinger, J. A. (2002). Insecticide decision protocols: A case study of untrained Filipino rice farmers. *Crop Protection*, *21*(9), 803–816.

Barbosa, P., & Benrey, B. (1998). The influence of plants on insect parasitoids: Implications for conservation biological control. In P. Barbosa (Ed.), *Conservation biological control* (pp. 55–82). San Diego, CA: Academic Press.

Barrion, A. T., & Litsinger, J. A. (1987). Meadow grasshopper *Conocephalus longipennis* damage to rice spikelets. *International Rice Research Newsletter*, *12*(1), 18.

Barrion, A. T., & Litsinger, J. A. (1994). Taxonomy of rice insect pests and their arthropod parasites and predators. In E. A. Heinrichs (Ed.), *Biology and Management of Rice Insects* (pp. 13–362). India and IRRI: Wiley Eastern Ltd.

Barrion, A. T., Pantua, P. C., & Litsinger, J. A. (1981). *Gryon nixoni* Masner (Hymenopera: Scelionidae): a new egg parasite of *Leptocorisa oratorius* in the Philippines. *Quarterly Newsletter, FAO PL. Prot. Committee for the South East Asia and the Pacific Region, 24*(3), 12.

Battisti, D. S., & Naylor, R. L. (2009). Historical warnings of future food insecurity with unprecedented seasonal heat. *Science*, *323*(5911), 240–244.

Bažok, R. (2022). Integrated pest management of field crops. *Agriculture*, *12*(3), 425.

Beard, R. L. (1963). Insect toxins and venoms. *Annual Review of Entomology*, *8*(1), 1–18.

Beena, R. (2013). Research paradigm and inference of studies on high temperature stress in rice (*Oryza sativa* L. In A. Hemantaranjan (Ed.), *Advances in plant physiology, an international treatise series* (Vol. 14, pp. 497–511). Scientifc Publishers.

Beevi, S. P., Lyla, K. R., & Narendran, T. C. (2000). Hymenopteran diversity in single-and double-cropped rice ecosystems in Kerala, India. *International Rice Research Notes*, *25*(1), 20–21.

Belay, K., & Abebaw, D. (2004). Challenges facing agricultural extension agents: A Case Study from South-western Ethiopia. *African Development Review*, *16*(1), 139–168.

Bellon, M. (1995). Farmers' knowledge and sustainable agroecosystem management: An operational definition and an example from Chiapas, Mexico. *Human Organization*, *54*(3), 263–272.

Bellows, T.S., & Fisher, T.W. (1999). *Handbook of Biological Control: Principles and Applications of Biological Control*. San Diego, CA: Academic Press.

Bentley, J. W. (1989). What farmers don't know can't help them: The strengths and weaknesses of indigenous technical knowledge in Honduras. *Agriculture and Human Values*, *6*, 25–31.

Bentley, J. W. (1992). The epistemology of plant protection: Honduran campesinos' knowledge of pests and natural enemies. In R. W. Gibson & A. Sweetmore (Eds.), *Proceeding Seminar on Crop Protection Resource–Poor Farmers* (pp. 107–118). Chatham, Kent: National Research Institute.

Bentley, J. W. (1992a). Alternatives to pesticides in Central America: Applied studies of local knowledge. *Culture & Agriculture*, *12*(44), 10–13.

Bentley, J. W. (1992b). The epistemology of plant protection: Honduran campesino knowledge of pests and natural enemies. In R. W. Gibson & A. Sweetmore (Eds.), *Proceedings of a Seminar on Crop Protection for Resource Poor Farmers* (pp. 107–118). Copenhagen: Technical Centre for Agricultural and Rural Cooperation/Natural Resources Institute.

Bentley, J. W. (1994). Facts, fantasies, and failures of farmer participatory research. *Agriculture and Human Values*, *11*, 140–150.

Bentley, J. W., & Andrews, K. L. (1991). Pests, peasants, and publications: Anthropological and entomological views of an integrated pest management program for small–scale Honduran farmers. *Human Organization*, *50*, 113–124.

Bentley, J., & Rodriguez, G. (2001). Honduran folk entomology. *Current Anthropology*, *42*(2), 285–300.

Bentur, J. S., & Kalode, M. B. (1985). Natural enemies of rice leaf-and plant-hoppers in Andhra Pradesh. *Entomon*, *10*(4), 271–274.

Bentur, J. S., Sain, M., & Kalode, M. B. (1982). Studies on egg and nymphal parasites of rice planthoppers, *Nilaparvata lugens* (stål) and *Sogatella furcifera* (Horvath).

Berkes, F. (2008). *Sacred ecology* (2nd ed.). Routledge.

Bernard, H., & David, N. (2001). Impediments to sustainable agriculture in China. In Promoting global innovation of agricultural science and technology and sustainable agriculture development. *International Conference on Agricultural Science and Technology, November 7–9, 2001, Beijing, China*.

Bernays, E., & Graham, M. (1988). On the evolution of host specificity in phytophagous arthropods. *Ecology*, *69*(4), 886–892.

Bertrand, C., Baudry, J., Burel, F., Beverly, J. L., Uto, K., Wilkes, J., & Bothwell, P. (2016). Seasonal variation in the effect of landscape structure on ground-dwelling arthropods and biological control potential. *Basic and Applied*, *38*(2), 289–303.

Betz, L., Kunze, I., Prajeesh, P., Suma, T. R., & Padmanabhan, M. (2014). The social–ecological web: A bridging concept for transdisciplinary research. *Current Science*, *107*(4), 572–579.

Bezemer, T. M., & Mills, N. J. (2001). Host density responses of *Mastrus ridibundus*, a parasitoid of the codling moth, *Cydia pomonella*. *Biological Control*, *22*(2), 169–175.

Bhandari, A. K., Kumar, A., & Singh, G. K. (2012). Feature extraction using Normalized Difference Vegetation Index (NDVI): A case study of Jabalpur city. *Procedia Technology*, *6*, 612–621.

Bharati, L. R., & Kushwaha, K. S. (1988). Parasitoids of leaf folder pupae from Haryana, India. *International Rice Research Newsletter, 13*(5), 31.

Bhat, F. M., & Riar, C. S. (2015). Health benefits of traditional rice varieties of temperate regions. *Medicinal and Aromatic Plants*, *4*(3), 198.

Bhattacharjee, P. P., & Ray, D. C. (2010). Pest management beliefs and practices of Manipuri rice farmers in Barak Valley, Assam. *Indian Journal of Traditional Knowledge*, *9*(4), 673–676.

Bhattacharyya, B., Basit, A., & Saikia, K. (2000). Parasitoids of rice hispa in Assam. *Insect Environment*, *5*(4), 159.

Bianchi, F. J. J. A., Booij, C. J. H., & Tscharntke, T. (2006). Sustainable pest regulation in agricultural landscapes: A review on landscape composition, biodiversity and natural pest control. *Proceedings of the Royal Society B: Biological Sciences*, *273*, 1715–1727.

Biggerstaff, B. J., & Tweedie, R. L. (1997). Incorporating variability in estimates of heterogeneity in the random effects model in meta- analysis. *Statistics in medicine*, *16*(7), 753–768.

Bindu, M. R., George, S. P., Suja, G., Vilasinim, T. N., & Ansuachamma, Y. (2014). Evaluation of different rice (*Oryza sativa* L.) varieties for upland situations of Kerala. *International Journal of Agricultural Sciences*, *10*(1), 369–371.

Bisen, D., Bisen, U., & Bisen, S. (2019). Studies on major insect pests of rice crop (*Oryza sativa*) at Balaghat district of Madhya Pradesh. *Journal of Entomology and Zoology Studies*, *7*(2), 625–629.

Bishopp, F. C. (1923). The Puss Caterpillar and the Effects of its Sting on Man. *Circular. United States Department of Agriculture*, *288*, 14.

Bito, D., Novotny, V., Burwell, C., Nakamura, A., Kitching, R., & Ødegaard, F. (2011). Predator pressure, herbivore abundance and plant damage along a subtropical altitudinal gradient. *Memoirs of the Queensland Museum*, *55*(2), 451–461.

Black, A., & Liljebald, A. (2006). *Integrating social values in vegetation models via GIS: The missing link for the Bitterroot National Forest* (Final report JFSP project no. 04–2–1–114). Missoula, MT: Aldo Leopold Wilderness Research Institute.

Blüthgen, N. (2010). Why network analysis is often disconnected from community ecology: A critique and an ecologist's guide. *Basic and Applied Ecology*, *11*(3), 185–195.

Bohrer, C. B., Junior, J. R., Fernandes, D., Sordi, R., Guimarães, J. A., Assreuy, J., & Termignoni, C. (2007). Kallikrein–kinin system activation by

Lonomia obliqua caterpillar bristles: Involvement in edema and hypotension responses to envenomation. *Toxicon*, *49*(5), 663–669.

Boinski, S., & Fowler, N. L. (1989). Seasonal patterns in a tropical lowland forest. *Biotropica*, *21*(3), 223–233.

Bommarco, R., Kleijn, D., & Potts, S. G. (2013). Ecological intensification: Harnessing ecosystem services for food security. *Trends in Ecology & Evolution*, *28*(4), 230–238.

Bonman, J. M., Khush, G. S., & Nelson, R. J. (1992). Breeding rice for resistance to pests. *Annual Review of Phytopathology*, *30*(1), 507–528.

Borah, R. K. (1994). Parasitization efficacy of *Trichogramma japonicum* on rice stem borers in Assam.*Annals of Agricultural Research*, *15*(1), 124–125.

Bouček, Z. (1988). Australasian Chalcidoidea (Hymenoptera). A Biosystematic Revision of Genera of Fourteen Families with a Reclassification of Species. Wallingford, UK: CAB International.

Bouček, Z., & Askew, R. R. (1968). Palaearctic Eulophidae sine Tetrastichinae. In V. Delucchi & G. Remaudière (Eds.), *Index of Entomophagous Insects* (pp. 53–59). François, Paris.

Bowers, M. D. (1990). Recycling plant natural products for insect defense. In D. L. Evans & J. O. Schmidt (Eds.), *Insect defenses: Adaptive mechanisms and strategies of prey and predators* (pp. 353–386). Albany, New York: State University of New York Press.

Bowers, M. D. (1993). Aposematic caterpillars: Lifestyles of the warningly colored and unpalatable. In N. Stamp & T. Casey (Eds.), *Ecological and Evolutionary Constraints on Caterpillars and the Implications for Pest Management* (pp. 331–371). New York: Chapman & Hall.

Braun-Blanquet, J. (1979). *Fitosociolog´ıa*. Madrid, Spain: Blume. p. 820.

Brewer, M. J., Noma, T., Elliott, N. C., Kravchenko, A. N., & Hild, A. L. (2008). A landscape view of cereal aphid parasitoid dynamics reveals sensitivity to farm- and region-scale vegetation structure. *European Journal of Entomology*, *105*(3), 503.

Brosius, J. P., Lovelace, G. W., & Marten, G. (1989). Ethnoecology: An approach to understanding traditional agricultural knowledge. In G. G. Marten (Ed.), *Traditional agriculture in Southeast Asia: A human ecology perspective* (pp. 187–198). Boulder and London: Westview Press.

Brown, B. J., & Marten, G. G. (1986). The ecology of traditional pest management in Southeast Asia. In G. G. Marten (Ed.), *Traditional agriculture in Southeast Asia: A human perspective* (Vol. 12, pp. 241-272). Boulder, CO: Westview.

Brunold, S. (1981). A survey of pest control practices of small rice farmers in Iloilo Province. *Philippine Bureau of Plant Industry Plant Protection News*, *10*(3), 15–17.

Bughio, A. R., Hussain, T., & Qureshi, Z. A. (1994). Host range and rate of parasitism by an egg parasite, *Telenomus remus* Nixon (Hymenoptera: Scelionidae). In *Proceedings of the Pakistan Congress of Zoology* (Vol. 14, pp. 103–106). Tandojam, Pakistan: Atomic Energy Agricultural Research Centre.

Burnett, T. (1954). Influences of natural temperatures and controlled host densities on oviposition of an insect parasite. *Physiological Zoology*, *27*(3), 239–248.

Büttow, G. T., Pazini, J. D. B., Seidel, E. J., Silva, F. F. D., Grützmacher, A. D., & Martins, J. F. D. S. (2017). Relationship between the occurrence of the rice water weevil and water depth in flooded rice crop. *Pesquisa Agropecuária Brasileira*, *52*, 557–560.

Cammell, M. E., & Knight, J. D. (1992). Effect of climate change on the population dynamics of crop pests. *Advances in Ecological Research, 22,* 117–162.

Campbell, L. M. (2005). Overcoming obstacles to interdisciplinary research. *Conservation Biology*, *19*(2), 574–577.

Caporali, F., Lieblein, G., Von Fragstein, P., & Francis, C. (2007). Integration of research and education in agroecology and organic farming. In *Proceedings of the ENOAT Workshop, Pieve Tesino, Italy* (pp. 30–31). Department of Plant Production, University of Tuscia, Viterbo, Italy.

Castellanos, I., & Barbosa, P. (2006). Evaluation of predation risk by a caterpillar using substrate-borne vibrations. *Animal Behaviour*, *72*(2), 461–469.

Castellanos, I., Barbosa, P., Zuria, I., Tammaru, T., & Christman, M. C. (2011). Contact with caterpillar hairs triggers predator-specific defensive responses. *Behavioral Ecology*, *22*(5), 1020–1025.

Castillo, A., Torres, A., Velázquez, A., & Bocco, G. (2005). The use of ecological science by rural producers: A case study in Mexico. *Ecological Applications*, *15*(2), 745–756.

Catling, H. D., Islam, Z., & Alam, B. (1983). Egg parasitism of the yellow rice borer, *Scirpophaga incertulas* (Lep.: Pyralidae) in Bangladesh deepwater rice. *Entomophaga*, *28*, 227–239.

Cendaña, S. M., & Calora, F. B. (1967). Insect pests of rice in the Philippines. In *The major insect pests of the rice plant: Proceedings of a symposium at the IRRI, Sept., 1964* (pp. 591–616). Baltimore, Maryland: Johns Hopkins Press.

Centre for Agriculture and Bioscience International (CABI). (2019). *Exorista xanthaspis*. In *Invasive Species Compendium*. Wallingford, UK: CAB International. Retrieved from www.cabi.org/isc/datasheet/23770. Accessed September 10, 2020.

Chaigarun, S., Kessomboon, N., Kessomboon, P., Somboon, S., Khangkhan, P., & Heong, K. L. (2011). Comparison of biodiversity index in pesticide treated and untreated rice field in Northeast of Thailand. *CMU. Journal of Natural Sciences*, *10*(1), 71–79.

Chakraborty, K. (2012). Relative composition of egg parasitoid species of yellow stem borer, Scirpophaga incertulas Wlk. In paddy field at Uttar Dinajpur, West Bengal, India. *Current Biotica*, *6*(1), 42–52.

Chandler, J. A., & Highton, R. B. (1975). The succession of mosquito species (Diptera, Culicidae) in rice fields in the Kisumu area of Kenya, and their possible control. *Bulletin of Entomological Research*, *65*(2), 295–302.

Chandra, A., Das, R., Singh, B., Pait, B., Singh, R., Bhagawati, R., Srivastava, A., & Gogoi, J. (2017). *Puntius* spp. As a potential lure against Gundhi bug in North East region of India. *Environmental Ecology*, *35*, 863–866.

Chandra, G. (1979). Taxonomy and bionomics of the insect parasites of rice leafhoppers and planthoppers in the Philippines and their importance in natural biological control. *Philippine Entomologist*, *4*(3), 119–139.

Chandraker, H. K., Pophaly, D. J., Gupta, R., & Kaushik, U. K. (1989). Naturally occurring biological control of rice gall midge at Raipur, India. *Oryza*, *26*(4), 393–395.

Chandramohan, N., & Chelliah, S. (1984). Parasite complex of yellow stem borer (YSB). *International Rice Research Newsletter*, *9*(6), 21.

Chandramohanan, K. T., Radhakrishnan, V. V., & Mohanan, K. V. (2016). Performance evaluation of some native rice cultivars of the Kaippad farming system of Kerala State of India. *Universal Journal of Agricultural Research*, *4*, 37–41.

Chapin, F. S., Carpenter, S. R., Kofinas, G. P., Folke, C., Abel, N., Clark, W. C., Olsson, P., Smith, D. M. S., Walker, B., Young, O. R., Berkes, F., Biggs, R., Grove, J. M., Naylor, R. L., Pinkerton, E., Steffen, W., & Swanson, F. J. (2010). Ecosystem stewardship: Sustainability strategies for a rapidly changing planet. *Trends in Ecology & Evolution*, *25*(4), 241–249.

Chathukulam, J., & John, M. S. (2006). Issues in Tribal Development: The Recent Experience of Kerala. In C. R. Govinda (Ed.), *Tribal Development in India: The Contemporary Debate* (pp. 82–202). New Delhi: Sage Publications.

Chattopadhyay, S., & Kumar, S. S. (2013). *Glimpses of Kerala through maps*. Centre for Earth Science Studies, Trivandrum.

Chavan, S. M., & Patel, K. G. (2018). Morphological basis of resistance in rice against yellow stem borer, *Scirpophaga incertulas* (Walker). *Indian Journal of Entomology*, *80*(1), 27–35.

Chen, Y. X. (1989). Investigation of dryinids of rice planthoppers in Sinan County, Guzhou, China. *Insect Knowledge*, *26*(2), 77–79.

Cheng, C. H. (1987). Investigation on bionomics of the rice leaffolder, *Cnaphalocrocis medinalis* (Guenee) in the south of Taiwan. *Plant Protection Bulletin*, *29*, 135–146.

Chhetry, G. K. N., & Belbahri, L. (2009). Indigenous pest and disease management practices in traditional farming systems in north east India. A review. *Journal of Plant Breeding and Crop Science*, *1*(3), 28–38.

Claridge, M. F., & Singhrao, J. S. (1978). Diversity and altitudinal distribution of grasshoppers (Acridoidea) on a Mediterranean mountain. *Journal of Biogeography*, 239–250.

Claridge, M. F., Morgan, J. C., Steenkiste, A. E., Iman, M., & Damayanti, D. (1999). Seasonal patterns of egg parasitism and natural biological control of rice brown planthopper in Indonesia. *Agricultural and Forest Entomology*, *1*(4), 297–304.

Clausen, C. P. (1978). *Introduced parasites and predators of arthropod pests and weeds: A world review (Biological Control, economic plants)*. Agriculture Handbook (No. 480). U.S. Department of Agriculture.

Clough, Y., Kruess, A., & Tscharntke, T. (2007). Organic versus conventional arable farming systems: Functional grouping helps understand staphylinid response. *Agriculture, Ecosystems & Environment, 118*(1–4), 285–290.

Cobbold, S. M., & MacMahon, J. A. (2012). Guild mobility affects spider diversity: Links between foraging behavior and sensitivity to adjacent vegetation structure. *Basic and Applied Ecology*, *13*(7), 597–605.

Cohen, J. (1978). *Food webs and niche space*. Princeton, NJ: Princeton University Press.

Cohen, J. E. (1989). *Ecologists Co-operative Web Bank (ECOWeBTM)*. Version 1.0. Machine Readable Database of Food Webs. Rockefeller University, New York.

Colding, J., Folke, C., & Elmqvist, T. (2003). Social institutions in ecosystem management and biodiversity conservation. *Tropical Ecology*, *44*(1), 25–41.

Colmenarez, Y., Corniani, N., Mundstock, S., Sampaio, M., & Vásquez, C. (2018). Use of parasitoids as a biocontrol agent in the neotropical region: challenges and potential. In *Horticultural crops* (pp. 171–185). London: IntechOpen.

Conelly, W. T. (1987). Perception and management of crop pests among subsistence farmers in South Nyanza, Kenya. In J. Tait & B. Napompeth (Eds.), *Management of pests and pesticides: Farmers' perceptions and practices* (pp. 198–209). Westview Press. Colorado.

Corbett, G. H. (1933). Results on stem borer experiments in Krian during the 1931–32 padi season. *Malayan Agricultural Journal*, *21*(8), 362–378.

Corbett, J., Rambaldi, G., Kyem, P., Weiner, D., Olson, R., Muchemi, J., McCall, M., & Chambers, R. (2006). Overview: mapping for change–the emergence of a new practice. *Participatory Learning and Action*, *54*, 13–19.

Cornell, H. V., & Hawkins, B. A. (1995). Survival patterns and mortality sources of herbivorous insects: Some demographic trends. *The American Naturalist*, *145*(4), 563–593.

Cornell, H. V., Hawkins, B. A., & Hochberg, M. E. (1987). Refuge use by parasitoids and other enemies: Theory and evidence. *Annual Review of Ecology and Systematics, 18*, 143–166.

Costamagna, A. C., Menalled, F. D., & Landis, D. A. (2004). Host density influences parasitism of the armyworm *Pseudaletia unipuncta* in agricultural landscapes. *Basic and Applied Ecology*, *5*(4), 347–355.

Cott, H. B. (1940). *Adaptive coloration in animals*. Methuen & Co., Ltd.

Craig, W. J., Harris, T. M., & Weiner, D. (Eds.). (2002). *Community Participation and Geographic Systems*. New York: Taylor & Francis.

Currado, I., & Olmi, M. (1979). On the identity of some Indian dryinid parasites of rice leafhoppers (Hymenoptera: Dryinidae). *Il Riso, 28*(2), 179–181.

Dale, D. (1994). Insect pests of the rice plant – their biology and ecology. In E. A. Heinrichs (Ed.), *Biology and management of rice insects* (pp. 363–487). Wiley Eastern Ltd., India and International Rice Research Institute.

Damalas, C. A. (2009). Understanding benefits and risks of pesticide use. *Scientific Research and Essays*, *4*(10), 945–949.

Damalas, C. A., & Hashemi, S. M. (2010). Pesticide risk perception and use of personal protective equipment among young and old cotton growers in northern Greece. *Agrociencia*, *44*(3), 363–371.

Damman, H. (1986). The osmaterial glands of the swallowtail butterfly *Eurytides marcellus* as a defence against natural enemies. *Ecological Entomology*, *11*(3), 261–265.

Damos, P. T., & Savopoulou-Soultani, M. (2010). Development and statistical evaluation of models in forecasting moth phenology of major lepidopterous peach pest complex for Integrated Pest Management programs. *Crop Protection*, *29*(10), 1190–1199.

Daniel, J. A., & Ramaraju, K. (2017). Diversity of chalcidids (Chalcididae: Hymenoptera) among three rice growing zones of Tamil Nadu, India. *Journal of Entomology and Zoology Studies*, *5*(3), 541–546.

