

**PHYSICO-CHEMICAL PARAMETERS, INSECT PESTS AND
PARASITOID DIVERSITY IN SELECTED CONVENTIONAL
AND KAIPAD RICE FIELDS OF NORTH KERALA**

Thesis submitted for the degree of
DOCTOR OF PHILOSOPHY IN ZOOLOGY

By
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**DEPARTMENT OF ZOOLOGY
UNIVERSITY OF CALICUT
KERALA, INDIA
2021**

CERTIFICATE

This is to certify that this thesis entitled **“Physico-chemical parameters, Insect Pests and parasitoid diversity in selected Conventional and Kaipad rice fields of North Kerala”** is an authentic work carried out by **Sri. Rajesh K. M.** in the department of Zoology, University of Calicut under my supervision and guidance and no part thereof has been presented earlier for any other degree. I also certify that this thesis is free from plagiarism after having checked using **Ouriginal** 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 25%.

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I do hereby declare that this thesis entitled **“Physico-chemical parameters, Insect Pests and parasitoid diversity in selected Conventional and Kaipad rice fields of North Kerala”** Submitted to the University of Calicut in partial fulfillment for the Doctoral degree in Zoology, is a bona fide research work done by me under the supervision and guidance of Dr. M. Nasser, Professor, Department of Zoology, University of Calicut and no part of the thesis has been presented by me for the award of any other degree, diploma or similar title.

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Rajesh K M

My mother worked hard to raise money for my education in the lower classes
..Because, they had given that much importance to education..This thesis is
dedicated to my beloved mother,

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GENERAL INTRODUCTION

Rice

Rice belongs to Family Poaceae and is a self-pollinated plant associated with wet, humid conditions cultivated mostly in the tropics. *Oryza sativa* and *Oryza glaberrima* are the two most important cultivated species of rice. At the global level, it is a staple food crop and is consumed by more than 60 per cent of the world population. The crop is cultivated mostly in developing countries and is the primary source of income and employment for more than 100 million households in Asia and Africa (Kakde and Patel, 2018), and among the Asian countries, India has the largest area of 29.4 per cent of global area under rice cultivation (Humaira et al., 2015).

The main rice growing season in the country is the *kharif* with the sowing time of June-July and harvesting time of November-December. In India, about 84% of the rice crop is cultivated during *kharif* and 7% of the cropped area is cultivated during *pre-kharif* season. Summer (*rabi*) rice is sown from November to February with harvests between March and June using early maturing varieties (Rice in India- A Status paper).

History of Rice Cultivation

About 10,000–14,000 years ago, *Oryza sativa* was domesticated from the wild grass *Oryza rufipogon* roughly, and the subspecies– *indica* (found in tropical regions) and *japonica* (found in the subtropical and temperate regions of East Asia) – are not believed to have been derived from independent domestication events. Another cultivated species *O. glaberrima*, was domesticated later in West Africa. Recent genetic evidence shows that, both *indica* and *japonica*, come from a single domestication event that happened 8,200–13,500 years ago in the Pearl River valley region of China. Rice and farming implements dating back at least 8,000 years have been found (ricepedia.org/culture/history-of-rice-cultivation).

Rice cultivation in the World

China, India, Indonesia, Bangladesh, Vietnam, Thailand, Burma, Philippines, Japan, Brazil, United States, Korea, Egypt, Pakistan, Taiwan and Australia are the rice cultivating countries in the World, and the major contributors are China, India and Indonesia. The current scenario shows that there is an increasing trend in the rice production all over the world. In the year 1999-2000, total world rice production was 409.0 million tones and it was increased to 718.9 million tons in the year 2010-11 (Chauhan et al., 2017).

Rice cultivation in the India

India is the second largest rice producing country after China, and its annual production is around 85-90 million tons, and consumption is around 85 million tones. The productivity in India is much lower than in Egypt, Japan, China, Vietnam, USA, Indonesia and Bangladesh.

In India, rice is cultivated round the year across different seasons in different ecological areas, and are classified into, irrigated, uplands, rain-fed lowlands, deep water and coastal wetlands (saline soils). Irrigated rice is grown in bunded fields; Upland rice is mostly grown as direct seeded. Rain-fed low land rice ecosystem is usually transplanted, and is grown in leveled, bunded fields that retain surface water. Flood-prone rice is adapted to conditions of temporary submergence of 1-10 days, or long periods (1-5 months) of standing water ranging in depth from 50 cm to 400 cm or more, or daily tidal fluctuations that sometimes may also cause complete submergence (Rice knowledge portal, 2015).

Punjab, Haryana, Andhra Pradesh, Karnataka, Odisha, Tamil Nadu and Kerala have contributed the major Indian rice varieties. Only less than a thousand varieties are known to be available presently, mainly through interested farmers and some NGO efforts to conserve them; the rest has for practical purpose been lost forever and we will remain ignorant about their various invaluable properties, features and adaptations. Efforts to record information about the traditional varieties, especially about their ecological features are few and far between.