Daniel, J. A., & Ramaraju, K. (2019a). Diversity of parasitic Hymenoptera in three rice-growing tracts of Tamil Nadu, India. *Journal of Threatened Taxa*, *11*(13), 14681–14690.

Daniel, J. A., & Ramaraju, K. (2019b). List of parasitic hymenopterans recorded from rice ecosystems of India. *Journal of Experimental Zoology, India*, *22*(2), 877–889.

Daniel, J. A., & Ramaraju, K. (2020). Platygastroidea from rice ecosystems of Tamil Nadu. *Indian Journal of Entomology, 82*(4), 813–818.

Daniel, J. A., & Ramaraju, K. (2020a). Collecting parasitic Aculeata (Hymenoptera) from rice ecosystems of Tamil Nadu, India. *Journal of Threatened Taxa*, *12*(8), 15828–15834.

Daniel, J. A., Ramaraju, K., & Rameshkumar, A. (2019a). Comparative studies of mymarid diversity from three different zones of paddy ecosystem in Tamil Nadu, India. *Entomon, 44*(3), 173–182.

Daniel, J. A., Ramaraju, K., Kumar, S. M., Jeyaprakash, P., & Chitra, N. (2019b). Study on varietal preferences and seasonal incidence of parasitoids of rice pests. *Entomon*, *44*(1), 65–72.

Daniel, J. A., Ramaraju, K., Kumar, S. M., Jeyaprakash, P., & Chitra, N. (2019c). Influence of weather on the parasitoid catches in three rice growing agroclimatic zones of Tamil Nadu. *Indian Journal of Entomology*, *81*(1), 55–60.

Daniel, J. A., Ramaraju, K., Poorani, J., & Nikhil, K. (2019d). Comparision of Eurytomidae and Eupelmidae (Hymenoptera: Chalcidoidea) diversity from three rice growing zones of Tamil Nadu. *Madras Agricultural Journal*, *106*.

Daniel, J. A., Ramaraju, K., Rajmohana, K., & Kumar, P. G. (2019e). On a collection of Ceraphronoidae, Figitidae, Evanoidea and Diapriidae from three rice growing zones of Tamil Nadu. *Journal of Entomological Research*, *43*(2), 213–222.

Daniel, J. A., Ramaraju, K., Sudheer, K., & Vishnu, K. (2020). Ichneumonid fauna associated with rice ecosystems of Tamil Nadu, India. *Journal of Biological Control*, *34*(1), 15–25.

Darwin, C. (1859). *On the origin of species*. London: John Murray.

Das, D., & Saikia, P. (2010). Indigenous technical knowledge for management of rice pests in Assam. *Annals of Plant Protection Sciences*, *18*(1), 123–126.

Dass, R., & Parshad, B. (1984). Rearing of important lepidopterous pests on known artificial diet and screening for preferred hosts of parasite, *Telenomus remus* Nixon (Hymenoptera: Scelionidae. *Journal of Entomological Research*, *8*(1), 89–92.

de Almeida, M. A. F., Prado, A. P., & Geden, C. J. (2002). Influence of temperature on development time and longevity of *Tachinaephagus zealandicus* (Hymenoptera: Encyrtidae), and effects of nutrition and emergence order on longevity. *Environmental Entomology*, *31*(2), 375–380.

De Datta, S. K. (1981). *Principles and practices of rice production*. Singapore: John Wiley & Sons, Inc.

de Kraker, J. V., Huis, A., Heong, K. L., Lenteren, J. C., & Rabbinge, R. (1999). Population dynamics of rice leaffolders (Lepidoptera: Pyralidae) and their natural enemies in irrigated rice in the Philippines. *Bulletin of Entomological Research*, *89*(5), 411–421.

Deka, M. K., Bhuyan, M., & Hazarika, L. K. (2006). Traditional pest management practices of Assam. *Indian Journal of Traditional Knowledge*, *5*(1), 75–78.

dela-Cruz, C. G., & Litsinger, J. A. (1986). Suitability of ratoon rice as host to insects. *International Rice Research Newsletter*, *11*(5), 27.

Del-Claro, K. (2004). Multitrophic relationships, conditional mutualisms, and the study of interaction biodiversity in tropical savannas. *Neotropical Entomology*, *33*(6), 665–672.

Deml, R., & Dettner, K. (2003). Comparative morphology and secretion chemistry of the scoli in caterpillars of *Hyalophora cecropia*. *Naturwissenschaften*, *90*(10), 460–463.

Descamps, M. (1956). Insectes nuisibles au riz dans le Nord Cameroun. *Agronomie Tropicale*, *11*, 732–755.

Dessart, P., & Cancemi, P. (1986). Tableau dichotomique des genres de Ceraphronidae (Hymenoptera) avec commentaires et nouvelles espèces. *Frustula Entomologica*, *7–8*, 307–372.

Deutsch, C. A., Tewksbury, J. J., Huey, R. B., Sheldon, K. S., Ghalambor, C. K., Haak, D. C., & Martin, P. R. (2008). Impacts of climate warming on terrestrial ectotherms across latitude. *Proceedings of the National Academy of Sciences*, *105*(18), 6668–6672.

Devetak, M., Bohinc, T., Kač, M., & Trdan, S. (2015). Seasonal dynamics of the cabbage armyworm (*Mamestra brassicae* [L.]) and the bright-line brown-eyes moth (*Mamestra oleracea* [L.]) in Slovenia. *Horticultural Science*, *41*, 80–88.

Devi, I. P. (2007). Pesticide use in the rice bowl of Kerala: Health costs and policy options. *SANDEE Working Paper*, *21*.

DeVries, P. J. (1987). *The butterflies of Costa Rica and their natural history. Vol. I: Papilionidae, Pieridae and Nymphalidae*. Princeton: Princeton University Press.

DeVries, P. J. (1991). Foam barriers, a new defense against ants for milkweed butterfly caterpillars (Nymphalidae: Danainae). *Journal of Research on the Lepidoptera*, *30*, 261–266.

DeVries, P. J. (1997). *The butterflies of Costa Rica and their natural history: Vol. II. Riodinidae*. Princeton: Princeton University Press.

Di Giovanni, F., Scaramozzino, P. L., Loni, A., & Lucchi, A. (2021). Taxonomic revision of the *Campoplex difformis* group (Ichneumonidae, Campopleginae), with particular reference to species of economic importance. *European Journal of Taxonomy*, *740*, 1–35.

Diniz, I. R., Hay, J. D., Rico-Gray, V., Greeney, H. F., & Morais, H. C. (2012). Shelter-building caterpillars in the cerrado: Seasonal variation in relative abundance, parasitism, and the influence of extra-floral nectaries. *Arthropod-Plant Interactions*, *6*, 583–589.

Dormann, C. F., Blüthgen, N., Moore, J., McCann, K., Ruiter, P., & Wolters, V. (2017). Food webs versus interaction networks: Principles, pitfalls and perspectives. *Cambridge University Press*, *3*, 1–11.

Doutt, R. L., & Viggiani, G. (1968). The classification of the Trichogrammatidae (Hymenoptera: Chalcidoidea). *Proceedings of the California Academy of Sciences, 4th series, 35*, 477–586.

Dresner, E. (1958). A Poison Bait for Control of *Leptocorisa acuta* (Thunb.). *Journal of Economic Entomology*, *51*(3), 405–405.

Dutcher, J. D. (2007). *A review of resurgence and replacement causing pest outbreaks in IPM* (pp. 27–43). Springer.

Dyer, L. A. (1995). Tasty generalists and nasty specialists? Antipredator mechanisms in tropical lepidopteran larvae. *Ecology*, *76*(5), 1483–1496.

Dyer, L. A. (1997). Effectiveness of caterpillar defenses against three species of invertebrate predators. *Journal of Research on the Lepidoptera*, *34*(1), 48–68.

Dyer, L. A., & Floyd, T. (1993). Determinants of predation on phytophagous insects: The importance of diet breadth. *Oecologia*, *96*(4), 575–582.

Dyer, L., & Bowers, M. (1996). The importance of sequestered iridoid glycosides as a defense against an ant predator. *Journal of Chemical Ecology*, *22*(8), 1527–1539.

Easterling, D. R., Evans, J. L., Groisman, P. Y., Karl, T. R., Kunkel, K. E., & Ambenje, P. (2000). Observed variability and trends in extreme climate events: A brief review. *Bulletin of the American Meteorological Society*, *81*(3), 417–426.

Edmunds, M. (1974). *Defence in animals: A survey of anti-predator defences*. New York: Longmans.

Eggleton, P., & Belshaw, R. (1993). Comparisons of dipteran, hymenopteran and coleopteran parasitoids: Provisional phylogenetic explanations. *Biological Journal of the Linnean Society*, *48*(3), 213–226.

Eggleton, P., & Gaston, K. J. (1990). Parasitoid" species and assemblages: Convenient definitions or misleading compromises? *Oikos*, *59*(3), 417–421.

Eichers, T. R. (1981). Use of pesticides by farmers. In D. Pimentel (Ed.), *CRC handbook of pest management in agriculture* (Vol. II, pp. 3–25). Boca Raton, USA: CRC Press Inc.

Eigenbrode, S. D., O'rourke, M., Wulfhorst, J. D., Althoff, D. M., Goldberg, C. S., Merrill, K., Morse, W., Nielsen–Pincus, M., Stephens, J., Winowiecki, L., & Bosque–Pérez, N. A. (2007). Employing philosophical dialogue in collaborative science. *BioScience*, *57*(1), 55–64.

Eisner, T., Eisner, M., & Siegler, M. (2007). *Secret weapons: Defenses of insects, spiders, scorpions, and other many-legged creatures*. Massachusetts: Belknap Press.

Elkinton, J. S., & Liebhold, A. M. (1990). Population dynamics of gypsy moth in North America. *Annual Review of Entomology*, *35*(1), 571–596.

Enoki, T., Nakashizuka, T., Nakano, S. I., Miki, T., Lin, Y. P., Nakaoka, M., Mizumachi, E., & Shibata, H. (2014). Progress in the 21st century: A roadmap for the Ecological Society of Japan. *Ecological Research*, *29*, 357–368.

Epstein, M. E., Smedley, S. R., & Eisner, T. (1994). Sticky integumental coating of a dalcerid caterpillar: A deterrent to ants. *Journal of the Lepidopterists Society*, *48*(4), 381–386.

ESRI. (2011). *ArcGIS Desktop: Release 10*. Environmental Systems Research Institute, Redlands.

Ess, D., & Morgan, M. (2003). *The Precision-Farming Guide for Agriculturists.* Moline, IL: Deere & Company

Evans, E. W. (1983). Niche relations of predatory stinkbugs (*Podisus* spp., Pentatomidae) attacking tent caterpillars (*Malacosoma americanum*, Lasiocampidae). *The American Midland Naturalist, 109*(2), 316–323.

Evans, H. E. (1964). A synopsis of the American Bethylidae (Hymenoptera, Bethylidae). *Bulletin of the Museum of Comparative Zoology*, *132*, 1–222.

Evans, M. A., & Schmidt, F. (1991). Repeated maternal book reading with two children: Language-normal and language-impaired. *First Language*, *11*(32), 269–286.

Evers, J. B., Vos, J. A. N., Andrieu, B., & Struik, P. C. (2006). Cessation of tillering in spring wheat in relation to light interception and red: Far-red ratio. *Annals of Botany*, *97*(4), 649–658.

Fagerholm, N., & Käyhkö, N. (2009). Participatory mapping and geographical patterns of the social landscape values of rural communities in Zanzibar, Tanzania. *Fennia-International Journal of Geography*, *187*(1), 43–60.

Fahad, S., Nie, L., Hussain, S., Khan, F., Khan, F. A., Saud, S., Muhammad, H., Li, L., Liu, X., Tabassum, A., et al. (2015). Rice pest management and biological control. *Sustainable Agriculture Review, 16*, 85–106.

Fahrig, L., & Jonsen, I. (1998). Effect of habitat patch characteristics on abundance and diversity of insects in an agricultural landscape. *Ecosystems*, *1*, 197–205.

Fasokun, T. O., Katahoire, A., & Oduran, A. B. (2005). *The psychology of adult learning in Africa*. Hamburg, Germany: UNESCO Institute for Education and Pearson Education, South Africa.

Fedorka, K. M., Copeland, E. K., & Winterhalter, W. E. (2013). Seasonality influences cuticle melanization and immune defense in a cricket: Support for a temperature-dependent immune investment hypothesis in insects. *Journal of Experimental Biology*, *216*(21), 4005–4010.

Fei, M., Gols, R., & Harvey, J. A. (2023). The biology and ecology of parasitoid wasps of predatory arthropods. *Annual Review of Entomology*, *68*, 109–128.

Ferino, M. P. (1968). The biology and control of the rice leaf-whorl maggot, *Hydrellia philippina* Ferino (Ephydridae, Diptera). *Philippine Agriculturist*, *52*(6), 332–383.

Fernando, H. E. (1970). Natural enemies of rice stem borers and feasibility of chemical and biological control of these pests in Ceylon. *Mushi*, *44*, 43–47.

Finke, D. L., & Snyder, W. E. (2010). Conserving the benefits of predator biodiversity. *Biological Conservation*, *143*(10), 2260–2269.

Flinn, P. W. (1991). Temperature-dependent functional response of the parasitoid *Cephalonomia waterstoni* (Gahan)(Hymenoptera: Bethylidae) attacking rusty grain beetle larvae (Coleoptera: Cucujidae). *Environmental Entomology*, *20*(3), 872–876.

Food and Agricultural Organization (FAO) of the United Nations. (2009). *FAOSTAT*. Retrieved from http://faostat.fao.org/site/567/DesktopDefault.aspx?PageID=567#ancor. Accessed June 12, 2020.

Food and Agriculture Organization (FAO). (2004). *FAO Rice Conference*. Retrieved from http://www.fao.org. Accessed April 15, 2020.

Foot, N. C. (1922). Pathology of the dermatitis caused by *Megalopyge opercularis*, a Texan caterpillar. *The Journal of Experimental Medicine*, *35*(5), 737.

Forster, D., Buehler, Y., & Kellenberger, T. (2009). Mapping urban and peri-urban agriculture using high spatial resolution satellite data. *Journal of Applied Remote Sensing*, *3*(1), 033523.

Fowler, S. V., Claridge, M. F., Morgan, J. C., Peries, I. D. R., & Nugaliyadde, L. (1991). Egg mortality of the brown planthopper, *Nilaparvata lugens* (Homoptera: Delphacidae) and green leafhoppers, *Nephotettix* spp.(Homoptera: Cicadellidae), on rice in Sri Lanka. *Bulletin of Entomological Research*, *81*(2), 16–167.

Fuat, S., Adam, N. A., Hazmi, I. R., & Yaakop, S. (2022). Interactions between *Metisa plana*, its hyperparasitoids and primary parasitoids from good agriculture practices (GAP) and non-gap oil palm plantations. *Community Ecology*, *23*, 429–438.

Fujisaka, S. (1990). Rainfed lowland rice: Building research on farmer practice and technical knowledge. *Agriculture, Ecosystems & Environment*, *33*(1), 57–74.

Fujisaka, S. (1991). What does" build research on farmer practice" mean? Rice crop establishment (beusani) in eastern India as an illustration. *Agriculture and Human Values*, *8*, 93–98.

Fujisaka, S. (1993). Were farmers wrong in rejecting a recommendation? The case of nitrogen at transplanting for irrigated rice. *Agricultural Systems*, *43*(3), 271–286.

Fujisaka, S., Dapusala, A., & Jayson, E. (1989). Hail Mary, kill the cat: A case of traditional upland crop pest control in the Philippines. *Philippine Quarterly of Culture and Society, 17*, 202–211.

Fujisaka, S., Kirk, G., Litsinger, J. A., Moody, K., Hosen, N., Yusef, A., Nurdin, F., Naim, T., Artati, F., Aziz, A., et al. (1991). *Wild pigs, poor soils, and upland rice: A diagnostic survey of Sitiung, Sumatra, Indonesia*. IRRI Research Paper Series No. 155, 9.

Fukamachi, S. (1980). Habitat and oviposition behavior of the rice leafroller moth, Cnaphalocrocis medinalis, Guenée. In *Proceedings of the Association for Plant Protection* (pp. 93–96). Kyushu, Japan.

Fukamachi, S. (1983). Nocturnal activity of the rice leafroller moth, Cnaphalocrocis medinalis Guenée. *Proceedings of the Association for Plant Protection of Kyushu*, *26,* 93–96.

Fuller, D. Q., Qin, L., & Harvey, E. (2008~~b~~). Evidence for a late onset of agriculture in the lower Yangtze region and challenges for an archaeobotany of rice. In A. Sanchez-Mazas, R. Blench, M. D. Ross, I. Peiros, & M. Lin (Eds.), *Past Human Migrations in East Asia: Matching Archaeology, Linguistics and Genetics* (pp. 40–83). Routledge, London.

Future Earth. (2013). *Future Earth initial design: Report of the transition team*. Paris: International Council for Science (ICSU).

Gagic, V., Hänke, S., Thies, C., Scherber, C., Tomanović, Ž., & Tscharntke, T. (2012). Agricultural intensification and cereal aphid–parasitoid–hyperparasitoid food webs: Network complexity, temporal variability and parasitism rates. *Oecologia*, *170*, 1099–1109.

Gagic, V., Petrović-Obradović, O., Fründ, J., Kavallieratos, N. G., Athanassiou, C. G., Starý, P., & Tomanović, Ž. (2016). The effects of aphid traits on parasitoid host use and specialist advantage. *PLoS One*, *11*(6), 0157674.

Gagic, V., Tscharntke, T., Dormann, C. F., Gruber, B., Wilstermann, A., & Thies, C. (2011). Food web structure and biocontrol in a four-trophic level system across a landscape complexity gradient. *Proceedings of the Royal Society B: Biological Sciences*, *278*(1720), 2946–2953.

García-Ruiz, E., Marco, V., & Pérez-Moreno, I. (2011). Effects of variable and constant temperatures on the embryonic development and survival of a new grape pest, *Xylotrechus arvicola* (Coleoptera: Cerambycidae). *Environmental Entomology*, *40*(4), 939–947.

Gaston, K. J. (2000). Global patterns in biodiversity. *Nature*, *405*(6783), 220–227.

Gaston, K. J., Reavey, D., & Valladares, G. R. (1991). Changes in feeding habit as caterpillars grow. *Ecological Entomology*, *16*, 339–344.

Gauld, I. D. (1987). Some factors affecting the composition of tropical ichneumonid faunas. *Biological Journal of the Linnean Society*, *30*(4), 299–312.

Gautam, R. D. (1987). Limitations in mass-multiplication of scelionid, *Telenomus remus* Nixon, a potential egg-parasitoid of *Spodoptera litura* (Fabricius). *Journal of Entomological Research*, *11*(1), 6–9.

Gboku, M., & Lekoko, R. N. (2007). Developing programmes for adult learners in Africa. In *African perspectives on adult learning series*. Hamburg/Cape Town: UNESCO Institute for Lifelong Learning (UIL)/Pearson.

Géneau, C. E., Wäckers, F. L., Luka, H., Daniel, C., & Balmer, O. (2012). Selective flowers to enhance biological control of cabbage pests by parasitoids. *Basic and Applied Ecology*, *13*(1), 85–93.

Gentry, G. L., & Dyer, L. A. (2002). On the conditional nature of neotropical caterpillar defenses against their natural enemies. *Ecology*, *83*(11), 3108–3119.

George, S. P., Bastian, D., Radhakrishan, N. V., & Aipe, K. C. (2006). Evaluation of aromatic rice varieties in Wayanad, Kerala. *Journal of Tropical Agriculture*, *43*, 67–69.

Gibbons, W., Haynes, R. R., & Thomas, J. L. (1990). *Poisonous plants and venomous animals of Alabama and adjoining states*. Tuscaloosa: University of Alabama Press.

Gibson, G. A. P. (1995). Parasitic wasps of the subfamily Eupelminae: Classification and revision of the world genera (Hymenoptera: Chalcidoidea: Eupelmidae). *Memoirs on Entomology, International*, *5*, 1–421.

Gill, H. K., & Garg, H. (2014). Pesticides: Environmental impacts and management strategies. In M. L. Larramendy & S. Soloneski (Eds.), *Pesticides—Toxic aspects* (pp. 187–230). London: IntechOpen.

Glass, E. H., & Thurston, H. D. (1978). Traditional and modern crop protection in perspective. *Bioscience*, *28*(2), 109–115.

Gnanakumar, M., Rajmohana, K., Bijoy, C., Balan, D., & Nishi, R. (2012). Diversity of Hymenopteran Egg Parasitoids in Organic and Conventional Paddy Ecosystems. *Tropical Agricultural Research*, *23*(4), 300–308.

Goane, L., Casmuz, A., Salas, H., Willink, E., Mangeaud, A., & Valladares, G. (2015). Impact of natural control agents of the citrus leafminer *Phyllocnistis citrella* on lemon trees varies among seasons. *Bulletin of Entomological Research*, *105*(6), 685–693.

Godfray, H. C. J. (1994). *Parasitoids: Behavioral and evolutionary ecology* (Vol. 12). Princeton: Princeton University Press.

Godfray, H. C. J., Hassell, M. P., & Holt, R. D. (1994). The population dynamic consequences of phenological asynchrony between parasitoids and their hosts. *Journal of Animal Ecology, 63*(1), 1–10.

Goodale, K., Parsons, G. J., & Sherren, K. (2015). The nature of the nuisance—damage or threat—determines how perceived monetary costs and cultural benefits influence farmer tolerance of wildlife. *Diversity, 7*(3), 318–341.

Goodell, G. E. (1984). Bugs, bunds, banks, and bottlenecks: Organizational contradictions in the new rice technology. *Economic Development and Cultural Change*, *33*(1), 23–41.

Goodell, G. E., Kenmore, P. E., Litsinger, J. A., Bandong, J. P., De la Cruz, C. G., & Lumaban, M. D. (1982). Rice insect pest management technology and its transfer to small-scale farmers in the Philippines. In *Report of an Exploratory Workshop on the Role of Anthropologists and Other Social Scientists in Interdisciplinary Teams Developing Improved Food Production Technology* (pp. 25–42). Los Baños, Laguna, Philippines: International Rice Research Institute.

Gopi, G., & Manjula, M. (2018). Speciality rice biodiversity of Kerala: Need for incentivising conservation in the era of changing climate. *Current Science*, *114*(5), 997–1006.

Gopi, G., Kumar, N. A., & Nambi V. A. (2004). Vayals: A traditional classification of agricultural landscapes. *LEISA India*, *6*(4), 27–28.

Gord, G., Bu, K. K., & Sugonyaev, E. S. (1993). *Goniozus hanoiensis* Gordh, sp. N. (Hymenoptera, Bethylidae)-a parasite of the rice leaf roller *Cnaphalocrosis medinalis* Guenée in North Vietnam. *Ėntomologicheskoe Obozrenie*, *72*(1), 177–185.

Gould, F., Brown, Z. S., & Kuzma, J. (2018). Wicked evolution: Can we address the sociobiological dilemma of pesticide resistance? *Science*, *360*(6390), 728–732.

Government of Western Australia (GWA). (n.d.). *Mechanical, physical and cultural control methods. Agriculture and Food, Department of Primary Industries and Regional Development*. Retrieved February 15, 2020 from https://www.agric.wa.gov.au/pests-weeds-diseases/control-methods/mechanical-physical-and-cultural.

Grab, H., Branstetter, M. G., Amon, N., Urban-Mead, K. R., Park, M. G., Gibbs, J., Blitzer, E. J., Poveda, K., Loeb, G., & Danforth, B. N. (2019). Agriculturally dominated

landscapes reduce bee phylogenetic diversity and pollination services. *Science*, *363*(6424), 282–284.

Graham, N. R. (2021). *Resolving ecological, evolutionary, and global change effects on biodiversity dynamics: A review and empirical study* (Doctoral dissertation, University of California, Berkeley).

Grant, J. B. (2006). Diversification of gut morphology in caterpillars is associated with defensive behavior. *Journal of Experimental Biology*, *209*(15), 3018–3024.

Grant, J. B. (2007). Ontogenetic colour change and the evolution of aposematism: A case study in panic moth caterpillars. *Journal of Animal Ecology*, *76*(3), 439–447.

Gratton, C., & Welter, S. C. (2001). Parasitism of natural populations of *Liriomyza helianthi* Spencer and *Calycomyza platyptera* (Thomson) (Diptera: Agromyzidae). Biological *Control*, *22*(1), 81–97.

Greene, E. (1989). A diet-induced developmental polymorphism in a caterpillar. *Science*, *243*(4891), 643–646.

Greeney, H. F., & Warren, A. D. (2011). The natural history, immature stages, and shelter building behavior of Dion carmenta (Lepidoptera: Hesperiidae: Hesperiinae) in eastern Ecuador. *Annals of the Entomological Society of America*, *104*(6), 1128-1134.

Greeney, H. F., Dyer, L. A., & Pyrcz, T. W. (2010a). First description of the early-stage biology of the genus Mygona: The natural history of the satyrine butterfly, *Mygona irmina* in eastern Ecuador. *Journal of Insect Science*, *11*(1), 5.

Greeney, H. F., Dyer, L. A., & Smilanich, A. M. (2012). Feeding by lepidopteran larvae is dangerous: A review of caterpillars' chemical, physiological, morphological, and behavioral defenses against natural enemies. *Invertebrate Survival Journal*, *9*(1), 7–34.

Greeney, H. F., Dyer, L. A., DeVries, P. J., Walla, T. R., Salazar, V. L., Simbaña, W., & Salgaje, L. (2010b). Early stages and natural history of *Perisama oppelii* (Latreille, 1811) (Nymphalidae, Lepidoptera) in eastern Ecuador. *Kempffiana*, *6*, 16–30.

Greeney, H. F., Pyrcz, T. W., Dyer, L. A., Z, S., M., & Walla, T. R. (2010c). The early stages and natural history of *Corades medeba* Hewitson, 1850 in Eastern Ecuador (Lepidoptera: Nymphalidae: Satyrinae: Pronophilina). *Tropical Lepidoptera Research*, *20*(1), 8–13.

Grensted, L. W. (1946). An assemblage of Diptera on Cow-parsnip. *Entomologist's Monthly Magazine*, *82*, 180.

Grist, D. H., & Lever, R. J. A. W. (1969). *Pests of Rice*. Longmans: Green and Co.

Gross, P. (1993). Insect behavioral and morphological defenses against parasitoids. *Annual Review of Entomology*, *38*(1), 251–273.

Gu, H., & Subramanian, S. M. (2012). *Socio-ecological production landscapes: Relevance to the green economy agenda*. United Nations University Institute of Advanced Studies.

Guedes, R. N. C., Zanuncio, T. V., Zanuncio, J. C., & Medeiros, A. G. B. (2000). Species richness and fluctuation of defoliator Lepidoptera populations in Brazilian plantations of *Eucalyptus grandis* as affected by plant age and weather factors. *Forest Ecology and Management*, *137*(1–3), 179–184.

Guillerme, S., Kumar, B. M., Menon, A., Hinnewinkel, C., Maire, E., & Santhoshkumar, A. V. (2011). Impacts of public policies and farmer preferences on agroforestry practices in Kerala, India. *Environmental Management*, *48*, 351–364.

Gunderson, K., & Watson, A. (2007). Understanding place meanings on the bitterroot national forest, Montana. *Society and Natural Resources*, *20*(8), 705–721.

Günthart, H. (1984). Zikaden (Hom. Auchenorrhyncha) aus der alpinen Hohenstufe der Schweizer Zentralalpen. *Mitteilungen der Schweizerischen Entomologischen Gesellschaft, 57*, 129–130.

Gunton, R. M., & Pöyry, J. (2016). Scale-specific spatial density dependence in parasitoids: A multi-factor meta-analysis. *Functional Ecology*, *30*(9), 1501–1510.

Gupta, A., & Kalesh, S. (2012). Reared parasitic wasps attacking hesperiids from Western Ghats (Kerala, India) with description of a new species of Dolichogenidea (Hymenoptera: Braconidae) as a larval parasitoid of *Thoressa evershedi* (Evans) (Lepidoptera: Hesperiidae). *Zootaxa*, *3413*, 29–43.

Gupta, A., Saji, K., & Manoj, P. (2016). Parasitoids of butterflies: Reassignment of *Dolichogenidea hasorae* (Wilkinson, 1928) as a new combination along with new host–parasitoid linkages and notes on host specificity from Kerala, India. *Journal of Biological Control*, *30*(2), 61–67.

Gupta, M., & Pawar, A. D. (1989). Biological control of rice leafhoppers and planthoppers in Andhra Pradesh. *Plant Protection Bulletin*, *41*(1–2), 6–11.

Gurr, G. M., Liu, J., Read, D. M., Catindig, J. L. A., Cheng, J. A., Lan, L. P., & Heong, K. L. (2011). Parasitoids of Asian rice planthopper (Hemiptera: Delphacidae) pests and prospects for enhancing biological control by ecological engineering. *Annals of Applied Biology*, *158*(2), 149–176.

Gurr, G. M., Read, D. M., Catindig, J. L. A., Cheng, J., Liu, J., Lan, L. P., & Heong, K. L. (2012). Parasitoids of the rice leaffolder *Cnaphalocrocis medinalis* and prospects for enhancing biological control with nectar plants. *Agricultural and Forest Entomology*, *14*(1), 1–12.

Gurung, A. B. (2003). Insects–a mistake in God's creation? Tharu farmers' perception and knowledge of insects: A case study of Gobardiha Village Development Committee, Dang–Deukhuri, Nepal. *Agriculture and Human Values*, *20*, 337–370.

Hagen, M., Kissling, W. D., Rasmussen, C., Marcus, A. M., De Aguiar, M. A. M., Brown, L. E., et al. (2012). Biodiversity, species interactions and ecological networks in a fragmented world. *Advances in Ecological Research, 46*, 89–210.

Hall, S. J., & Raffaelli, D. G. (1993). Food webs – theory and reality. *Advances in Ecological Research, 24*, 187–239.

Hammer, Ø., Harper, D. A., & Ryan, P. D. (2001). PAST: Paleontological statistics software package for education and data analysis. *Palaeontologia Electronica*, *4*(1), 9.

Han, C. M., Shin, J. H., Kim, S. K., & Ryu, J. G. (2023). Analysis of volatile compounds of several rice varieties according to endosperm type using an electronic nose. *Journal of Crop Science and Biotechnology*, *26*(3), 359–367.

Harborne, J. B. (1988). *The Flavonoids: Advances in Research Since 1980*. New York: Chapman and Hall.

Harrington, R., Fleming, R. A., & Woiwod, I. P. (2001). Climate change impacts on insect management and conservation in temperate regions: Can they be predicted? *Agricultural and Forest Entomology*, *3*(4), 233–240.

Harris, I. P. D. J., Jones, P. D., Osborn, T. J., & Lister, D. H. (2014). Updated high-resolution grids of monthly climatic observations–the CRU TS3. 10 Dataset. *International Journal of Climatology*, *34*(3), 623–642.

Harris, I., Osborn, T. J., Jones, P., & Lister, D. (2020). Version 4 of the CRU TS monthly high-resolution gridded multivariate climate dataset. *Scientific Data*, *7*(1), 109.

Hasanuzzaman, M., Nahar, K., Roy, T. S., Rahman, M. L., Hossain, M. Z., & Ahmed, J. U. (2009). Tiller dynamics and dry matter production of transplanted rice as affected by plant spacing and number of seedling per hill. *Academic Journal of Plant Sciences*, *2*(3), 162–168.

Hashemi, S. M., & Damalas, C. A. (2010). Farmers' perceptions of pesticide efficacy: reflections on the importance of pest management practices adoption. *Journal of Sustainable Agriculture*, *35*(1), 69-85.

Hassan, S. A. (1985). Standard methods to test the side-effects of pesticides on natural enemies of insects and mites developed by the IOBC/WPRS Working Group 'Pesticides and Beneficial Organisms'. *Bulletin, Organisation Européenne et Méditerranéenne pour la Protection des Plantes, 15*(2), 214–255.

Hassell, M. P. (1980). Foraging strategies, population models and biological control: A case study. *Journal of Animal Ecology*, *49*(2), 603–628.

Hassell, M. P. (1986). Parasitoids and host population regulation. In J. K. Waage & D. Greathead (Eds.), *Insect Parasitoids* (pp. 201–224). Royal Entomological Society Symposium. Oxford, Blackwell Scientific Publications.

Hassell, M. P., Comins, H. N., & Mayt, R. M. (1991). Spatial structure and chaos in insect population dynamics. *Nature*, *353*(6341), 255–258.

Hassell, M., & May, R. (1986). Generalist and specialist natural enemies in insect predator-prey interactions. *Journal of Animal Ecology*, *55*(3), 923–940.

He, J., He, Y., Lai, F., Chen, X., & Fu, Q. (2020). Biological traits of the pincer wasp *Gonatopus flavifemur* (Esaki & Hashimoto) associated with different stages of its host, the brown planthopper, *Nilaparvata lugens* (Stål). *Insects*, *11*(5), 279.

Hebert, P. D. N. (1980). Moth communities in montane Papua New Guinea. *Journal of Animal Ecology, 49*(3), 593–602.

Hedge, S., Yenagi, N. B., & Kasturiba, B. (2013). Indigenous knowledge of the traditional and qualified Ayurveda practitioners on the nutritional significance and use of red rice in medications. *Indian Journal of Traditional Knowledge*, *12*, 506–511.

Hegazi, E. M., Altahtawy, M. M., Hammad, S. M., & El-Sawaf, S. K. (1974). Notes on the biology of the *Chelonus inanitus* (L.) (Hymenoptera: Braconidae). *Journal of Applied Zoology*, *75*(3), 291–294.

Heinrichs, E. A., & Viajante, V. D. (1987). Yield loss in rice caused by the caseworm *Nymphula depunctalis* Guenee (Lepidoptera: Pyralidae). *Journal of Plant Protection in the Tropics*, *4*(1), 15–26.

Heong, K. L. (1984). Pest control practices of rice farmers in Tanjong Karang, Malaysia. *International Journal of Tropical Insect Science*, *5*(3), 221–226.

Heong, K. L. (1990). Feeding rates of the rice leaffolder, *Cnaphalocrocis medinalis* (Lepidoptera: Pyralidae), on different plant stages. *Journal of Agricultural Entomology*, *7*(2), 81–90.

Heong, K. L., & Escalada, M. M. (1997). Perception change in rice pest management: A case study of farmers' evaluation of conflict information. *Journal of Applied Communications*, *81*(2), 3–17.

Heong, K. L., Aquino, G. B., & Barrion, A. T. (1991). Arthropod community structures of rice ecosystems in the Philippines. *Bulletin of Entomological Research*, *81*(4), 407–416.

Heong, K. L., Escalada, M. M., & Lazaro, A. A. (1992). *Pest management practices of rice farmers in Leyte, Philippines*. Los Baños, Philippines: International Rice Research Institute.

Heong, K. L., Escalada, M. M., & Mai, V. (1994). An analysis of insecticide use in rice: case studies in the Philippines and Vietnam. *International Journal of Pest Management, 40*(2), 173–178.

Heong, K. L., Escalada, M. M., Sengsoulivong, V., & Schiller, J. (2002). Insect management beliefs and practices of rice farmers in Laos. *Agriculture, Ecosystems & Environment*, *92*(2–3), 137–145.

Hespenheide, H. A. (1991). Bionomics of leaf-mining insects. *Annual Review of Entomology*, *36*(1), 535–560.

Hickling, R., Roy, D. B., Hill, J. K., Fox, R., & Thomas, C. D. (2006). The distributions of a wide range of taxonomic groups are expanding polewards. *Global Change Biology*, *12*(3), 450–455.

Hidaka, T. (1958). Biological investigation on *Telenomus gifuensis* Ashmead (Hym: Scelionidae), an egg parasite of *Scotinophara lurida* Burmeister (Hem. Pentatomidae) in Japan. *Acta Hymenopterologica*, *1*, 75–93.

Hidaka, T. (1965). Studies on the natural enemies of insects injurious to rice plant in Tohoku district in Japan. 1. On the parasites and predators attacking the rice stem borer and their ecological peculiarities. *Bulletin of Tokoku Agricultural Experiment Station*, *32*, 145–160.

Hijmans, R. J., Cameron, S. E., Parra, J. L., Jones, P. G., & Jarvis, A. (2005). Very high resolution interpolated climate surfaces for global land areas. *International Journal of Climatology: A Journal of the Royal Meteorological Society*, *25*(15), 1965–1978.

Hmwe, K. M., Aung, N. N., Su, A. A., Soe, K. K., Mon, T. L., Lwin, K. M., Thu, M. M., Soe, T. T., & Htwe, M. L. (2020). Diversity of Insect Pest and Predator Species in Monsoon and Summer Rice Fields of Taungoo Environs, Myanmar. *Advances in Entomology*, *8*(3), 117–129.

Hole, D. G., Perkins, A. J., Wilson, J. D., Alexander, I. H., Grice, P. V., & Evans, A. D. (2005). Does organic farming benefit biodiversity? *Biological Conservation*, *122*(1), 113–130.

Holt, R. D. (1977). Predation, apparent competition, and the structure of prey communities. *Theoretical Population Biology*, *12*(2), 197–229.

Holt, R. D., & Lawton, J. H. (1993). Apparent competition and enemy-free space in insect host-parasitoid communities. *The American Naturalist*, *142*(4), 623–645.

Holzschuh, A., Steffan- Dewenter, I., & Tscharntke, T. (2010). How do landscape composition and configuration, organic farming and fallow strips affect the diversity of bees, wasps and their parasitoids? *Journal of Animal Ecology*, *79*(2), 491–500.

Horgan, F. G., Ramal, A. F., Villegas, J. M., Jamoralin, A., Bernal, C. C., Perez, M. O., Pasang, J. M., Naredo, A. I., & Almazan, M. L. P. (2017). Effects of bund crops and insecticide treatments on arthropod diversity and herbivore regulation in tropical rice fields. *Journal of Applied Entomology*, *141*(8), 587–599.

Hosseyni-Moghaddam, M., & Soltani, J. (2013). An investigation on the effects of photoperiod, aging and culture media on vegetative growth and sporulation of rice blast pathogen *Pyricularia oryzae*. *Progress in Biological Sciences*, *3*(2), 135–143.

Hrcek, J., Miller, S. E., Whitfield, J. B., Shima, H., & Novotny, V. (2013). Parasitism rate, parasitoid community composition and host specificity on exposed and semi-concealed caterpillars from a tropical rainforest. *Oecologia*, *173*, 521–532.

Hu, G., Lim, K. S., Horvitz, N., Clark, S. J., Reynolds, D. R., Sapir, N., & Chapman, J. W. (2016). Mass seasonal bioflows of high-flying insect migrants. *Science*, *354*(6319), 1584–1587.

Hu, Y., Ban, Y., Zhang, X., Liu, J., & Zhuang, D. (2008). Spatial-temporal pattern of GIMMS NDVI and its dynamics in Mongolian Plateau. In *2008 International Workshop on Earth Observation and Remote Sensing Applications* (pp. 1–6). Beijing, China.

Huang, S. H., Cheng, C. H., & Wu, W. J. (2010). Possible impacts of climate change on rice insect pests and management tactics in Taiwan. *Crop, Environment & Bioinformatics*, *4*, 269–279.

Huber, J. (1986). Systematics, biology, and hosts of the Mymaridae and Mymarommatidae (Insecta: Hymenoptera). *Entomography*, *4*, 185–243.

Hunter, A. F. (2000). Gregariousness and repellent defences in the survival of phytophagous insects. *Oikos*, *91*(2), 213–224.

Hurlbert, S. H., Shannon-Wienner, E. C., Pielou, M. S. Y., & Wu, Z. F. (1989). The diversity of arthropod communities in paddy fields. *Journal of Fujuan Agricultural College*, *18*(4), 532–538.

Ichikawa, K. (2013). Understanding socio-ecological production landscapes in the context of Cambodia. *International Journal of Environmental and Rural Development*, *41*(1), 57–62.

Inclán, D. J., Cerretti, P., & Marini, L. (2014). Interactive effects of area and connectivity on the diversity of tachinid parasitoids in highly fragmented landscapes. *Landscape Ecology*, *29*, 879–889.

Indira Ghandi Agricultural University (IGAU). (1997). Pilot project on technology assessment and refinement through the Institution–Village Linkage Programme. Indira Gandhi Agricultural University, Raipur.

Ings, T. C., Montoya, J. M., Bascompte, J., Blüthgen, N., Brown, L., Dormann, C. F., Edwards, F., Figueroa, D., Jacob, U., Jones, J. I., Lauridsen, R. B., Ledger, M. E., Lewis, H. M., Olesen, J. M., Veen, F. J. F., Warren, P. H., & Woodward, G. (2009). Ecological networks–beyond food webs. *Journal of Animal Ecology*, *78*(1), 253–269.

Intergovernmental Panel on Climate Change (IPCC). (2001). Climate Change 2001: The Scientific Basis. In J. T. Houghton et al. (Eds.), *Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, United Kingdom: Cambridge University Press.

International Rice Research Institute (IRRI). (2006). *Control of rice insect pests*. Retrieved from http://www.knowledgebank.irri.org/ericeproduction/PDF_&_Docs/Control_of_rice_insect_pests.pdf. Accessed July 5, 2020.

International Rice Research Institute (IRRI). (2014). *Beneficial organisms that attack insect pests*. Retrieved from http://www.knowledgebank.irri.org/images/docs/beneficial-organisms-that-attack-insect-pests.pdf. Accessed April 24, 2020.

Irshad, M. (1977). Parasites of grasshopper eggs associated with paddy in Pakistan. *International Rice Research Newsletter*, *2*(5), 19.

Ishii-Eiteman, M. J., & Power, A. G. (1997). Response of green rice leafhoppers to rice-planting practices in northern Thailand. *Ecological Applications*, 7(1), 194–208.

Islam, Z. (2001). *Crop Protection Compendium* (2001 ed.) (pp. 1–28). CAB International (UK). (CD and Online).

Islam, Z., & Karim, A. N. M. R. (1995). Some aspects of biology and behaviour of *Telenomus rowani* and *Tetrastichus schoenobii* egg parasitoids of rice yellow stem borer. *Bangladesh Journal of Entomology*, *5*(121), 61–63.

Israel, H., & Richter, R. R. (2011). A guide to understanding meta–analysis. *Journal of Orthopaedic & Sports Physical Therapy*, *41*(7), 496–504.

Israel, P., & Prakasa-Rao, P. S. (1969). Record of *Anagrus* sp. A mymarid (Hymenoptera) parasite on eggs of *Sogatella furcifera* Horvath on rice in India. *Current Science*, *38*(13), 320–321.

Itoh, M., Kojima, H., Ho, P. C., Chang, C. W., Chen, T. Y., Hsiao, S. S. Y., Kobayashi, Y., Fujibayashi, M., Kao, S. J., Hsieh, C. H., Fukui, M., Okuda, N., Miki, T., & Shiah, F. K. (2017). Integrating isotopic, microbial, and modeling approaches to understand methane dynamics in a frequently disturbed deep reservoir in Taiwan. *Ecological Research*, *32*, 861–871.

Iwao, S. I., & Wellington, W. G. (1970). The western tent caterpillar: Qualitative differences and the action of natural enemies. *Researches on Population Ecology*, *12*(1), 81–99.

Jacobson, C., Allen, W., Veltman, C., Ramsey, D., Forsyth, D. M., Nicol, S., Todd, C., & Barker, R. (2009). Collaborative learning as part of adaptive management of forests affected by deer. In C. Allan & G. Stansky (Eds.), *Adaptive environmental management: A practitioner's guide* (pp. 275–294). Dordrecht: Springer Science and Business Media.

Jahn, G. C., Sophea, P., Bunnarith, K., & Chanthy, P. (1997). Pest management practices of lowland rice farmers in Cambodia. In K. L. Heong & M. M. Escalada (Eds.), *Pest Management of Rice Farmers in Asia* (pp. 35–51). Manila, Philippines: International Rice Research Institute.

Jahn, G. L., Litsinger, J. A., Chen, Y., & Barrion, A. T. (2007). Integrated pest management of rice: ecological concepts. In O. Koul, G. W. Cuperus, E. W. Cuperus, & M. A. Hill (Eds.), *Ecologically Based Integrated Pest Management* (pp. 315–366). Wallingford: CAB International.

Jahn, T., Bergmann, M., & Keil, F. (2012). Transdisciplinarity: Between mainstreaming and marginalization. *Ecological economics*, *79*, 1–10.

Jansen, K. (1998). *Political ecology, mountain agriculture, and knowledge in Honduras*. Amsterdam: Thela Publishers.

Jeffries, M. J., & Lawton, J. H. (1984). Enemy free space and the structure of ecological communities. *Biological Journal of the Linnean Society*, *23*, 269–286.

Jena, M., Adak, T., Rath, P. C., Gowda, G. B., Patil, N. B., Prasanthi, G., & Mohapatra, S. D. (2018). Paradigm shift of insect pests in rice ecosystem and their management strategy. *ORYZA–An International Journal on Rice*, *55*, 82–89.

Jepsen, J. U., Hagen, S. B., Ims, R. A., & Yoccoz, N. G. (2008). Climate change and outbreaks of the geometrids *Operophtera brumata* and *Epirrita autumnata* in subarctic birch forest: Evidence of a recent outbreak range expansion. *Journal of Animal Ecology*, *77*(2), 257–264.

Jervis, M. A., Hawkins, B. A., & Kidd, N. A. (1996). The usefulness of destructive host feeding parasitoids in classical biological control: Theory and observation conflict. *Ecological Entomology*, *21*(1), 41–46.

Johnson, L. K. (1983). *Apiomerus pictipes*. In D.H. Janzen (Ed.), *Costa Rican natural history* (pp. 684–687). University of Chicago Press.

Johnson, M. T., & Stinchcombe, J. R. (2007). An emerging synthesis between community ecology and evolutionary biology. *Trends in Ecology & Evolution*, *22*(5), 250–257.

Johnson, N. F., Chen, H., & Huber, B. A. (2018). New species of *Idris* Förster (Hymenoptera, Platygastroidea) from Southeast Asia, parasitoids of the eggs of pholcid spiders (Araneae, Pholcidae). *ZooKeys, 811*, 65–80.

Johnson, S. D. (1992). Climatic and phylogenetic determinants of flowering seasonality in the Cape flora. *Journal of Ecology*, *81*, 567–572.

Jonathan, J. K. (2006). *Ichneumonologia Indica, Hymenoptera: Ichneumonidae*. Kolkata, India: Zoological Survey of India.

Jones, D. L., & Miller, J. H. (1959). Pathology of the dermatitis produced by the urticating caterpillar, Automeris io. *AMA Archives of Dermatology*, *79*(1), 81–85.

Jonsson, M., Wratten, S. D., Robinson, K. A., & Sam, S. A. (2009). The impact of floral resources and omnivory on a four trophic level food web. *Bulletin of Entomological Research*, *99*(3), 275–285.

Joseph, K. J., Narendran, T. C., & Joy, P. J. (1973). Oriental *Brachymeria*: A monograph on the oriental species of *Brachymeria*. *Zoology Monograph*, *1*, 7–215.

Joshi, B. G., & Rao, R. S. N. (1980). Biological control of pests of tobacco. In *Proceedings of the 3rd workshop of the All-India coordinated project on biological control of crop pests and weeds* (pp. 81–88). Punjab Agricultural University, Project Directorate of Biological Control, Bengaluru.

Kajita, H. (1973). Rearing of *Apanteles chilonis* Munakata on rice stem borer *Chilo suppressalis* Walker on a semi artificial diet. *Japanese Journal of Applied Entomology and Zoology*, *17*(1), 5–9.

Kallyadan, A., & Nasser, M. (2024). Making shelter for enemies: parasitoid-induced shelter-building behaviour in *Parapoynx stagnalis*. *Journal of Natural History*, *58*(21–24), 658–673.

Kamal, N. Q., & Dyck, V. A. (1992). Biology of *Goniozu*s nr. *indicus* (Bethylidae: Hymenoptera. *Bangladesh Journal of Entomology*, *2*, 9–12.

Kanagarajan, R., & Manickavasagam, S. (2007). Diversity and status of chalcidids (Chalcididae: Hymenoptera) in agroecosystems. *Plant Archives*, *7*(2), 661–663.

Kannan, K. P., & Pushpangadan, K. (1990). Dissecting agricultural stagnation in Kerala: An analysis across crops, seasons and regions. *Economic and Political Weekly, 25*(35/36), 1991–2004.

Karieva, P. (1990). Establishing a foothold for theory in biological control practice: using models to guide experimental design and release protocols. In R. R. Baker & P. E. Dunn (Eds.), *New Directions in Biological Control* (pp. 65-81). New York: Alan R. Liss.

Karp, D. S., Chaplin-Kramer, R., Meehan, T. D., Martin, E. A., DeClerck, F., Grab, H., ... & Wickens, J. B. (2018). Crop pests and predators exhibit inconsistent responses to surrounding landscape composition. *Proceedings of the National Academy of Sciences, 115*(33), 7863–7870.

Karthikeyan, K., & Jacob, S. (2010). *Pseudomonas flourescens* and *Heterorhabditis indica* Poinar for the management of major insect pests of rice. *Journal of Biopesticides*, *3*(1), 96–99.

Karthikeyan, K., Sosamma, J., & Purushothaman, S. M. (2007). Field evaluation of egg parasitoids, *Trichogramma japonicum* Ashmead and *Trichogramma chilonis* Ishii, against rice yellow stem borer and leaf folder. *Journal of Biological Control*, *21*(2), 261–265.

Karuppaiah, V., & Sujayanad, G. K. (2012). Impact of climate change on population dynamics of insect pests. *World Journal of Agricultural Sciences*, *8*, 240–246.

Katayama, N. (2016). Bird diversity and abundance in organic and conventional apple orchards in northern Japan. *Scientific Reports*, *6*(1), 34210.

Katayama, N., Osada, Y., Mashiko, M., Baba, Y. G., Tanaka, K., Kusumoto, Y., Okubo, S., Ikeda, H., & Natuhara, Y. (2019). Organic farming and associated management practices benefit multiple wildlife taxa: A large-scale field study in rice paddy landscapes. *Journal of Applied Ecology*, *56*(8), 1970–1981.

Katsumata, S., Toshima, H., & Hasegawa, M. (2018). Xylosylated detoxification of the rice flavonoid phytoalexin sakuranetin by the rice sheath blight fungus *Rhizoctonia solani*. *Molecules*, *23*(2), 276.

Kaur, S., Shenhmar, M., & Brar, K. S. (2000). Parasitoids of insect pests of rice in the Punjab. *Insect Environment*, *6*(2), 82–83.

Kaur, T., Brar, B. S., & Dhillon, N. S. (2008). Soil organic matter dynamics as affected by long-term use of organic and inorganic fertilizers under maize–wheat cropping system. *Nutrient Cycling in Agroecosystems*, *81*, 59–69.

Kaur. R., & Brar, K. S. (2008). Evaluation of different doses of *Trichogramma* species for the management of leaf folder and stem borer on Basmati rice. *Journal of Biological Control*, *22*(1), 131–135.

Kawazu, K., Suzuki, Y., Yoshiyasu, Y., Castillon, E. B., Ono, H., Vuong, P. T., Huang, F. K., Adati, T., Fukumoto, T., & Tatsuki, S. (2005). Attraction of *Cnaphalocrocis medinalis* (Lepidoptera: Crambidae) males in Southeast Asia to female sex pheromone traps: Field tests in southernmost China, northern Vietnam and southern Philippines with three synthetic pheromone blends regarding geographic variations. *Applied Entomology and Zoology*, *40*(3), 483–488.

Kemp, W. P., & Simmons, G. A. (1978). The influence of stand factors on parasitism of spruce budworm eggs by *Trichogramma minutum*. *Environmental Entomology*, *7*(5), 685–688.

Kenis, M., Plessis, H., Berg, J., Ba, M. N., Goergen, G., Kwadjo, K. E., Baoua, I., Tefera, T., Buddie, A., Cafà, G., Offord, L., Rwomushana, I., & Polaszek, A. (2019).

Telenomus remus, a candidate parasitoid for the biological control of *Spodoptera frugiperda* in Africa, is already present on the continent. *Insects*, *10*(4), 92.

Kenmore, P. E., Heong, K. L., & Putter, C. A. J. (1985). Political, social and perceptual aspects of integrated pest management programs. In *Proceedings of the Seminar on Integrated Pest Management in Malaysia* (pp. 47–69). Kuala Lumpur: MAPPS.

Kenmore, P. E., Litsinger, J. A., Bandong, J. P., Santiago, A. C., & Salac, M. M. (1987). Philippine rice farmers and insecticides: thirty years of growing dependency and new options for change. In J. Tait & B. Napompeth (Eds.), *Management of pests and pesticides* (pp. 98–109). Boulder: Westview.

Kennard, C. P. (1965). Pests and diseases of rice in British Guiana and their control. *Plant Protection Bulletin*, *13*(4), 73–78.

Kephart, C. F. (1914). The poison glands of the larva of the brown-tail moth (*Euproctis chrysorrhoea* Linn). *The Journal of Parasitology*, *1*(2), 95–103.

Kerala Agricultural University (KAU). (2018). *Wayanadan Nellinangal: Directory of farmers conserving traditional rice varieties*. Government of Kerala, Department of Agricultural Development and Farmers Welfare – Kerala Agricultural University.

Kerala Soil Health Information System (KSHIS). (2019). *Agro ecology*. Department of Agriculture, Government of Kerala. Retrieved from https://keralasoilfertility.net/en/agroecology.jsp. Accessed May 25, 2020.

Khan, M. M. H., & Alam, M. I. (2007). Influence of management practices and growth stages of rice on the abundance and diversity of insect pests and natural enemies. *Annals of Bangladesh Agriculture, 11*(2), 21–32.

Khatam, A., Muhammad, S., Chaudhry, K. M., Mann, A. H., Haq, I., Khan, Z. U., & Amin, H. (2010). Strengths and weaknesses of Farmers' Field Schools approach as perceived by farmers. *Sarhad Journal of Agriculture*, *26*(26), 685–688.

Khoshoo, T. N. (1994). India's biodiversity: Tasks ahead. *Current Science*, *67*(8), 577–582.

Khush, G. S. (1995). Breaking the yield frontier of rice. *GeoJournal*, *35*, 329–332.

Khush, G. S. (1997). Origin, dispersal, cultivation and variation of rice. *Plant Molecular Biology*, *35*, 25–34.

Khush, G. S. (2002). The promise of biotechnology in addressing current nutritional problems in developing countries. *Food and Nutrition Bulletin*, *23*(4), 354–357.

Khush, G. S. (2005). What it will take to feed 5.0 billion rice consumers in 2030. *Plant Molecular Biology*, *59*, 1–6.

Khush, G. S., & Virmani, S. S. (1985). Breeding rice for disease resistance. *Progress in plant breeding*, *1*, 239–279.

Kim, H., Heinrichs, E., & Mylvaganam, P. (1986). Egg Parasitism of *Scirpophaga incertulas* Walker (Lepidoptera: Pyralidae) by Hymenopterous Parasitoids in IRRI Rice Fields. *한국식물보호학회지*, *25*(1), 37–40.

Kingston, R., Carver, S., Evans, A., & Turton, I. (2000). Web-based public participation geographical information systems: An aid to local environmental decision-making. *Computers, Environment and Urban Systems*, *24*(2), 109–125.

Kiritani, K. (1979). Pest management in rice. *Annual Review of Entomology*, *24*(1), 279–312.

Kiritani, K. (2006). Predicting impacts of global warming on population dynamics and distribution of arthropods in Japan. *Population Ecology*, *48*(1), 5–12.

Kisimoto, R., & Dyck, V. A. (1976). Climate and rice insects. In *Proceedings of the Symposium on Climate and Rice* (pp. 361–391). Los Baños, Philippines: International Rice Research Institute.

Kitamura, K. (1988). Comparative studies on the biology of Dryinid wasps in Japan: 5) Development and reproductive capacity of hosts attacked by *Haplogonatopus apicalis* (Hymenoptera, Dryinidae) and the development of progenies of the parasites in their hosts. *Japanese Journal of Entomology, 56*, 659–666.

Kitching, I. J., Rawlins, J. E., & Kristensen, N. P. (1998). Lepidoptera, moths and butterflies. *Evolution, Systematics, and Biogeography, Handbook for Zoology*, *4*, 355–401.

Ko, K., Liu, Y., Hou, M., Babendreier, D., Zhang, F., & Song, K. (2014). Evaluation for potential *Trichogramma* (Hymenoptera: Trichogrammatidae) strains for control of the striped stem borer (Lepidoptera: Crambidae) in the Greater Mekong Subregion. *Journal of Economic Entomology*, *107*(3), 955–963.

Kobayashi, M., & Wada, T. (1979). Hymenopterous parasites of the rice leaf roller, *Cnaphalocrocis medinalis* Guenee, and their activities observed in the paddy fields of Chikugo. *Proceedings of the Association for Plant Protection of Kyushu*, *25*, 64–66.

Kobayashi, M., Nugaliyadde, L., & Kudagamage, C. (1990). Natural enemies of the rice gall midge, *Orseolia oryzae* (Wood-Mason) observed in yala season in Sri Lanka. *Japan Agricultural Research Quarterly*, *23*(4), 323–328.

Kobayashi, M., Nugaliyadde, L., & Kudagamage, C. (1995). Distribution of *Opheonia indica*, a predator of rice gall midge in paddy fields of Sri Lanka. *Japan Agricultural Research Quarterly*, *29*, 89–91.

Koch, J. B., & General, D. E. M. (2019). A preliminary assessment of bumble bee (Hymenoptera: Apidae) habitat suitability across protected and unprotected areas in the Philippines. *Annals of the Entomological Society of America*, *112*(1), 44–49.

Kogan, M. (1998). Integrated pest management: Historical perspectives and contemporary developments. *Annual Review of Entomology*, *43*(1), 243–270.

Kondo, T. (1917). The two- and three-brooded rice borers. Nagasaki Agricultural Experiment Station [Extra Report No. 18, 103 pp., in Japanese]. *Review of Applied Entomology, Series A-1916, 8*, 234–236.

Koskinen, J., Leinonen, U., Vollrath, A., Ortmann, A., Lindquist, E., d'Annunzio, R., & Käyhkö, N. (2019). Participatory mapping of forest plantations with Open Foris and

Google Earth Engine. *ISPRS Journal of Photogrammetry and Remote Sensing*, *148*, 63–74.

Krishnaiah, K., & Varma, N. (2011). *Changing Insect Pest Scenario in the Rice Ecosystem—A National Perspective*. Directorate of Rice Research, Rejendranagar: Hyderabad, India.

Krishnamurthy, K. S. (1991). *The Wealth of Susruta*. International Institute of Ayurveda. Coimbatore, Tamil Nadu, India.

Krishnankutty, J., Raju, R. K., Blakeney, M., & Siddique, K. H. (2021). Is traditional rice reviving? An exploratory study in Kerala, India. *International Journal of Agricultural Resources, Governance and Ecology*, *17*(1), 15–37.

Kumar, A. D., & Reddy, D. N. (2021). The Pesticide Management Bill 2020. *Current Science*, *121*(3), 348.

Kumar, A., Gopi, G., & Prajeesh, P. (2010). Genetic erosion and degradation of ecosystem services in wetland rice fields: A case study from Western Ghats, India. In L. Stewart & C. David (Eds.), *Agriculture, Biodiversity and Markets: Livelihoods and Agroecology in Comparative Perspective* (pp. 137–156). London: Earthscan.

Kumar, D., & Srinath, P. (2011). Climate Trends in Wayanad: Voices from the Community. In *UGC sponsored conference on 'Recent Trends in Climate & Impact of Climate Change on South-West India'* at the St. Joseph's College, Devagiri, Kozhikode, Kerala.

Kumar, K., Gupta, S. C., Baidoo, S. K., Chander, Y., & Rosen, C. J. (2005). Antibiotic uptake by plants from soil fertilized with animal manure. *Journal of Environmental Quality*, *34*(6), 2082–2085.

Kumar, S. M., C., S. P., & Venugopal, M. S. (1995). Effect of pesticides on the rice gall midge parasitoid Platygaster oryzae Cameron. *Agricultural Science Digest*, *15*(3), 1–103.

Kumar, S., & Stohlgren, T. J. (2009). Maxent modeling for predicting suitable habitat for threatened and endangered tree *Canacomyrica monticola* in New Caledonia. *Journal of Ecology and Natural Environment*, *1*(4), 94–98.

Kumar, T. T. (1988). *History of Rice in India: Mythology, Culture and Agriculture*. Delhi, India: Gian Publishing.

Kunkel, K. E., Andsager, K., & Easterling, D. R. (1999a). Long-term trends in extreme precipitation events over the conterminous United States and Canada. *Journal of Climate*, *12*(8), 2515–2527.

Kunkel, K. E., Pielke, R. A., & Changnon, S. A. (1999b). Temporal fluctuations in weather and climate extremes that cause economic and human health impacts: A review. *Bulletin of the American Meteorological Society*, *80*(6), 1077–1098.

Kureha, S., Kobayashi, S., Asari, S., & Ishihara, T. (1974). Life history and control of mole cricket, *Gryllotalpa africana* Polisot de Beauvois. *Proceedings of the Kanto Tosan Plant Protection Society*, *21*, 192–197.

Kwon, Y. S., Chung, N., Bae, M. J., Li, F., Chon, T. S., & Park, Y. S. (2012). Effects of meteorological factors and global warming on rice insect pests in Korea. *Journal of Asia-Pacific Entomology*, *15*(3), 507–515.

Kyttä, M., & Kahila, M. (2006). *PehmoGIS elinympäristön koetun laadun kartoittajana [SoftGIS Methodology in Revealing the Localized Experiences of Living Environment]*. Helsinki, Finland: Helsinki University of Technology, Centre for Urban and Regional Studies, Publication B 90, Otamedia, Espoo.

Lakra, V., Singh, M. K., Sinha, R., & Kudada, N. (2010). Indigenous technology of tribal farmers in Jharkhand. *Indian Journal of Traditional Knowledge*, *9*(2), 261–263.

Landis, D. A., Wratten, S. D., & Gurr, G. M. (2000). Habitat management to conserve natural enemies of arthropod pests in agriculture. *Annual Review of Entomology*, *45*(1), 175–201.

Latha, M., Nizar, M. A., Abraham, Z., John, K. J., Nair, R. A., Mani, S., & Dutta, M. (2013). Rice landraces of Kerala State of India: A documentation. *International Journal of Biodiversity and Conservation*, *5*(4), 250–263.

Latif, P. H., & Wahab, K. H. (2007). Effect of integrated crop management on weed density, weed dry matter production and grain yield of wet seeded rice in Kuttanad, Kerala. *Plant Archives*, *7*, 725–727.

Lawton, J. H. (1986). The effect of parasitoids on phytophagous insect communities. In J. Waage & D. Greathead (Eds.), *Insect Parasitoids*. 13th Symposium of the Royal Entomological Society, London (pp. 265–287). London: Academic.

Lawton, J. H., MacGarvin, M., & Heads, P. A. (1987). Effects of altitude on the abundance and species richness of insect herbivores on bracken. *Journal of Animal Ecology, 56*, 147–160.

Le Roux, P. C., & McGeoch, M. A. (2008). Changes in climate extremes, variability and signature on sub-Antarctic Marion Island. *Climatic Change, 86*, 309–329.

Lederhouse, R. C. (1990). Avoiding the hunt: primary defences of lepidopteran caterpillars. In D. L. Evans & J. Schmidt (Eds.), *Insect Defences: Adaptive Mechanisms and Strategies of Prey and Predator* (pp. 175–189). Albany, U.S.A.: State University of New York Press.

Leung, H., Zhu, Y., Revilla–Molina, I., Fan, J. X., Chen, H., Pangga, I., Cruz, C. V., & Mew, T. W. (2003). Using genetic diversity to achieve sustainable rice disease management. *Plant Disease*, *87*(10), 1156–1169.

Li, B. C., & He, J. X. (1991). The investigation of fluctuation on numbers of three species of Mymaridae parasitising the eggs of planthoppers and their protection and utilization. *Natural Enemies of Insects*, *13*, 156–161.

Lill, J. T., & Marquis, R. J. (2007). Microhabitat manipulation: ecosystem engineering by shelter-building insects. In K. M. D. Cuddington, J. E. Byers, A. Hastings, & W. G. Wilson (Eds.), *Ecosystem Engineers: Concepts, Theory, and Applications in Ecology* (pp. 107–138). San Diego, CA: Elsevier Press.

Lim, G. S., & Heong, K. L. (1984). The role of insecticides in rice integrated pest management. In *Judicious and Efficient Use of Insecticides on Rice* (pp. 19–40).

Lin, N. Q. (1983). A preliminary report on a species of ephydrid fly, *Paralimna* sp. *Wuyi Science Journal*, *3*, 151–156.

Lin, P. A., Paudel, S., Lai, P. C., Gc, R. K., Yang, D. H., & Felton, G. W. (2023). Integrating water and insect pest management in agriculture. *Journal of Pest Science*, 97, 1–18.

Lindstedt, C., Lindström, L., & Mappes, J. (2008). Hairiness and warning colours as components of antipredator defence: Additive or interactive benefits? *Animal Behaviour*, *75*(5), 1703–1713.

Lingappa, S. (1972). Bionomics of the rice leaf-folder, *Cnapholocrocis medinalis* Guënee (Lepidoptera: Pyralidae). *Mysore Journal of Agricultural Sciences*, *6*(2), 123–134.

Litsinger, J. A. & Ruhendi. (1984). Rice stubble and straw mulch suppression of preflowering insect pests of cowpeas sown after puddled rice. *Environmental Entomology*, *13*, 509–514.

Litsinger, J. A. (1993). A farming systems approach to insect pest management for upland and lowland rice farmers in tropical Asia. In M. A. Altieri (Ed.), *Crop Protection Strategies for Subsistence Farmers* (pp. 45–101). Boulder, CO: Westview Press.

Litsinger, J. A. (1994). Cultural, morphological, and physical control of rice insects. In E. A. Heinrichs (Ed.), *Biology and management of rice insects* (pp. 549–584). New Delhi, India: Wiley Eastern Ltd

Litsinger, J. A., & Moody, K. (1976). Integrated pest management in multiple cropping systems. In R. I. Papendick, P. A. Sanchez, & G. B. Triplett (Eds.), *Multiple Cropping* (Special Publication No. 27, pp. 293–316). Madison, WI: American Society of Agronomy.

Litsinger, J. A., Canapi, B., & Alviola, A. (1982). Farmer perceptions and control of rice pests in Solana, Cagayan Valley, a pre-green revolution area of the Philippines. *Philippine Entomologist, 5*, 373–383.

Litsinger, J. A., Hasse, V., Barrion, A. T., & Schmutterer, H. (1991). Response of *Ostrinia furnacalis* (Guenée)(Lepidoptera: Pyralidae) to intercropping. *Environmental Entomology*, *20*(4), 988-1004.

Litsinger, J. A., Libetario, E. M., & Barrion, A. T. (2003). Early planting and overseeding in the cultural control of rice seedling maggot *Atherigona oryzae* Malloch in the Philippines. *International Journal of Pest Management*, *49*(1), 57–69.

Litsinger, J. A., Libetario, E. M., & Canapi, B. L. (2009). Eliciting farmer knowledge, attitudes, and practices in the development of Integrated Pest Management programs for rice in Asia. In R. Peshin & A. K. Dhawan (Eds.), *Integrated pest management: Dissemination and impact* (pp. 119–273). Dordrecht: Springer.

Litsinger, J. A., Price, E. C., & Herrera, R. T. (1980). Small farmer pest control practices for rainfed rice, corn, and grain legumes in three Philippine provinces. *Philippine Entomologist*, *4*(1–2), 65–68.

Liu, C., Berry, P. M., Dawson, T. P., & Pearson, R. G. (2005). Selecting thresholds of occurrence in the prediction of species distributions. *Ecography*, *28*(3), 385–393.

Li-Ying, L. (1982). Integrated rice insect pest control in the Guangdong Province of China. *Entomophaga*, *27*, 81–88.

Logan, J. A., Régnière, J., & Powell, J. A. (2003). Assessing the impacts of global warming on forest pest dynamics. *Frontiers in Ecology and the Environment*, *1*(3), 130–137.

Lohaus, K., Vidal, S., & Thies, C. (2013). Farming practices change food web structures in cereal aphid–parasitoid–hyperparasitoid communities. *Oecologia*, *171*, 249–259.

Lomelí-Flores, J. R., Barrera, J. F., & Bernal, J. S. (2010). Impacts of weather, shade cover and elevation on coffee leafminer *Leucoptera coffeella* (Lepidoptera: Lyonetiidae) population dynamics and natural enemies. *Crop Protection*, *29*(9), 1039–1048.

Lorenz, G. N., Bateman, N., Hardke, J., & Cato, A. (2018). Insect management in rice. In J. T. Hardke (Ed.), *Arkansas Rice Production Handbook* (pp. 145–168). University of Arkansas, Cooperative Extension Service Publication.

Lou, Y. G., Zhang, G. R., Zhang, W. Q., Hu, Y., & Zhang, J. (2014). Biological control of rice insect pests in China. *Biological Control*, *68*, 103–116.

Louis, T. L. (2018). *Biodiversity, agricultural productivity, and landscape context in organic vs conventional rice paddy wetlands in Kerala, India* (Doctoral dissertation, University of British Columbia).

Lyla, K. R., Beevi, S. P., Babu, M. P., & Jalali, S. K. (2010). Biological Control of Rice Pests in 'kole' Lands of Kerala. *Journal of Biological Control*, 24, 268–270.

Macfadyen, S., Craze, P. G., Polaszek, A., Achterberg, K., & Memmott, J. (2011). Parasitoid diversity reduces the variability in pest control services across time on farms. *Proceedings of the Royal Society B: Biological Sciences*, *278*(1723), 3387–3394.

Macfadyen, S., Gibson, R., Polaszek, A., Morris, R. J., Craze, P. G., Planqué, R., Symondson, W. O., & Memmott, J. (2009). Do differences in food web structure between organic and conventional farms affect the ecosystem service of pest control? *Ecology Letters*, *12*(3), 229–238.

Machado, G., & Freitas, A. V. (2001). Larval defence against ant predation in the butterfly *Smyrna blomfildia*. *Ecological Entomology*, *26*(4), 436–439.

Magallona, E. D. (1989). Effects of insecticides in rice ecosystems in Southeast Asia. In P. Bourdeau, J. A. Haines, W. Klein, & C. R. Krishna Murti (Eds.), *Ecotoxicology and climate* (pp. 265–297). New York: Wiley.

Magurran, A. E. (1988). *Ecological Diversity and Its Measurement*. Princeton: Princeton University Press.

Mahrub, E. (1993). YRSB egg parasitoid potential on different varieties in an IPM. *Imupertanian*, *5*(3), 645–656.

Majumdar, D., Deka, S. N., Pujari, D., & Das, P. K. (2013). Traditional knowledge adopted by the farmers for management of rice pests in North bank plain zone of Assam. *Indian Journal of Traditional Knowledge*, *12*, 725–729.

Makandi, H. (2008). Mapping land use patterns using remote sensing, GIS and participatory methods. In N. Käyhkö, M. Orjala, & J. Mustelin (Eds.), *Sustainable landscapes in Zanzibar* (Publicationes Instituti Geographici Universitatis Turkuensis A172, pp. 55–61).

Malek, M. A. (2010). Screening of some hybrid rice varieties for resistance against major insect pests (Doctoral dissertation, Department of Entomology, Sher-e-Bangla Agricultural University, Dhaka–1207).

Malicky, H. (1970). New aspects of the association between lycaenid larvae (Lycaenidae) and ants (Formicidae), Hymenoptera. *Journal of Lepidopteran Society*, *24*(3), 190–202.

Manas, G. (2003). Prevalence and performance of natural enemies of rice yellow stemborer, *Scirpophaga incertulas* Walker in the coastal-saline tract of West Bengal. In *Biological control of lepidopteran pests: Proceedings of the Symposium of Biological Control of Lepidopteran Pests* (pp. 291–293). Society for Biocontrol Advancement.

Mandal, R. (2014). Flood, cropping pattern choice and returns in agriculture: A study of Assam plains, India. *Economic Analysis and Policy*, *44*(3), 333–344.

Manilal, K. S. (1990). Ethnobotany of the rices of Malabar. In *Contribution to Indian Ethnobotany* (pp. 243–253). Calcutta: Botanical Survey of India.

Manisegaran, S., Letchoumanane, S., & Hanifa, A. M. (1997). Natural parasitism of rice leaf folder *Cnaphalocrocis medinalis* (Guenee) in Karaikal region. *Journal of Biological Control*, *11*, 73–75.

Manjunath, T. M. (1979). Recent records of natural enemies of brown planthopper in India. *International Rice Research Newsletter*, *4*(4), 20.

Manjunath, T. M., Rai, P. S., & Gavi, G. (1978). Natural enemies of brown planthopper and green leafhopper in India. *International Rice Research Newsletter*, *3*(2), 11.

Marciano, V. P., Mandac, A. M., & Flinn, J. C. (1981). Insect management practices of rice farmers in Laguna, Philippines. *Philippine Journal of Crop Science*, *6*(1/2), 14–20.

Margalef, R. D. (1958). Information theory in ecology. *General Systems*, *3*, 36–71.

Margles, S. W., Peterson, R. B., Ervin, J., & Kaplin, B. A. (2010). Conservation without borders: Building communication and action across disciplinary boundaries for effective conservation. *Environmental Management*, *45*, 1–4.

Martin-Pierra, F., & Lobo, J. M. (1993). Altitudinal distribution patterns of copronecrophage Scarabaeoidae in Veracruz, Mexico. *The Coleopterists Bulletin*, *47*, 321–334.

Mathur, K., Das, P., & Sasmal, S. (1989). *Eurytoma* species: New facultative hyperparasitoids on *Platygaster oryzae*. *Indian Journal of Agricultural Science*, *59*(3), 184–185.

Matteson, P. C. (2000). Insect pest management in tropical Asian irrigated rice. *Annual Review of Entomology*, *45*(1), 549–574.

Matteson, P. C., Altieri, M. A., & Gagné, W. C. (1984). Modification of small farmer practices for better pest management. *Annual Review of Entomology*, *29*(1), 383–402.

Matteson, P. C., Gallagher, K. D., & Kenmore, P. E. (1994). Extension of integrated pest management for planthoppers in Asian irrigated rice: Empowering the user. In R. F. Denno & T. J. Perfect (Eds.), *Planthoppers: Their Ecology and Management* (pp. 656–685). New York: Chapman and Hall.

Matthews, R. W. (1974). Biology of Braconidae. *Annual Review of Entomology*, *19*(1), 15–32.

Maunsell, S. C., Kitching, R. L., Burwell, C. J., & Morris, R. J. (2015). Changes in host–parasitoid food web structure with elevation. *Journal of Animal Ecology*, *84*(2), 353–363.

McFarland, C. D., & Hoy, M. A. (2001). Survival of *Diaphorina citri* (Homoptera: Psyllidae) and its two parasitoids, *Tamarixia radiata* (Hymenoptera: Eulophidae) and *Diaphorencyrtus aligarhensis* (Hymenoptera: Encyrtidae), under different relative humidities and temperature regimes. *Florida Entomologist, 84*, 227–233.

McFarland, N. (1988). *Portraits of South Australian Geometrid Moths*. Lawrence: Allen Press.

McIntyre, N., Yuan, M., Payne, R., & Moore, J. (2004). Development of a value-based approach to managing recreation on Canadian Crown Lands. In T. Sievenen, J. Errkonen, J. Saarinen, S. Tuulentie, & E. Virtanen (Eds.), *Proceedings of the second international conference on monitoring and management of visitor flows in recreation and protected areas* (pp. 291–299). Helsinki: Finnish Forest Research Institute.

McKinlay, R. G. (1985). Effect of undersowing potatoes with grass on potato aphid numbers. *Annals of Applied Biology*, *106*(1), 23–29.

McLaughlin, A., & Mineau, P. (1995). The impact of agricultural practices on biodiversity. *Agriculture, Ecosystems & Environment*, *55*(3), 201–212.

Meir, C. (2000). Learning and changing: Helping farmers move to natural pest control. In G. Stoll (Ed.), *Natural crop protection in the tropics: Letting information come to life* (pp. 265–279). Weikersheim, Germany: Margraf Verlag.

Memmott, J., & Godfray, H. C. J. (1994). The use and construction of parasitoid webs. In B. A. Hawkins & W. Sheehan (Eds.), *Parasitoid Community Ecology* (pp. 299–307). Oxford: Oxford University Press.

Memmott, J., Godfray, H. C. J., & Gauld, I. D. (1994). The structure of a tropical host-parasitoid community. *Journal of Animal Ecology, 63*, 521–540.

Menalled, F. D., Marino, P. C., Gage, S. H., & Landis, D. A. (1999). Does agricultural landscape structure affect parasitism and parasitoid diversity? *Ecological Applications*, *9*(2), 634–641.

Menon, P. L. D., Narendran, T. C., John, P., & Job, B. (2016). Distribution and diversity of Chalcidoidea (Hymenoptera) associated with rice ecosystem in Palakkad district of Kerala state. *International Journal of Entomology Research*, *1*(4), 6–9.

Messenger, P. S. (1968). Bioclimatic studies of the aphid parasite *Praon exsoletum*: I. effects of temperature on the functional response of females to varying host densities. *The Canadian Entomologist*, *100*(7), 728–741.

Messing, R. H., Klungness, L. M., & Jang, E. B. (1997). Effects of wind on movement of *Diachasmimorpha longicaudata*, a parasitoid of tephritid fruit flies, in a laboratory flight tunnel. *Entomologia Experimentalis et Applicata*, *82*(2), 147–152.

Michener, C. D. (1979). Biogeography of the bees. *Annals of the Missouri Botanical Garden, 66*(2), 277–347.

Midega, C. A., Nyang'au, I. M., Pittchar, J., Birkett, M. A., Pickett, J. A., Borges, M., & Khan, Z. R. (2012). Farmers' perceptions of cotton pests and their management in western Kenya. *Crop Protection*, *42*, 193–201.

Midi, H., & Bagheri, A. (2010). Robust multicollinearity diagnostic measure in collinear data set. In *Proceedings of the 4th International Conference on Applied Mathematics, Simulation, Modeling* (pp. 138–142). World Scientific and Engineering Academy and Society.

Miller, K., McAdam, M., & McAdam, R. (2014). The changing university business model: a stakeholder perspective. *R&D Management*, *44*(3), 265–287.

Miranda, M., Parrini, F., & Dalerum, F. (2013). A categorization of recent network approaches to analyse trophic interactions. *Methods in Ecology and Evolution*, *4*(10), 897–905.

Mishra, S. (2009). Farming system in Jeypore tract of Orissa, India. *Asian Agricultural History*, *13*(4), 271–292.

Mita, T., & Hong, T. P. (2014). Dryinidae collected from rice paddy in Vietnam (Hymenoptera: Chrysidoidea. *Japanese Journal of Systematic Entomology*, *20*(2), 245–246.

Mkenda, P. A., Ndakidemi, P. A., & Mbega, E. (2017). Potentials and challenges of natural pest control for sustainable legume production in Africa. *International Journal of Biosciences*, *10*(3), 357–373.

Mochida, O. M., Joshi, R. C., & Litsinger, J. A. (1987). Climatic factors affecting the occurrence of insect pests. In R. M. Welch, & G. D. Sherwood (Eds.), *Weather and Rice* (pp. 149–164). International Rice Research Institute, Los Baños.

Mohaupt, V., Völker, J., Altenburger, R., Birk, S., Kirst, I., Kühnel, D., Küster, E., Semerádová, S., Šubelj, G., & Whalley, C. (2020). *Pesticides in European rivers, lakes and groundwaters—Data assessment*. ETC/ICM. Magdeburg, Germany.

Mohyuddin, A. I. (1972). Distribution, biology and ecology of *Dentichasmias busseolae* Heinr. *Bulletin of Entomological Research*, *62*(2), 161–168.

Molofsky, J. (1994). Population dynamics and pattern formation in theoretical populations. *Ecology*, *75*(1), 30–39.

Montllor, C. B., & Bernays, E. A. (1993). Invertebrate predators and caterpillar foraging. In N. E. Stamp & T. M. Casey (Eds.), *Caterpillars: Ecological and evolutionary constraints on foraging* (pp. 170–202). Chapman & Hall.

Montoya, J. M., Rodríguez, M. A., & Hawkins, B. A. (2003). Food web complexity and higher-level ecosystem services. *Ecology Letters*, *6*(7), 587–593.

Moore, W., Profita, J., & Koehler, C. (1979). Soaps for home landscape insect control. *California Agriculture, 33*(6), 13–14.

Morales, H. (2002). Pest management in traditional tropical agroecosystems: Lessons for pest prevention research and extension. *Integrated Pest Management Reviews*, *7*, 145–163.

Mumford, J. D., & Norton, G. A. (1984). Economics of decision making in pest management. *Annual Review of Entomology*, *29*(1), 157–174.

Munyuli, T., Cihire, K., Rubabura, D., Mitima, K., Kalimba, Y., Tchombe, N., Mulangane, E. K., Birhashwira, O., Umoja, M., & Mukendi, R. T. (2017). Farmers′ perceptions, believes, knowledge and management practices of potato pests in South–Kivu Province, eastern of Democratic Republic of Congo. *Open Agriculture*, *2*(1), 362–385.

Muralikrishnan, L., Padaria, R. N., Dass, A., Choudhary, A. K., Kakade, B., Shokralla, S., El–Abedin, T. K. Z., Almutairi, K. F., & Elansary, H. O. (2021). Elucidating traditional rice varieties for consilient biotic and abiotic stress management under changing climate with landscape–level rice biodiversity. *Land*, *10*(10), 1058.

Murphy, S. M., Leahy, S. M., Williams, L. S., & Lill, J. T. (2010). Stinging spines protect slug caterpillars (Limacodidae) from multiple generalist predators. *Behavioral Ecology*, *21*(1), 153–160.

Murphy, S. M., Lill, J. T., Bowers, M. D., & Singer, M. S. (2014). Enemy-free space for parasitoids. *Environmental entomology*, *43*(6), 1465–1474.

Musolin, D. L. (2007). Insects in a warmer world: Ecological, physiological and life-history responses of true bugs (Heteroptera) to climate change. *Global Change Biology*, *13*(8), 1565–1585.

Musolin, D. L., & Fujisaki, K. (2006). Changes in ranges: Trends in distribution of true bugs (Heteroptera) under conditions of the current climate warming. *Russian Entomological Journal*, *15*(2), 175–179.

Muthayya, S., Sugimoto, J. D., Montgomery, S., & Maberly, G. F. (2014). An overview of global rice production, supply, trade, and consumption. *Annals of the New York Academy of Sciences*, *1324*(1), 7–14.

Nafukho, F. M., Amutabi, M. N., & Otunga, R. N. (2005). *Foundations of adult education in Africa*. Cape Town, South Africa: Pearson/UNESCO.

Nagenthirarajah, S., & Thiruchelvam, S. (2008). Knowledge of Farmers about Pest Management Practices in Pambaimadu, Vavuniya District: An Ordered Probit Model Approach. *Sabaramuwa University Journal*, *8*(1), 79–89.

Nageswara-Rao, P. P., Shobha, S. V., Ramesh, K. S., & Somashekhar, R. K. (2005). Satellite-based assessment of agricultural drought in Karnataka state. *Journal of the Indian Society of Remote Sensing*, *33*, 429–434.

Nair, C. G. (1911). *Wayanad- its peoples and traditions* (Vol. III). Madras, India: Government Press.

Nakadai, R. (2017). Species diversity of herbivorous insects: A brief review to bridge the gap between theories focusing on the generation and maintenance of diversity. *Ecological Research*, *32*(6), 811–819.

Nalini, T., & Manickavasagam, S. (2011). Field incidence of rice mealy bug *Brevennia rehi* (Lindinger) (Hemiptera: Pseudococcidae) and its gregarious parasitoid *Rhopus nigroclavatus* (Ashmead) (Hymenoptera: Encyrtidae). *Plant Archives*, *11*(2), 809–812.

Nambudiri, S. (2018). *Flood deposits rich in micro-nutrients*. The Times of India. Retrieved from https://timesofindia.indiatimes.com/city/kochi/flood-deposits-rich-in-micro-nutrients/articleshow/65802646.cms. Accessed September 12, 2020.

Narayanan, N. C. (2006). For and against grain land use: Politics of rice in Kerala, India. *International Journal of Rural Management*, *2*(1), 123–144.

Narayanasamy, P. (2006). Traditional knowledge of tribals in crop protection. *Indian Journal of Traditional Knowledge, 5*(1), 64–70.

Narendran, T. C. (1984). Key to Indian genera of the family Chalcididae [Hym.: Chalcidoidea]. *Entomophaga*, *29*, 431–438.

Narendran, T. C., & Fousi, K. (2002). A new genus and a new species of Eulophidae (Hymenoptera: Chalcidoidea) from the rice ecosystems of Central Kerala, India. *Journal of Ecobiology*, *14*(2), 137–141.

Narendran,T.C. (1994). *Torymidae and Eurytomidae of Indian subcontinent (Hymenoptera: Chalcidoidea*. Feroke, India: Printex.

Nazarea–Sandoval, V. D. (1991). Ethnoagronomy and ethnogastronomy: On indigenous typology and use of biological resources. *Agriculture and Human Values*, *8*, 121–131.

Nazarea–Sandoval, V. D., & Rhoades, R. E. (1994). Rice, reason, and resistance: A comparative study of farmers' vs. Scientists' perception and strategies. In R. S. Zeigler, S. A. Leong, & P. S. Ten (Eds.), *Rice Blast Disease* (pp. 559–575). Wallingford, UK: CAB International.

Nelder, J. A., & Wedderburn, R. W. (1972). Generalized linear models. *Journal of the Royal Statistical Society Series A: Statistics in Society*, *135*(3), 370–384.

Nelson, R., Coe, R., & Haussmann, B. I. (2019). Farmer research networks as a strategy for matching diverse options and contexts in smallholder agriculture. *Experimental Agriculture, 55*, 125–144

Nestel, D., Dickschen, F., & Altieri, M. A. (1994). Seasonal and spatial population loads of a tropical insect: The case of the coffee leaf- miner in Mexico. *Ecological Entomology*, *19*(2), 159–167.

Neuenschwander, P. (2004). Harnessing nature in Africa: Biological pest control can benefit the pocket, health and the environment. *Nature*, *432*, 801–802.

Newsom, L. D. (1980). The next rung up the integrated pest management ladder. *Bulletin of the ESA*, *26*(3), 369–374.

Nguyen, H., Lamb, D., Herbohn, J., & Firn, J. (2014). Designing mixed species tree plantations for the tropics: Balancing ecological attributes of species with landholder preferences in the Philippines. *PLoS One*, *9*(4), 95267.

Nieman, W. A., Wilkinson, A., & Leslie, A. J. (2020). Farmer attitudes and regional risk modelling of human–wildlife conflict on farmlands bordering the Boland Mountain Complex, South Africa. *African Journal of Wildlife Research*, *50*(1), 36–54.

NITI Ayog. (2016). *Strategy for New India*. Retrieved from https://www.niti.gov.in/sites/default/files/2019-01/Strategy_for_New_India_2.pdf. Accessed March 22, 2021.

Noble, W. A. (2019). Kerala. In *Encyclopedia Britannica*. Retrieved from https://www.britannica.com/place/Kerala. Accessed June 23, 2020.

Norton, G. A., & Heong, K. L. (1988). An approach to improving pest management: Rice in Malaysia. *Crop Protection*, *7*(2), 84–90.

Norton, G. A., & Mumford, J. D. (Eds.). (1993). *Decision tools for pest management*. CAB International.

Norton, G. W., Heong, K. L., Johnson, D., & Savary, S. (2010). Rice pest management: Issues and opportunities. In S. Pandey & D. Byerlee (Eds.), *Rice in the global economy: Strategic research and policy issues for food security* (pp. 297–332). International Rice Research Institute.

Novotny, V., & Basset, Y. (1998). Seasonality of sap-sucking insects (Auchenorrhyncha, Hemiptera) feeding on Ficus (Moraceae) in a lowland rain forest in New Guinea. *Oecologia*, *115*, 514–522.

Noyes, J. S. (2019). *Universal Chalcidoidea Database. World Wide Web electronic publication*. Retrieved from https://www.nhm.ac.uk/our-science/data/chalcidoids/database/. Accessed August 2, 2019.

Ntiri, E. S., Calatayud, P. A., Berg, J., & Le Ru, B. P. (2019). Spatio-temporal interactions between maize lepidopteran stemborer communities and possible implications from the recent invasion of *Spodoptera frugiperda* (Lepidoptera: Noctuidae) in Sub-Saharan Africa. *Environmental Entomology*, *48*(3), 573–582.

O'Hara, J. E., Henderson, S. J., & Wood, D. M. (2019). *Preliminary checklist of the Tachinidae of the world* (p. 681). Retrieved from http://www.nadsdiptera.org/Tach/WorldTachs/Checklist/Worldchecklist.html. Accessed 14 February 2020.

Oakley, P. (Ed.). (1991). *Projects with People: The Practice of Participation in Rural Development*. Geneva: International Labour Organization.

Odum, H. T. (1953). Factors controlling marine invasion into Florida fresh waters. *Bulletin of Marine Science*, *3*(2), 134–156.

Ohwaki, A. (2015). Ground arthropod communities in paddy fields during the dry period: Comparison between different farming methods. *Journal of Asia-Pacific Entomology*, *18*(3), 413–419.

Okonya, J. S., & Kroschel, J. (2016). Farmers' knowledge and perceptions of potato pests and their management in Uganda. *Journal of Agriculture and Rural Development in the Tropics and Subtropics (JARTS)*, *117*(1), 87–97.

Olmi, M. (1984). *A revision of the Dryinidae (Hymenoptera)*. *Memoirs of the American Entomological Institute, 37*, 1–1913.

Ooi, P. A. C. (1996). Experiences in educating rice farmers to understand biological control. *Entomophaga*, *41*(3–4), 375–385.

Ooi, P. A. C., & Shepard, B. M. (1994). Predators and parasitoids of rice insects. In E. A. Heinrichs (Ed.), *Biology and Management of Rice Insects* (pp. 613–656). Wiley Eastern Ltd., India and International Rice Research Institute, Manila, Philippines.

Ôtake, A. (1967). Studies on the egg parasites of the smaller brown planthopper *Laodelphax striatellus* (Fallen) (Hemiptera: Delphacidae): I. A device for assessing the parasitic activity, and the results obtained in 1966. *Bulletin of the Shikoku Agricultural Experiment Station*, *17*, 91–103.

Otake, A., Somasundaram, P. H., & Abeykoon, M. B. (1976). Studies on populations of *Sogatella furcifera* Horvath and *Nilaparvata lugens* Stål (Hemiptera: Delphacidae) and their parasites in Sri Lanka. *Applied Entomology and Zoology*, *11*(4), 284–294.

Ovawanda, E. A., Witjaksono, W., & Trisyono, Y. A. (2016). Insect biodiversity in organic and non-organic rice ecosystem in the District of Bantul. *Jurnal Perlindungan Tanaman Indonesia*, *20*(1), 15–21.

Paaijmans, K. P., Blanford, S., Bell, A. S., Blanford, J. I., Read, A. F., & Thomas, M. B. (2010). Influence of climate on malaria transmission depends on daily temperature variation. *Proceedings of the National Academy of Sciences*, *107*(34), 15135–15139.

Padmakumari, A. P., & Pasalu, I. C. (2005). Paspalidium midge, *Orseolia fluvialis*, and its parasitoids on rice. *Oryza*, *42*(2), 164–166.

Padmakumari, A. P., Katti, G., & Reddy, V. R. K. (2017). Aromatic rice as a trap crop for yellow stem borer management in rice. *Agriculture Update*, *12*, 1–8.

Pal, S., Mandal, R., Sarkar, I., Ghimiray, T. S., Sharma, B. R., Roy, A., et al. (2017). Species diversity and community structure of arthropod pests and predators in

flax, *Linum usitatissimum* L., from Darjeeling (India). *Brazilian Archives of Biology and Technology, 60*, 1–9.

Palis, F. G. (1998). Changing farmers' perceptions and practices: The case of insect pest control in central Luzon, Philippines. *Crop Protection*, *17*(7), 599–607.

Palis, F. G. (2006). The role of culture in farmer learning and technology adoption: A case study of farmer field schools among rice farmers in central Luzon, Philippines. *Agriculture and Human Values*, *23*, 491–500.

Palis, F. G., Morin, S., & Hossain, M. (2002). Social capital and diffusion of integrated pest management technology: A case study in Central Luzon, Philippines. In *Social Research Conference, CIAT, Cali, Columbia* (pp. 11–14).

Panda, S. K., Rout, S. D., Mishra, N., & Panda, T. (2011). Phytotherapy and traditional knowledge of tribal communities of Mayurbhanj district, Orissa, India. *Journal of Pharmacognosy and Phytotherapy*, *3*(7), 101–113.

Pandya, H. V., Shah, A. H., Patel, C. B., Purohit, M. S., & Rai, A. B. (1995). Study on egg parasitism of rice yellow stem borer in Gujarat. *Gujarat Agricultural University Research Journal*, *21*(1), 197–199.

Pantoja, A., & Fuxa, J. R. (1992). Prevalence of biotic control agents in the fall armyworm *Spodoptera frugiperda* (JE Smith) (Lepidoptera: Noctuidae). *Folia Entomológica Mexicana*, *84*, 79–84.

Park, C. G., Kim, H. Y., & Lee, J. H. (2010a). Parameter estimation for a temperature-dependent development model of *Thrips palmi* Karny (Thysanoptera: Thripidae). *Journal of Asia-Pacific Entomology*, *13*(2), 145–149.

Park, H. H., Cho, J. R., Park, C. G., Kim, K. H., Goh, H. G., & Lee, S. G. (2010b). The occurrence of rice leaf-folder *Cnaphalocrocis medinalis* Guenee (Lepidoptera: Crambidae) in Suwon and its response to insecticides. *Korean Journal of Applied Entomology*, *49*(3), 219–226.

Parmesan, C., & Yohe, G. (2003). A globally coherent fingerprint of climate change impacts across natural systems. *Nature*, *421*(6918), 37–42.

Parveen, S., & Nakagoshi, N. (2001). An analysis of pesticide use for rice pest management in Bangladesh. *Journal of International Development and Cooperation*, *8*(1), 107–126.

Patanakamjorn, S., & Pathak, M. D. (1967). Varietal resistance of rice to the Asiatic rice borer, *Chilo suppressalis* (Lepidoptera: Crambidae), and its association with various plant characters. *Annals of the Entomological Society of America*, *60*(2), 287–292.

Pathak, M. D. (1968). Ecology of common insect pests of rice. *Annual Review of Entomology*, *13*(1), 257–294.

Pathak, M. D., & Dhaliwal, G. S. (1981). *Trends and strategies for rice insect problems in tropical Asia.* IRRI Research Paper Series, International Rice Research Institute, Philippines.

Pathak, M. D., & Khan, Z. R. (1994). *Insect pests of rice.* Philippines: International Rice Research Institute.

Pathak, P. K., Agrora, B. R., & Lal, M. N. (1986). Rice gall midge (GM) in Tarai region of Uttar Pradesh. *International Rice Research Newsletter (Philippines)*, *18*(4), 38.

Pati, P., & Mathur, K. C. (1982). New records of parasitoids attaching rice leaf folder, *Cnaphalocrocis medinalis* Guënee, in India. *Current Science*, *51*(18), 904–905.

Patterson, D. T., Westbrook, J. K., Joyce, R. J. V., Lingren, P. D., & Rogasik, J. (1999). Weeds, insects, and diseases. *Climatic Change*, *43*(4), 711–727.

Pearson, R. G., Raxworthy, C. J., Nakamura, M., & Townsend Peterson, A. (2007). Predicting species distributions from small numbers of occurrence records: A test case using cryptic geckos in Madagascar. *Journal of Biogeography*, *34*(1), 102–117.

Péré, C., Jactel, H., & Kenis, M. (2013). Response of insect parasitism to elevation depends on host and parasitoid life-history strategies. *Biology Letters*, *9*(4), 20130028.

Perez-Alvarez, R., Nault, B. A., & Poveda, K. (2018). Contrasting effects of landscape composition on crop yield mediated by specialist herbivores. *Ecological Applications*, *28*(3), 842–853.

Perfect, T. J., & Cook, A. G. (1982). Diurnal periodicity of fight in some Delphacidae and Cicadellidae associated with rice. *Ecological Entomology*, *7*(3), 317–326.

Perrin, R. M. (1977). Pest management in multiple cropping systems. *Agro-Ecosystems*, *3*, 93–118.

Peshin, R., Kumar, J. V., & Kalra, R. (2009). Diffusion of innovation theory and integrated pest management. *Integrated Pest Management: Dissemination and Impact*, *2*, 1–29.

Peterson, A. T., Soberón, J., Pearson, R. G., Anderson, R. P., Martínez-Meyer, E., Nakamura, M., & Araújo, M. B. (2011). *Ecological Niches and Geographic Distributions* (MPB-49). Princeton: Princeton University Press.

Pfannenstiel, R. S., & Browning, H. W. (1995). Field evaluations of parasitoids of larval stalkborers against *Eoreuma loftini* (Lepidoptera: Pyralidae) in rice. *Journal of Entomological Science*, *30*(3), 406–414.

Phillips, S. J., Anderson, R. P., & Schapire, R. E. (2006). Maximum entropy modeling of species geographic distributions. *Ecological modelling*, *190*, 231–259.

Pickett, C. H., & Bugg, R. L. (Eds.). (1998). *Enhancing Biological Control: Habitat Management to Promote Natural Enemies of Agricultural Pests*. Berkeley: University of California Press.

Pielou, E. C. (1966). The measurement of diversity in different types of biological collections. *Journal of Theoretical Biology, 13*, 131–144.

Pillai, K. S., & Nair, M. R. G. K. (1979). Biology and habits of the rice case worm *Nymphula depunctalis* Guen in Kerala. *Entomon*, *4*(1), 13–16.

Pimentel, D. (2005). Environmental and economic costs of the application of pesticides primarily in the United States. *Environment, Development and Sustainability*, *7*, 229–252.

Pimm, S. L., Lawton, J. H., & Cohen, J. E. (1991). Food web patterns and their consequences. *Nature*, *350*(6320), 669–674.

Plummer, R., & Armitage, D. R. (2007). Charting the new territory of adaptive co-management: A Delphi study. *Ecology and Society, 12*(2), 10.

Podestá, G. P., Natenzon, C. E., Hidalgo, C., & Toranzo, F. R. (2013). Interdisciplinary production of knowledge with participation of stakeholders: A case study of a collaborative project on climate variability, human decisions and agricultural ecosystems in the Argentine Pampas. *Environmental Science & Policy*, *26*, 40–48.

Polaszek, A., Fitton, M. G., Bianchi, G., & Huddleston, T. (1994). The parasitoids of the African white rice borer, *Maliarpha separatella* Ragonot (Lepidoptera: Pyralidae). *Bulletin of Entomological Research*, *84*(1), 65–89.

Pontius, J., Dilts, R., & Bartlett, A. (Eds.). (2002). *From Farmer Field Schools to Community IPM: Ten Years of IPM Training in Asia*. FAO Regional Office, Bangkok, Thailand.

Poolprasert, P., & Jongjitvimol, T. (2014). Arthropod communities inhabiting organic rice agroecosystem. *International Conference on Agricultural, Ecological and Medical Sciences*, *29*(30), 1–5.

Porter, J. H., Parry, M. L., & Carter, T. R. (1991). The potential effects of climatic change on agricultural insect pests. *Agricultural and Forest Meteorology*, *57*(1–3), 221–240.

Porter, T. J., Pisaric, M. F., Field, R. D., Kokelj, S. V., Edwards, T. W., deMontigny, P., Healy, R., & LeGrande, A. N. (2014). Spring-summer temperatures since AD 1780 reconstructed from stable oxygen isotope ratios in white spruce tree-rings from the Mackenzie Delta, northwestern Canada. *Climate Dynamics*, *42*, 771–785.

Potineni, K., & Agarwal, R. K. (1984). Parasitization of gall midge by *Neanastatus grallarius* (Masi). *International Rice Research Newsletter, 9*(1), 27.

Poulin, R. (2010). Network analysis shining light on parasite ecology and diversity. *Trends in Parasitology*, *26*(10), 492–498.

Prabhakaran, P. V., & Tharemmal, A. (2019). Influence of water on Odonates in the paddy fields of Kannur district, Kerala. *International Journal of Advance Research, Ideas and Innovations in Technology*, *5*(4), 268–271.

Prakash, A., Rao, J., Berliner, J., Arup, M., Adak, T., Lenka, S., Singh, N. K., & Nayak, U. K. (2014). Emerging pest scenario in rice in India. *Journal of Applied Zoological Researches*, *25*(2), 179–181.

Prasad, S. S., Gupta, P. K., Singh, R. V., & Mishra, J. P. (2013). Susceptible rice cultivar as trap crop for management of *Scirpophaga incertulas* under semi deep water condition. *Annals of Plant Protection Sciences*, *21*(2), 421–423.

Premila, K. S. (2003). *Major predators in rice ecosystems and their potential in rice pest management* (Doctoral dissertation, Department of Agricultural Entomology, College of Agriculture, Vellayani, Kerala Agricultural University).

Press Trust of India (PTI). (2012, July 29). Traditional rice varieties vanishing in Kerala. *The Hindu Business Line*. Retrieved from https://www.thehindubusinessline.com/economy/agri-business/Traditional-rice-varietiesvanishing-in-KeralaStudy/article20476098.ece. Accessed May 14, 2020.

Pretty, J. N., Noble, A. D., Bossio, D., Dixon, J., Hine, R. E., de Vries, F., & Morison, J. I. L. (2006). Resource-conserving agriculture increases yields in developing countries. *Environmental Science & Technology, 40*(5), 1114–1119.

Price, L. L. (2001). Demystifying farmers' entomological and pest management knowledge: A methodology for assessing the impacts on knowledge from IPM-FFS and NES interventions. *Agriculture and Human Values*, 18, 153–176.

Price, L. L., & Gurung, A. B. (2006). Describing and measuring ethno–entomological knowledge of rice pests: Tradition and change among Asian rice farmers. *Environment, Development and Sustainability*, *8*, 507–517.

Price, P. W. (1991). The plant vigor hypothesis and herbivore attack. *Oikos, 62*(2), 244–251.

Prill-Brett, J. (1986). The Bontok: Traditional wet-rice and swidden cultivators of the Philippines. In G. G. Marten (Ed.), *Traditional agriculture in Southeast Asia: A human ecology perspective* (pp. 171–186). Boulder: Westview Press.

Priya, T. R., Nelson, A. R. L. E., Ravichandran, K., & Antony, U. (2019). Nutritional and functional properties of coloured rice varieties of South India: A review. *Journal of Ethnic Foods*, *1*(6), 1–11.

Proceedings: Animal Sciences, *91*, 165–176.

Pumariño, L., Sileshi, G. W., Gripenberg, S., Kaartinen, R., Barrios, E., Muchane, M. N., Midega, C., & Jonsson, M. (2015). Effects of agroforestry on pest, disease and weed control: A meta-analysis. *Basic and Applied Ecology*, *16*(7), 573–582.

Quicke, D. L. J. (2015). *The Braconid and Ichneumonid Parasitoid Wasps: Biology, Systematics, Evolution and Ecology*. Hoboken: Wiley-Blackwell Publishing Ltd.

Radhika, A. M., Thomas, K. J., Kuruvila, A., & Raju, R. K. (2018). Assessing the impact of geographical indications on well–being of rice farmers in Kerala. *International Journal of Intellectual Property Rights*, *9*(2), 1–11.

Rahman, S., Sharma, M. P., & Sahai, S. (2006). Nutritional and medicinal values of some indigenous rice varieties. *Indian Journal of Traditional Knowledge, 5*(4), 454–458.

Rahmann, G. (2011). Biodiversity and organic farming: What do we know? *Landbauforschung, 61*(3), 189–208.

Rajendram, G. F., & Devarajah, F. R. (1990). Survey of some rice insect pests and their predators in three districts of Sri Lanka. *Journal of the National Science Council of Sri Lanka*, *18*(1), 79–92.

Rajesh, K. M., Sinu, P. A., & Nasser, M. (2021). *Eleocharis dulcis* (Burm. F) as a promising trap plant for the biocontrol of rice white stem borer, *Scirpophaga innotata* (Walker). *Biological Control*, *160*, 104676.

Rajesh, K. M., Zeya, S. B., Ranjith, A. P., & Nasser, M. (2020). New distributional records of fairyflies (Hymenoptera: Chalcidoidea: Mymaridae) from rice-agroecosystems of Kerala. *Halteres*, *10*, 48–61.

Rajmohana, K. (2006). Studies on Proctotrupoidea and Platygastroidea (Hymenoptera: Insecta) of Kerala. *Memoirs Zoological Survey of India*, *2*(1), 1–53.

Rajmohana, K., & Nisha, M. S. (2013). *Telenomus oryzae* (Hymenoptera: Platygastridae), a new egg parasitoid of the rice black bug, *Scotinophara* (Heteroptera: Pentatomidae) from India. *Halteres*, *4*, 79–86.

Rajmohana, K., & Patra, S. (2019). Scelionidae and Platygastridae (Hymenoptera: Platygastroidea) of India. In *Indian Insects* (pp. 159-171). CRC Press.

Ramprasad, V., Krishnaprasad, G., & Manasi, S. (2003). *The path of rediscovery*. Bangalore: Green Foundation.

Ranjith, A. P., Rajesh, K. M., & Nasser, M. (2015a). Taxonomic studies on Oriental *Microplitis* Foerster (Hymenoptera: Braconidae, Microgastrinae) with description of two new species from South India. *Zootaxa*, *3963*(3), 369–415.

Ranjith, A. P., Veena, T., Rajesh, K. M., & Nasser, M. (2015b). Diversity, abundance and host-parasitoid association of Microgastrine (Hymenoptera: Braconidae) wasps in rice fields of Kerala. In *Proceedings of the National Workshop on the Identification of Bees, Wasps, Beetles and Bugs* (pp. 61–72).

Rao, C. S. (2019). Ecologically sustainable strategies for pest management. *Extension Digest*, *3*(1), 2–26.

Rao, C. S., Rao, N. V., & Razvi, S. A. (1983). Parasitism, a key factor in checking rice pest populations. *Entomon, 8*(1), 97–100.

Rao, V. N., & Behera, K. S. (1986). Biology of *Eupteromalus parnarae* Gahan, a hyperparasite of *Cardiochiles nigricollis* Cameroon (Hymenoptera: Pteromalidae). *Indian Journal of Agricultural Science*, *56*(5), 394–395.

Rao, V. P. (1963). *Survey for natural enemies of paddy pests*. U.S.P.L.480 Project. Central Insecticides Board and Registration Committee.

Rao, V. P. (1970). Aims, objectives and future of biological control of rice stem borers. *Mushi*, *44*(2), 11–14.

Rao, V. P. (1972). Rice stem borers and their natural enemies in India, Pakistan, Ceylon and Malaysia. *Mushi*, *45*, 7–23.

Rao, V. P., Chacko, M. J., Phalak, V. R., & Rao, H. D. (1970). Leaf-feeding caterpillars of paddy and their natural enemies in India. *Journal of the Bombay Natural History Society, 66*(3), 455–477.

Rapusas, H. R., Schiller, J. M., & Sengsoulivong, V. (1997). Pest management practices of rice farmers in the rainfed lowland environment of the Lao PDR. In K. L. Heong & M. M. Escalada (Eds.), *Pest Management of Rice Farmers in Asia* (pp. 99–114)., Los Baños: International Rice Research Institute.

Rath, G. C. (2006). *Tribal development in India: The contemporary debate*. New Delhi: Sage Publications.

Raveendran, V., Jayaprakash, A., & Mohandas, C. (1978). Cyst nematode infestation of rice in Kerala State, India. *International Rice Research Newsletter*, *3*(5), 15.

Reader, T., & Hochuli, D. F. (2003). Understanding gregariousness in a larval Lepidopteran: The roles of host plant, predation, and microclimate. *Ecological Entomology*, *28*(6), 729–737.

Reed, M., Evely, A., Cundill, G., Fazey, J., Glass, J., Lang, A., Newig, J., Parrish, B., Preett, C., Raymond, C., & Stringer, L. (2010). What is social learning? *Ecology and Society*, *15*(4).

Reichelderfer, K. H., & Bottrell, D. G. (1985). Evaluating the economic and sociological implications of agricultural pests and their control. *Crop Protection*, *4*(3), 281–297.

Reissig, W. H., Heinrichs, E. A., Litsinger, J. A., Moody, K., Fiedler, L., Mew, T. W., & Barrion, A. T. (1986). *Illustrated Guide to Integrated Pest Management in Rice in Tropical Asia*. Los Baños, Philippines: International Rice Research Institute.

Rekha, T., Martin, K. P., Sreekumar, V. B., & Madassery, J. (2011). Genetic diversity assessment of rarely cultivated traditional indica rice (*Oryza sativa* L.) varieties. *Biotechnology Research International, 2011*, 1–8.

Remmel, T., Davison, J., & Tammaru, T. (2011). Quantifying predation on folivorous insect larvae: The perspective of life-history evolution. *Biological Journal of the Linnean Society*, *104*(1), 1–18.

Ricklefs, R. E. (1987). Community diversity: Relative roles of local and regional processes. *Science*, *235*(4785), 167–171.

Risch, S. (1980). The population dynamics of several herbivorous beetles in a tropical agroecosystem: The effect of intercropping corn, beans and squash in Costa Rica. *Journal of Applied Ecology*, *17*(3), 593–611.

Risch, S. J., Andow, D., & Altieri, M. A. (1983). Agroecosystem diversity and pest control: Data, tentative conclusions, and new research directions. *Environmental Entomology*, *12*(3), 625–629.

Robinet, C., & Roques, A. (2010). Direct impacts of recent climate warming on insect populations. *Integrative Zoology*, *5*(2), 132–142.

Robinson, P., Genskow, K., Shaw, B., & Shepard, R. (2012). Barriers and opportunities for integrating social science into natural resource management: Lessons from national estuarine research reserves. *Environmental Management*, *50*, 998–1011.

Rocca, M., & Greco, N. M. (2015). Structure of the Tortricid–Parasitoid Community in a Recently Introduced Crop. *Neotropical Entomology*, *44*, 553–559.

Rocha, A. B., Lourenção, A. L., Miranda Filho, H. S., Hayashi, P. C., & Ramos, V. J. (2012). Resistência de clones de batata a *Bemisia tabaci* biótipo B. *Horticultura Brasileira*, *30*, 32–38.

Rogers, E. (1995). *Diffusion of Innovations* (4th ed.). New York, The Free Press.

Rola, A. C., Chupungco, A. R., Adalla, C. B., Hoque, M. M., Stuart, T. H., & Sumayao, B. R. (1988). *Results of the benchmark survey*. Integrated Pest Management Extension and Women Project. Los Baños, Laguna, Philippines.

Rola, A., & Pingali, P. (1993). *Pesticides, rice productivity, and farmers' health: An economic assessment*. Los Baños, Philippines: International Rice Research Institute.

Rola, A., Jamias, S., & Quizon, J. (2002). Do Farmer Field School Graduates Retain and Share What They Learn? An Investigation in Iloilo, Philippines. *Journal of International Agricultural and Extension Education*, *9*, 65–76.

Röling, N. G., & Fliert, E. (1998). Introducing integrated pest management in rice in Indonesia: A pioneering attempt to facilitate large–scale change. In S. Röling & M. A. E. Wagemakers (Eds.), *Facilitating Sustainable Agriculture: Participatory Learning and Adaptive Management in Times of Environmental Uncertainty* (pp. 153–171). Cambridge, UK: Cambridge University Press.

Röling, N. G., & Wagemakers, M. A. E. (Eds.). (1998). *Facilitating Sustainable Agriculture: Participatory Learning and Adaptive Management in Times of Environmental Uncertainty*. Cambridge, UK: Cambridge University Press.

Rooney, N., & McCann, K. S. (2012). Integrating food web diversity, structure and stability. *Trends in Ecology & Evolution*, *27*(1), 40–46.

Root, R. B. (1973). Organization of a plant-arthropod association in simple and diverse habitats: The fauna of collards (*Brassica oleracea*). *Ecological Monographs*, *43*(1), 95–124.

Roschewitz, I., Hücker, M., Tscharntke, T., & Thies, C. (2005). The influence of landscape context and farming practices on parasitism of cereal aphids. *Agriculture, Ecosystems & Environment*, *108*(3), 218–227.

Rosenzweig, C., Elliott, J., Deryng, D., Ruane, A. C., Müller, C., Arneth, A., Boote, K. J., Folberth, C., Glotter, M., Khabarov, N., Neumann, K., Piontek, F., Pugh, T. A. M., Schmid, E., Stehfest, E., Yang, H., & Jones, J. W. (2014). Assessing agricultural risks of climate change in the 21st century in a global gridded crop model intercomparison. *Proceedings of the National Academy of Sciences*, *111*(9), 3268–3273.

Rota, J., & Wagner, D. L. (2008). Wormholes, sensory nets and hypertrophied tactile setae: The extraordinary defence strategies of Brenthia caterpillars. *Animal Behaviour*, *76*(5), 1709–1713.

Rothfusz, L. P. (1990). *The heat index equation (or, more than you ever wanted to know about heat index)* (p. 9023). National Oceanic and Atmospheric Administration, National Weather Service, Office of Meteorology.

Rothschild, G. H. L. (1971). The biology and ecology of rice stem-borers in Sarawak (Malaysian Borneo). *Journal of Applied Ecology*, *8*, 287–322.

Rott, A. S., & Godfray, H. C. J. (2000). The structure of a leafminer parasitoid community. *Journal of Animal Ecology*, *69*, 274–289.

Rowntree, J. K., Cameron, D. D., & Preziosi, R. F. (2011). Genetic variation changes the interactions between the parasitic plant-ecosystem engineer *Rhinanthus* and its hosts. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *366*(1569), 1380–1388.

Rubia, E. G., Lazaro, A. A., Heong, K. L., & Norton, G. A. (1996). Farmers' perceptions of the white stem borer *Scirpophaga innotata* (Walker), in Cilamaya, West Java, Indonesia. *Crop Protection*, *15*(4), 327–333.

Rutsaert, P., Pieniak, Z., Regan, Á., McConnon, Á., & Verbeke, W. (2013). Consumer interest in receiving information through social media about the risks of pesticide residues. *Food Control*, *34*(2), 386–392.

Ruxton, G. D., & Sherratt, T. N. (2006). Aggregation, defence and warning signals: The evolutionary relationship. *Proceedings of the Royal Society B: Biological Sciences*, *273*(1600), 2417–2424.

Ryan, J., Ryan, M. F., & McNaeidhe, F. (1980). The effect of interrow plant cover on populations of cabbage rootfly, *Delia brassicae* (Wied.). *Journal of Applied Ecology*, *17*, 31–40.

Sabale, J. P., Das, C., & Samui, R. P. (2010). Influence of weather factors on light trap catches of green leaf hopper at Pattambi, Kerala. *Journal of Agrometeorology*, *12*(1), 108–110.

Sæthre, M. G., & Hofsvang, T. (2002). Effect of temperature on oviposition behavior, fecundity, and fertility in two northern European populations of the codling moth (Lepidoptera: Tortricidae. *Environmental Entomology*, *31*(5), 804–815.

Saito, T., Abe, D., & Sekiya, K. (2008). Sakuranetin induces adipogenesis of 3T3–L1 cells through enhanced expression of PPARγ2. *Biochemical and Biophysical Research Communications*, *372*(4), 835–839.

Salmah, M. C., Siregar, A. Z., Hassan, A., & Nasution, Z. (2017). Dynamics of aquatic organisms in a rice field ecosystem: Effects of seasons and cultivation phases on abundance and predator-prey interactions. *Tropical Ecology*, *58*, 177–191.

Sandre, S. L., Tammaru, T., & Maend, T. (2007). Size-dependent colouration in larvae of Orgyia antiqua (Lepidoptera: Lymantriidae): A trade-off between warning effect and detectability? *European Journal of Entomology*, *104*(4), 745–752.

Santhosh, S., & Karthikeyan, K. (2017). A new species of *Tetrastichus* Haliday (Hymenoptera: Eulophidae) parasitizing the rice case worm, *Parapoynx stagnalis* (Zeller) (Lepidoptera: Crambidae) from India. *Oriental Insects*, *51*(2), 160-165.

Santiago, J. O., & Buot, I. E., Jr. (2018). Assessing the status of pinuchu as an indicator of socio-ecological resilience of Chaya Socio-Ecological Production Landscape, Ifugao, Philippines. *Biodiversitas*, *19*(6), 2010–2019.

Sarawgi, A. K., & Bhisne, R. (2007). Studies on genetic divergence of aromatic rice germplasm for agro-morphological and quality characters. *Oryza*, *44*(1), 74–76.

Saseendran, S. A., Singh, K. K., Rathore, L. S., Singh, S. V., & Sinha, S. K. (2000). Effects of climate change on rice production in the tropical humid climate of Kerala, India. *Climatic Change*, *44*, 495–514.

Schiffer, E. (2007). Net-Map toolbox: Influence Mapping of Social Networks. Retrieved from https://netmap.files.wordpress.com/2008/04/netmap_manual.pdf. Accessed July 15, 2020.

Schiffer, E., & Hauck, J. (2010). Net–Map: Collecting social network data and facilitating network learning through participatory influence network mapping. *Field Methods*, *22*(3), 231–249.

Schmidt, G. T. (1974). Host-acceptance behavior of *Campoletis sonorensis* toward *Heliothis zea*. *Annals of the Entomological Society of America*, *67*(6), 835–844.

Schmidt, M. H., & Tscharntke, T. (2005). Landscape context of sheetweb spider (Araneae: Linyphiidae) abundance in cereal fields. *Journal of Biogeography*, *32*(3), 467–473.

Schmidt, M. H., Thies, C., Nentwig, W., & Tscharntke, T. (2008). Contrasting responses of arable spiders to the landscape matrix at different spatial scales. *Journal of Biogeography*, *35*(1), 157–166.

Schmidt, P., Stiefel, J., & Hürlimann, M. (1997). *Extension of complex issues: Success factors in integrated pest management*. St. Gallen, CH: Swiss Centre for Development Cooperation in Technology and Management.

Schoenly, K., Beaver, R. A., & Heumier, T. A. (1991). On the trophic relations of insects: A food-web approach. *The American Naturalist*, *137*(5), 597–638.

Schoenly, K., Cohen, J. E., Heong, K. L., & Litsinger, J. A. (1996). Food Web Dynamics of Irrigated Rice Fields at Five Elevations in Luzon, Philippines. *Bulletin of Entomological Research*, *86*(4), 451–466.

Schoonhoven, L. M., van Loon, J. J. A., & Jermy, T. (1998). *Insect-Plant Biology: From Physiology to Evolution*. Cheltenham, UK: Stanley Thornes.

Scott, J. (2000). *Social Network analysis: A handbook*. London: Sage.

Sebastian, M. K., & Azeez, P. (2014). *Ecological and Ethno-Cultural Examination of the Rise and Fall of Rice Culture in Southern India with Special Reference to the Western Ghats*. Coimbatore, India: Sálim Ali Centre for Ornithology and Natural History.

Segoli, M., & Rosenheim, J. A. (2012). Should increasing the field size of monocultural crops be expected to exacerbate pest damage? *Agriculture, Ecosystems & Environment*, *150*, 38–44.

Sgolastra, F., Fisogni, A., Quaranta, M., Bogo, G., Bortolotti, L., & Galloni, M. (2016). Temporal activity patterns in a flower visitor community of *Dictamnus albus* in relation to some biotic and abiotic factors. *Bulletin of Insectology*, *69*(2), 291–300.

Shah, F. M., Razaq, M., & Islam, Y. (2022). Contemporary Management of Insect Pests in Rice. In N. Sarwar, Atique-ur-Rehman, S. Ahmad, & M. Hasanuzzaman (Eds.), Modern Techniques of Rice Crop Production (pp. 349–376). Singapore: Springer publishers.

Shameer, K. S., Nasser, M., Mohan, C., & Hardy, I. C. (2018). Direct and indirect influences of intercrops on the coconut defoliator *Opisina arenosella*. *Journal of Pest Science*, *91*, 259–275.

Shannon, C. E., & Weaver, W. (1949). *The Mathematical Theory of Communication*. Urbana: University of Illinois Press.

Shao-Shi, L., Yu-Jie, G., Guo-Wen, H., & Di-Yun, L. (1997). Pest management practices of rice farmers in Hunan. In K. L. Heong & M. M. Escalada (Eds.), *Pest Management of Rice Farmers in Asia* (pp. 53–61). Los Baños: International Rice Research Institute.

Sharma, A., Shrestha, G., & Reddy, G. V. (2019). Trap crops: How far we are from using them in cereal crops? *Annals of the Entomological Society of America*, *112*(4), 330–339.

Sharma, S., Shera, P. S., & Sangha, K. S. (2020). Species composition of parasitoids and predators in two rice agro-farming systems—Effect of ecological intensification. *International Journal of Tropical Insect Science*, *40*, 233–238.

Sheela, M. S., Jiji, T., Nisha, M. S., & Joseph, R. (2005). A new record of *Meloidogyne graminicola* on rice, *Oryza sativa* in Kerala. *Indian Journal of Nematology*, *35*(2), 218.

Shen, X. C., Wang, K. Z., & Meng, G. (1988). The inoculative release of *Trichogramma dendrolimi* for controlling corn borer and rice leaf roller. *Colleques de l'INRA*, *43*, 575–580.

Shepard, R. N. (1974). Representation of structure in similarity data: Problems and prospects. *Psychometrika*, *39*, 373–421.

Sherif, M. R., Hendawy, A. S., & El-Habashy, M. M. (2008). Utilization of Trichogramma evanescens (Ashmead) for controlling rice stem borer, *Chilo agamemnon* Bles. in rice fields in Egypt. *Egyptian Journal of Biological Pest Control*, *18*(1), 11–16.

Shi, J., Li, J., Cook, E. R., Zhang, X., & Lu, H. (2012). Growth response of *Pinus tabulaeformis* to climate along an elevation gradient in the eastern Qinling Mountains, central China. *Climate Research*, *53*(2), 157–167.

Shmida, A., & Wilson, M. V. (1985). Biological Determinants of Species Diversity. *Journal of Biogeography*, *12*, 1–20.

Shrivastava, S. K., Shukla, B. C., Kittur, S. U., & Agrawal, R. K. (1987). Seasonal incidence of rice gall midge and its natural enemies in Madhya Pradesh, India. *International Journal of Pest Management*, *33*(1), 52–54.

Shurin, J. B., Gruner, D. S., & Hillebrand, H. (2006). All wet or dried up? Real differences between aquatic and terrestrial food webs. *Proceedings of the Royal Society B: Biological Sciences*, *273*(1582), 1–9.

Siddiq, E. A. (2000). Bridging the rice yield gap in India. In M. K. Papademetriou, F. J. Dent, & E. M. Herath (Eds.), *Bridging the rice yield gap in the Asia-Pacific region* (pp. 84–111). Food and Agriculture Organization.

Sileshi, G. (2006). Selecting the right statistical model for analysis of insect count data by using information theoretic measures. *Bulletin of Entomological Research*, *96*(5), 479–488.

Sileshi, G., Akinnifesi, F. K., Ajayi, O. C., & Place, F. (2008). Meta-analysis of maize yield response to woody and herbaceous legumes in sub-Saharan Africa. *Plant and Soil*, *307*, 1–19.

Sillén-Tullberg, B. (1988). Evolution of gregariousness in aposematic butterfly larvae: A phylogenetic analysis. *Evolution*, *42*(2), 293–305.

Silva, N. A. P., Frizzas, M. R., & Oliveira, C. M. (2011). Seasonality in insect abundance in the "Cerrado" of Goiás State, Brazil. *Revista Brasileira de Entomologia*, *55*(1), 79–87.

Singh, D., Agarwal, M., & Rizvi, S. M. A. (2011). Population dynamics of rice hopper complex and their natural enemies. *Insect Environment*, *16*(4), 168–170.

Singh, K. M., Jha, A., Meena, M., & Singh, R. (2012). Constraints of rainfed rice production in India: An overview. In P. K. Shetty, M. R. Hegde, & M. Mahadevappa (Eds.), *Innovations in rice production* (pp. 71–84). National Institute of Advanced Studies, Indian Institute of Science Campus.

Singh, P., Singh, P., & Singh, S. S. (2007). Response of aromatic rice (Pusa Basmati 1) to establishment methods, fertility levels and weed management practices. *Indian Journal of Weed Science*, *39*(1&2), 32-35.

Singh, R. K., Khush, G. S., Singh, U. S., Singh, A. K., & Singh, S. (2000). Breeding Aromatic Rice for High Yield, Improved Aroma and Grain Quality. In R. K. Singh, U. S. Singh, & G. S. Khush (Eds.), *Aromatic Rices* (pp. 71–105). New Delhi, India: Oxford and IBH Publishing Co. Pvt. Ltd.

Singh, R. P., & Rai, B. (2007). Effect of chemical fertilizers, organic manures, and soil amendments on production and economics of rice (*Oryza sativa*) wheat (*Triticum aestivum*) cropping system. *Research-on-Crops*, *8*(3), 530–532.

Singh, S. S. (1999). Studies on the occurrence of natural enemies of rice yellow stem borer. *Annals of Agricultural Research*, *20*(1), 125–126.

Sinha, B., Singha, R., & Choudhury, D. (2007). Ecological pest management for emerging pest problems. *LEISA Magazine*, 23(4), 11–12.

Sint, D., & Traugott, M. (2016). Food Web Designer: A flexible tool to visualize interaction networks. *Journal of Pest Science*, *89*(1), 1–5.

Sinzogan, A. A. C., Huis, A., Kossou, D. K., Jiggins, J., & Vodouhè, S. (2004). Farmers' knowledge and perception of cotton pests and pest control practices in Benin: Results of a diagnostic study. *NJAS-Wageningen Journal of Life Sciences*, *52*(3–4), 285–303.

Siregar, A. Z., & Matondang, I. R. (2017). Biodiversity insects used three traps of unpland rice fields in Simalungun District. *International Journal of Scientific & Technology Research*, *6*(2), 90–95.

Skamnioti, P., & Gurr, S. J. (2009). Against the grain: Safeguarding rice from rice blast disease. *Trends in Biotechnology*, *27*(3), 141–150.

Smith, J. G. (1976a). Influence of crop background on aphids and other phytophagous insects on Brussels sprouts. *Annals of Applied Biology*, *83*(1), 1–13.

Smith, J. G. (1976b). Influence of crop background on natural enemies of aphids on Brussels sprouts. *Annals of Applied Biology*, *83*(1), 15–29.

Smith, L. (1994). Temperature influences functional response of Anisopteromalus calandrae (Hymenoptera: Pteromalidae) parasitizing maize weevil larvae in shelled corn. *Annals of the Entomological Society of America*, *87*(6), 849–855.

Soam, S. K. (2005). Analysis of prospective geographical indications of India. *The Journal of World Intellectual Property*, *8*(5), 679–704.

Soroka, J., Bennett, A. M., Kora, C., & Schwarzfeld, M. D. (2020). Distribution of alfalfa weevil (Coleoptera: Curculionidae) and its parasitoids on the Canadian Prairies, with a key to described species of Nearctic Bathyplectes (Hymenoptera: Ichneumonidae. *The Canadian Entomologist*, *152*(5), 663–701.

Southwood, T. R. E., Wint, G. W., Kennedy, C. E., & Greenwood, S. R. (2004). Seasonality abundance, species richness and specificity of the phytophagous guild of insects on oak (Quercus) canopies. *European Journal of Entomology*, *101*(1), 43–50.

Stackhouse Jr, P. W., Gupta, S. K., Cox, S. J., Zhang, T., & Mikovitz, J. C. (2011). The NASA/GEWEX Surface Radiation Budget Release 3.0: 24.5-year dataset. *GEWEX News*, *21*, 10–12.

Stamp, N. E. (1984). Caterpillars *Euphydryas* spp. (Nymphalidae). *Journal of Research on the Lepidoptera*, *23*(1), 2–18.

Stamp, N. E., & Casey, T. M. (1993). *Caterpillars: Ecological and evolutionary constraints on foraging*. London: Chapman & Hall.

Stamp, N. E., & Wilkens, R. T. (1993). On the cryptic side of life: being unapparent to enemies and the consequences for foraging and growth of caterpillars. In N. E. Stamp & T. M. Casey (Eds.), *Caterpillars: Ecological and evolutionary constraints on foraging* (pp. 283–330). New York: Chapman & Hall Inc.

Stevenson, P. C., Kimmins, F. M., Grayer, R. J., & Raveendranath, S. (1996). Schaftosides from rice phloem as feeding inhibitors and resistance factors to brown planthoppers,

Nilaparvata lugens. *Proceedings of the 9th International Symposium on Insect–Plant Relationships*, *53*, 246–249.

Stireman, J. O. III, O'Hara, J. E., & Wood, D. M. (2006). Tachinidae: Evolution, behavior, and ecology. *Annual Review of Entomology*, *51*, 525–555.

Stireman, J. O., III, Dyer, L. A., Janzen, D. H., Singer, M. S., Lill, J. T., Marquis, R. J., Ricklefs, R. E., Gentry, G. L., Hallwachs, W., Coley, P. D., Barone, J. A., Greeney, H. F., Connahs, H., Barbosa, P., Morais, H. C., & Diniz, I. (2005). Climatic unpredictability and parasitism of caterpillars: Implications of global warming. *Proceedings of the National Academy of Sciences*, *102*(48), 17384–17387.

Storozheva, N. A. (1990). The parasitoid Anaphes. *Zashchita Rastenii Moskva*, *1*, 29.

Strong, D. R., Lawton, J. H., & Southwood, T. R. E. (1984). *Insects on Plants: Community Patterns and Mechanisms*. Oxford: Blackwell.

Subba-Rao, B. R., & Chawla, S. S. (1964). A catalogue of hymenopterous parasites of rice stem borers. *Indian Journal of Entomology*, *26*(3), 332–344.

Subba-Rao, B. R., & Hayat, M. (1986). The Chalcidoidea (Insecta: Hymenoptera) of India and the adjacent countries. Part II. A catalogue of Chalcidoidea of India and the adjacent countries. *Oriental Insects*, *20*, 1–430.

Sudhikumar, A. V. (2007). *Studies on the taxonomy and bionomics of some predacious spiders on insect pests of rice agroecosystem in Kuttanad, Kerala* (Doctoral dissertation, Mahatma Gandhi University).

Sudhikumar, A. V., Mathew, M. J., Sunish, E., & Sebastian, P. A. (2005). Seasonal variation in spider abundance in Kuttanad rice agroecosystem, Kerala, India (Araneae). *European Arachnology*, *1*, 181-190.

Sunderland, K. D., Powell, W., & Symondson, W. O. C. (2005). Populations and communities. In M. A. Jervis (Ed.), *Insects as natural enemies: A practical perspective* (pp. 299–524). Springer.

Sureshan, P. M. (2008). Pteromalinae (Pteromalidae: Chalcidoidea: Hymenoptera) of Indian Subcontinent. *Records of the Zoological Survey of India*, *205*, 1–170.

Suzuki, Y., Tho, T. H., Thuat, N. C., & Trang, V. B. (1994). Egg mortality factors of rice planthoppers in northern Vietnam. *Proceedings of the Association for Plant Protection of Kyushu (Japan)*, *40*, 90–93.

Swets, J. A. (1988). Measuring the accuracy of diagnostic systems. *Science*, *240*(4857), 1285–1293.

Swezey, O. H. (1940). A Survey of the Insect Pests of cultivated Plants in Guam. *Hawaiian Planters' Record*, *44*(3), 151–182.

Talukdar, A., Talukdar, N., Deka, S., & Sahariah, B. J. (2012). *Dillenia indica* (OUTENGA) as anti–diabetic herb found in Assam: A review. *International Journal of Pharmaceutical Sciences and Research*, *3*(8), 2482.

Tang, Y. L., Chen, K. W., & Xu, Z. F. (2010). Study on ontogenesis of *Telenomus remus* Nixon (Hymenoptera: Scelionidae. *Journal of Changjiang Vegetables*, *18*, 1–3.

Tautz, J., & Markl, H. (1978). Caterpillars detect flying wasps by hairs sensitive to airborne vibration. *Behavioral Ecology and Sociobiology*, *4*, 101–110.

Taylor, K. (2012). Landscape and meaning: Context for a global discourse on cultural landscape values. In K. Taylor & J. Lennon (Eds.), *Managing Cultural Landscapes* (pp. 21–44). Abingdon: Routledge.

Telayneh, G. (2010). *Major factors influencing farmers' participation in skill training program in Assosa Zone* (Master's thesis, Addis Ababa University).

Teo, T. (2011). Factors influencing teachers' intention to use technology: Model development and test. *Computers & Education*, *57*(4), 2432–2440.

The Times of India (TOI). (2020). *This is how different Indian states celebrate the harvest festival*. Retrieved from https://timesofindia.indiatimes.com/life-style/food-news/this-is-how-different-indian-states-celebrate-the-harvest-festival/photostory/73227443.cms?picid=73227650. Accessed March 12, 2020.

Theunissen, J. A. B. M., & Den Ouden, H. (1980). Effects of intercropping with Spergula arvensis on pests of Brussels sprouts. *Entomologia Experimentalis et Applicata*, *27*(3), 260–268.

Thies, C., Steffan-Dewenter, I., & Tscharntke, T. (2008). Interannual landscape changes influence plant–herbivore–parasitoid interactions. *Agriculture, Ecosystems & Environment*, *125*, 266–268.

Thomas, J. A., Elmes, G. W., Wardlaw, J. C., & Hochberg, M. E. (1998). Egg exposure and parasitism in the butterfly *Euphydryas aurinia* (Lepidoptera: Nymphalidae. *Oecologia*, *115*(4), 543–551.

Thompson, J. N. (2005). *The Geographic Mosaic of Coevolution*. Chicago: University of Chicago Press.

Thrupp, L. A. (2000). Linking agricultural biodiversity and food security: The valuable role of agrobiodiversity for sustainable agriculture. *International Affairs*, *76*(2), 265–281.

Thurston, H. D. (1990). Plant disease management practices of traditional farmers. *Plant Disease*, *74*(2), 96–102.

Thurston, H. D. (1998). Assessing indigenous and traditional knowledge in farming systems. In R.S. Zeigler, S.A. Leong, & P.S. Teng (Eds.), *Rice Blast Disease* (pp. 541–558). Wallingford, UK: CAB International.

Tilman, D., & Downing, J. A. (1994). Biodiversity and stability in grasslands. *Nature*, *367*(6461), 363–365.

Tindall, K. V., Bernhardt, J. L., Stout, M. J., & Beighley, D. H. (2013). Effect of depth of flooding on the rice water weevil, *Lissorhoptrus oryzophilus*, and yield of rice. *Journal of Insect Science*, *13*(1), 62.

Tiwari, N. K. (1972). *Tetrastichus fasciatus* Ashmead, a parasite of the gall midge *Bimba toombii* Grover. *Bollettino del Laboratorio di Entomologia Agraria "Filippo Silvestri" Portici*, *30*, 210–216.

Tjornhom, J. D., Heong, K. L., Gapud, V., Talekar, N. S., & Norton, G. W. (1997). Determinants of pesticide misuse in Philippine onion production. *Philippine Entomologist*, *1*(2), 139–149.

Toffoli, R., & Rughetti, M. (2017). Bat activity in rice paddies: Organic and conventional farms compared to unmanaged habitat. *Agriculture, Ecosystems & Environment*, *249*, 123–129.

Toledo, Á., & Burlingame, B. (2006). Biodiversity and nutrition: A common path toward global food security and sustainable development. *Journal of Food Composition and Analysis*, *19*(6–7), 477–483.

Tress, B., Tress, G., & Fry, G. (2005). Researchers' experiences, positive and negative, in integrative landscape projects. *Environmental Management*, *36*, 792–807.

Triapitsyn, S. V., Andreason, S. A., Power, N., Ganjisaffar, F., Fusu, L., Dominguez, C., & Perring, T. M. (2020). Two new species of *Ooencyrtus* (Hymenoptera, Encyrtidae), egg parasitoids of the bagrada bug *Bagrada hilaris* (Hemiptera, Pentatomidae), with taxonomic notes on *Ooencyrtus telenomicida*. *Journal of Hymenoptera Research*, *76*, 57–98.

Tscharntke, T., Tylianakis, J. M., Rand, T. A., Didham, R. K., Fahrig, L., Batáry, P., Bengtsson, J., Clough, Y., Crist, T. O., Dormann, C. F., Ewers, R. M., Fründ, J., Holt, R. D., Holzschuh, A., Klein, A. M., Kleijn, D., Kremen, C., Landis, D. A., Laurance, W., … Westphal, C. (2012). Landscape moderation of biodiversity patterns and processes- eight hypotheses. *Biological Reviews*, *87*(3), 661–685.

Tschorsnig, H. P. (2017). *Preliminary host catalogue of Palaearctic Tachinidae (Diptera)*. Retrieved from http://www.nadsdiptera.org/Tach/WorldTachs/CatPalHosts/Cat_Pal_tach_hosts_Ver1&2.pdf. Accessed January 02, 2020.

Tukahirwa, E. M., & Coaker, T. H. (1982). Effect of mixed cropping on some insect pests of brassicas; reduced *Brevicoryne brassicae* infestations and influences on epigeal predators and the disturbance of oviposition behaviour in *Delia brassicae*. *Entomologia Experimentalis et Applicata*, *32*(2), 129–140.

Tylianakis, J. M., Laliberté, E., Nielsen, A., & Bascompte, J. (2010). Conservation of species interaction networks. *Biological Conservation*, *143*(10), 2270–2279.

Tylianakis, J. M., Tscharntke, T., & Lewis, O. T. (2007). Habitat modification alters the structure of tropical host–parasitoid food webs. *Nature*, *445*(7124), 202–205.

Tyrväinen, L., Mäkinen, K., & Schipperijn, J. (2007). Tools for mapping social values of urban woodlands and other green areas. *Landscape and Urban Planning*, *79*(1), 5–19.

Uawisetwathana, U., Chevallier, O. P., & Xu, Y. (2019). Global metabolite profiles of rice brown planthopper–resistant traits reveal potential secondary metabolites for both constitutive and inducible defenses. *Metabolomics*, *15*, 151.

Ulina, E. S., Rizali, A., Manuwoto, S., Pudjianto, & Buchori, D. (2019). Does composition of tropical agricultural landscape affect parasitoid diversity and their host–parasitoid interactions? *Agricultural and Forest Entomology*, *21*(3), 318–325.

Umbanhowar, J., Maron, J., & Harrison, S. (2003). Density-dependent foraging behaviors in a parasitoid lead to density-dependent parasitism of its host. *Oecologia*, *137*, 123–130.

Uphoff, N. (2002). Changes and evolution in SRI methods. In N. Uphoff, E.C.M. Fernandes, L.P. Yuan, J.M. Peng, S. Rafaralahy, and J. Rabenandrasana (Eds.), *Assessment of the System for Rice Intensification* (pp. 8–14). Ithaca, NY, USA: Cornell International Institute for Food, Agriculture and Development,

Valladares, G. R., & Salvo, A. (1999). Insect–plant food webs could provide new clues for pest management. *Environmental Entomology*, *28*(4), 539–544.

Valladares, G. R., Salvo, A., & Godfray, H. C. J. (2001). Quantitative food webs of dipteran leafminers and their parasitoids in Argentina. *Ecological Research*, *16*, 925-939.

Valle, J. R., Picarelli, Z. P., & Prado, J. L. (1954). Histamine content and pharmacological properties of crude extracts from setae of urticating caterpillars. *Archives Internationales de Pharmacodynamie*, *98*, 324–334.

Van Achterberg, C. (1984). Essay on the phylogeny of Braconidae (Hymenoptera: Ichneumonoidea). *Entomologisk tidskrift*, *105*, 41–58.

van de Fliert, E., & Matteson, P. C. (1990). Rice integrated pest control training needs identified through a farmer survey in Sri Lanka. *Journal of Plant Protection in the Tropics, 7*(1), 15–26.

Van den Bosch, R., Messenger, P., & Gutierrez, A. (1982). *The history and development of biological control. In An introduction to biological control* (pp. 21–36). Boston, MA: Springer.

Van Emden, H. F. (1964). Effect of *(2-chloroethyl) trimethylammonium chloride* on the rate of increase of the cabbage aphid (*Brevicoryne brassicae* (L.)). *Nature, 201*(4922), 946–948.

Vanaja, T. (2013). Kaipad – A unique, naturally organic, saline prone rice ecosystem of Kerala, India. *American Journal of Environmental Protection*, *2*(2), 42–46.

Vanaja, T., Neema, V. P., Mammootty, K. P., Balakrishnan, P. C., & Naik, J. (2015). 'Ezhome-3' – A high yielding rice (*Oryza sativa* L.) variety for enhancing the varietal diversity of saline prone tidal farming ecosystem of Kerala. *International Journal of Tropical Agriculture*, *33*(4), 2489–2493.

Vanbergen, A. J., Aizen, M. A., Cordeau, S., Garibaldi, L. A., Garratt, M. P., Kovács–Hostyánszki, A., Lecuyer, L., Ngo, H. T., Potts, S. G., Settele, J., Skrimizea, E., & Young, J. C. (2020). Transformation of agricultural landscapes in the Anthropocene: Nature's contributions to people, agriculture and food security. In A. M. Annett (Ed.), *Advances in Ecological Research* (Vol. 63, pp. 193–253). Academic Press.

Vasconcellos, A., Andreazze, R., Almeida, A. M., Araujo, H. F., Oliveira, E. S., & Oliveira, U. (2010). Seasonality of insects in the semi-arid Caatinga of northeastern Brazil. *Revista Brasileira de Entomologia*, *54*, 471–476.

Vennila, S., Nisar, S., Kumar, M., Yadav, S. K., Paul, R. K., Rao, S. M., & Prabhakar, M. (2020). Impact of climate variability on species abundance of rice insect pests across agroclimatic zones of India. *Journal of Agrometeorology*, *22*, 60–67.

Verhagen, A. P., & Ferreira, M. L. (2014). Forest plots. *Journal of Physiotherapy*, *60*(3), 170–173.

Vijayalakshmi, K., Devi, T. D. N., Sridhar, S., & Arumugasamy, S. (2004). Organic paddy cultivation. *Centre for Indian Knowledge Systems*.

Voss, A., Denisovich, I., Gatalsky, P., Gavouchidis, K., Klotz, A., Roeder, S., & Voss, H. (2004). Evolution of a participatory GIS. *Computers, Environment and Urban Systems*, *28*(6), 635–651.

Voûte, A. D. (1946). Regulation of the density of insect populations in virgin forests and cultivated woods. *Archives Neerlandaises de Zoologie*, *7*(3), 435–470.

Vryzas, Z., Vassiliou, G., Alexoudis, C., & Papadopoulou-Mourkidou, E. (2009). Spatial and temporal distribution of pesticide residues in surface waters in northeastern Greece. *Water Research*, *43*(1), 1–10.

Waage, J. K. (1979). Foraging for patchily distributed hosts by the parasitoid, *Nemeritis canescens*. *The Journal of Animal Ecology*, 353–371.

Waage, J. K. (1983). Aggregation in field parasitoid populations: Foraging time allocation by a population of *Diadegma* (Hymenoptera, Ichneumonidae). *Ecological Entomology*, *8*(4), 447–453.

Waage, J. K., & Hassell, M. P. (1982). Parasitoids as biological control agents–a fundamental approach. *Parasitology*, *84*(4), 241–268.

Wada, T. (1979). Influence of temperature and the growing stages of the rice plant on the number of larval instars in the rice leaf roller, *Cnaphalocrocis medinalis* Guenée. *Japanese Journal of Applied Entomology and Zoology*, *23*, 178–182.

Wada, T., & Kobayashi, M. (1982). Mating status depending on the growing stage of the rice plant in the population of *Cnaphalocrocis medinalis* Guenée (Lepidoptera: Pyralidae). *Applied Entomology and Zoology*, *17*(2), 278–281.

Wada, T., Kobayashi, M., & Shimazu, M. (1980). Seasonal changes of the proportions of mated females in the field population of the rice leaf roller, *Cnaphalocrocis medinalis* Guenée (Lepidoptera, Pyralidae). *Applied Entomology and Zoology*, *15*(1), 81–89.

Wada, T., Watanabe, T., & Nik, M. N. (1991). Rice planthoppers and their natural enemies in paddy fields in the Muda area, West Malaysia. In *Research Highlights* (pp. 17–20). Tropical Research Center.

Wadsworth, Y. (1998). *What is participatory action research? Action Research International, Paper 2*. Retrieved from http://www.aral.com.au/ari/pywadsworth98.html. Accessed May, 24 2020.

Wagner, D. (2005). *Caterpillars of eastern North America: A guide to identification and natural history*. Princeton: Princeton University Press.

Wahl, D. B. (1993). Cladistics of the genera of Mesochorinae (Hymenoptera: Ichneumonidae. *Systematic Entomology*, *18*(4), 371–387.

Walde, S. J., & Murdoch, W. W. (1988). Spatial density dependence in parasitoids. *Annual Review of Entomology*, *33*(1), 441–466.

Wang, S. W., Curtis, P. D., & Lassoie, J. P. (2006). Farmer perceptions of crop damage by wildlife in Jigme Singye Wangchuck National Park, Bhutan. *Wildlife Society Bulletin*, *34*(2), 359–365.

Wang, Z. Z., Liu, Y. Q., Min, S. H. I., Huang, J. H., & Chen, X. X. (2019). Parasitoid wasps as effective biological control agents. *Journal of Integrative Agriculture*, *18*(4), 705–715.

Warren, M. S., Hill, J. K., Thomas, J. A., Asher, J., Fox, R., Huntley, B., Roy, D. B., Telfer, M. G., Jeffcoate, S., Harding, P., Jeffcoate, G., Willis, S. G., Greatorex-Davies, J. N., Moss, D., & Thomas, C. D. (2001). Rapid responses of British butterflies to opposing forces of climate and habitat change. *Nature*, *414*(6859), 65–69.

Watson, G. A., & Mahrita, W. (1985). Farmers' local and traditional rice crop protection techniques: Some examples from coastal swamplands, Kalimantan, Indonesia. *Indonesian Agriculture and Research Development Journal*, *7*, 25–30.

Way, M. J., & Heong, K. L. (1994). The role of biodiversity in the dynamics and management of insect pests of tropical irrigated rice–a review. *Bulletin of Entomological Research*, *84*(4), 567–587.

Weiss, M. R. (2003). Good housekeeping: Why do shelter-dwelling caterpillars fling their frass? *Ecology Letters*, *6*(4), 361–370.

Weisser, W. W., Volkl, W., & Hassell, M. P. (1997). The importance of adverse weather conditions for behavior and population ecology of an aphid parasitoid. *Journal of Animal Ecology*, *66*, 386–400.

Western Ghats Ecology Expert Panel (WGEEP). (2011). *Report of the Western Ghats Ecology Expert Panel. Ministry of Environment and Forests, Government of India.* Retrieved from *https://www.cppr.in/wp-content/uploads/2013/03/Gadgil-report.pdf.* Accessed May 15, 2020.

Whelan, C. J., Holmes, R. T., & Smith, H. R. (1989). Bird predation on gypsy moth (*Lymantria dispar*) larvae: An aviary study. *Environmental Entomology*, *18*(1), 43–45.

Whitham, T. G., Young, W. P., Martinsen, G. D., Gehring, C. A., Schweitzer, J. A., Shuster, S. M., & Kuske, C. R. (2003). Community and ecosystem genetics: A consequence of the extended phenotype. *Ecology*, *84*(3), 559–573.

Widawsky, D. A., & O'Toole, J. C. (1996). Prioritizing the rice research agenda for Eastern India. In R. E. Evenson, R. W. Herdt, & M. Hossain (Eds.), *Rice research in Asia: Progress and priorities* (pp. 109–129). International Rice Research Institute.

Widodo, S., Nasrullah, D. P., & Sumartono, S. S. (1979). Identifying constraints to higher rice yields in Yogyakarta, Indonesia. In R. R. Bruce & R. F. Ahuja (Eds.), *Farm-level Constraints to High Rice Yields in Asia* (pp. 1974–77). International Rice Research Institute.

Wijnhoud, J. D., Konboon, Y., & Lefroy, R. D. B. (2003). Nutrient budgets: Sustainability assessment of rainfed lowland rice-based systems in northeast Thailand. *Agriculture, Ecosystems and Environment*, *100*, 119–127.

Williamson, S., Little, A., Ali, M. A., Kimani, M., Meir, C., & Oruko, L. (2003). Aspects of cotton and vegetable farmers' pest management decision–making in India and Kenya. *International Journal of Pest Management*, *49*(3), 187–198.

Willis, G. H., & McDowell, L. L. (1982). Pesticides in agricultural runoff and their effects on downstream water quality. *Environmental Toxicology and Chemistry: An International Journal*, *1*(4), 267–279.

Winemiller, K. O., & Polis, G. A. (1996). Food webs: What can they tell us about the world? In G. A. Polis & K. O. Winemiller (Eds.), *Food Webs: Integration of Patterns and Dynamics* (pp. 1–22). Berlin: Springer.

Wiranto, A. S. P., Ningtyas, N. S., Rachmawati, R. D., Rahmatullah, R., & Sukirno, S. (2022). Diversity of insect based on growth stages of rice (*Oryza sativa* L. 'IR 64') at high altitude in Kepurun Village, Manisrenggo Sub-district, Klaten District, Central Java. In *Proceedings of the 7th International Conference on Biological Science (ICBS 2021)* (pp. 102–110). Atlantis Press International B.V.

Wirtz, R. A. (1984). Allergic and toxic reactions to non-stinging arthropods. *Annual Review of Entomology*, *29*(1), 47–69.

Wolda, H. (1978). Seasonal fluctuations in rainfall, food and abundance of tropical insects. *The Journal of Animal Ecology*, *47*, 369–381.

Wolda, H. (1980). Seasonality of tropical insects. I. Leafhoppers (Homoptera) in Las Cumbres, Panama. *Journal of Animal Ecology, 49*, 277–290.

Wolda, H. (1988). Insect seasonality: Why? *Annual Review of Ecology and Systematics*, *19*(1), 1–18.

Wratten, S. D., Gillespie, M., Decourtye, A., Mader, E., & Desneux, N. (2012). Pollinator habitat enhancement: Benefits to other ecosystem services. *Agriculture, Ecosystems & Environment*, *159*, 112–122.

Wu, K. M., Lu, Y. H., Feng, H. Q., Jiang, Y. Y., & Zhao, J. Z. (2008). Suppression of cotton bollworm in multiple crops in China in areas with Bt toxin–containing cotton. *Science*, *321*(5896), 1676–1678.

Wyckhuys, K. A., & O'Neil, R. J. (2010). Social and ecological facets of pest management in Honduran subsistence agriculture: Implications for IPM extension and natural resource management. *Environment, Development and Sustainability*, *12*, 297–311.

Wyckhuys, K. A., & O'Neil, R. J. (2007a). Local agro–ecological knowledge and its relationship to farmers' pest management decision making in rural Honduras. *Agriculture and Human Values*, *24*, 307–321.

Wyckhuys, K. A., & O'Neil, R. J. (2007b). Role of opinion leadership, social connectedness and information sources in the diffusion of IPM in Honduran subsistence maize agriculture. *International Journal of Pest Management*, *53*(1), 35–44.

Xiong, W., Wang, H., Wang, Q., Tang, J., Bowler, P. A., Xie, D., Pan, L., & Wang, Z. (2018). Non-native species in the Three Gorges Dam Reservoir: Status and risks. *BioInvasions Records*, *7*(2), 153–158.

Xu, Z., Olmi, M., & He, J. (2013). Dryinidae of the Oriental Region (Hymenoptera: Chrysidoidea. *Zootaxa*, *3614*(1), 1–460.

Yashiro, N. (1979). Studies on the Japanese species of *Oligosita* (Hymenoptera: Trichogrammatidae). *Transactions of the Shikoku Entomological Society*, *15*, 195–203.

Yasumatsu, Y. (1975). The richness of the insect fauna of rice-fields in Thailand; its importance for the development of integrated control in tropical rice culture. *Agronomie Tropicale*, *38*(1), 52–55.

Yihdego, Y., Salem, H. S., & Muhammed, H. H. (2019). Agricultural pest management policies during drought: Case studies in Australia and the state of Palestine. *Natural Hazards Review*, *20*(1), 05018010.

Yoshimoto, C. M. (1975). Cretaceous chalcidoid fossils from Canadian amber. *The Canadian Entomologist*, *107*(5), 499–527.

Yu, D. S., & Byers, J. R. (1994). Inundative release of *Trichogramma brassicae* Bezdenko (Hymenoptera: Trichogrammatidae) for control of European corn borer in sweet corn. *Canadian Entomologist*, *126*(2), 291–301.

Yu, X., Heong, K. L., Hu, C., Barrion, A. T., et al. (1996). Role of non-rice habitats for conserving egg parasitoids of rice planthoppers and leafhoppers. In N. Hokyo & G. Norton (Eds.), *Proceedings of the International Workshop on Pest Management Strategies in Asian Monsoon Agroecosystems* (pp. 63–67). Kyushu National Agricultural Experimental Station, Ministry of Agriculture, Forestry and Fisheries.

Zalom, F. G., Grigarick, A. A., & Way, M. O. (1980). Habits and relative population densities of some Hydrophilids in California rice fields. *Hydrobiologia*, *75*, 195–200.

Zeng, J., Qiu, J., Wu, Z., Liu, X., & Li, Y. (2024). Impact of the Three Gorges Dam on hydrological connectivity and vegetation growth of Poyang Lake floodplain, China. *Journal of Hydrology*, *130831*.

Zhang, C., & Jin. L. (1992). Preliminary study of biology of rice planthopper's parasite *Haplogonatopus japonica* Esaki et Hashimoto. *Natural Enemies of Insects, 14*(2), 57–61.

Zhang, Z. Q. (1986). A study on biological and ecological characteristics of *Apanteles ruficrus* Haliday. *Natural Enemies of Insects, 8*(2), 84–97.

Zhang, Z. Q. (1991). Effects of draining paddy fields for control of white backed planthopper. *Insect Knowledge*, *28*(6), 321–325.

Zhao, Z. H., Hui, C., Hardev, S., Ouyang, F., Dong, Z., & Ge, F. (2014). Responses of Cereal Aphids and Their Parasitic Wasps to Landscape Complexity. *Journal of Economic Entomology, 107*(2), 630–637.

Zhao, Z. H., Hui, C., He, D. H., & Ge, F. (2013). Effects of position within wheat field and adjacent habitats on the density and diversity of cereal aphids and their natural enemies. *Biocontrol*, *58*, 765–776.

Zhu, X., Zhang, M., Wang, S., Qiang, F., Zeng, T., Ren, Z., & Dong, L. (2015). Comparison of monthly precipitation derived from high-resolution gridded datasets in arid Xinjiang, central Asia. *Quaternary International*, *358*, 160–170.

Zhu, Y., Wang, Y., Chen, H., & Lu, B. R. (2003). Conserving traditional rice varieties through management for crop diversity. *Bioscience*, *53*(2), 158–162.

Zimmerer, K. S., & Young, K. R. (Eds.). (1998). *Nature's Geography: New Lessons for Conservation in Developing Countries*. University of Wisconsin Press.

Zulfiqar, M. A., Sabri, M. A., Raza, M. A., Hamza, A., Hayat, A., & Khan, A. (2010). Effect of temperature and relative humidity on the population dynamics of some insect pests of maize. *Pakistan Journal of Life and Social Science*, *8*, 16–18.

Zvereva, E. L., & Kozlov, M. V. (2006). Consequences of simultaneous elevation of carbon dioxide and temperature for plant–herbivore interactions: A meta-analysis. *Global Change Biology, 12*(1), 27–41.