Rice cultivation in the Kerala

Rice, the single most important cereal in the state is cultivated in distinct agro-ecosystems across the state, starting with lands below sea level to rice paddies in the high ranges at 800 – 1500 m MSL.

Based on the duration of the crop completion time, there are three kinds of rice varieties, namely short, medium and long duration varieties (<http://agritech.tnau.ac.in>).

The rice varieties possess special traits like biotic and abiotic stress resistance, capability to survive extreme agro-edaphic situations, medicinal and nutraceutical properties, and aroma. These varieties are an invaluable and unique gene pool that should be preserved as a community asset for coming generations. The local land races grown in different agro climatic areas of Kerala vary in a range of characters such as crop duration, plant height, tillering, color of plant parts, panicle and grain characters, and biomass yield in terms of both grain and straw.

Rice cultivation in the Special fields

In Kerala, we have special kinds of rice cultivating fields, i.e., Kole lands, Pokkali lands, Kuttanad and Kaipad. The Kole region is situated in the Trichur and Malappuram Districts of Kerala State, and area is extended upto 18602 Ha, which is 2.35 % of the gross rice cultivation area in the state. The Kole lands are seen mainly under the sea level so that the salinity intrusion is one of the important characteristic of those areas. The rice cultivation happens in two seasons, Puncheda (January- May) and Mundakan (August- December)(Sebastian et al., 2014).

Pokkali rice cultivation is practiced in the coastal wetlands of Alappuzha, Trichur and Ernakulam districts with alternative rice and prawn cultivation in two phases viz.Low saline phase (June – November) and High saline phase (December – May).

Another kind of rice cultivation is in Kuttanad region, during two seasons Puncta (October/November – January/February) and additional crop (June/July – September/October).

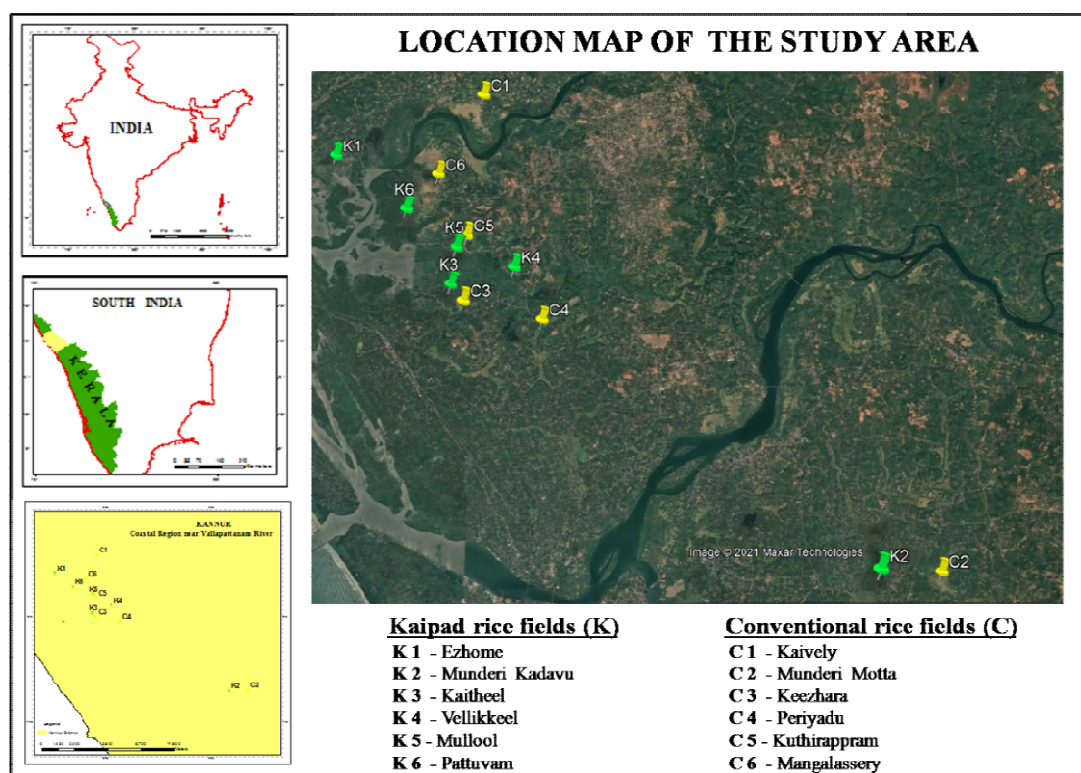
Rice cultivation in the Kaipad.

Kaipad is an unique coastal wetland rice production system which is saline affected and naturally organic production tract of North Kerala spread across Kozhikode, Kannur and Kasargod districts, and purely organic rice is cultivated here. Kaipad is the short form of 'Kayalpadam'. 'Kayal' and 'padam', two malayalam terminologies of 'salt water area' and 'rice field' respectively. The approximate area of Kaipad tract is about 4100 ha. The Pokkali tract of south Kerala is said to be synonymous with Kaipad tract of North Kerala (Chandramohanan and Mohanan, 2012). Kaipad rice cultivation affected by tidal in flow and tidal outflow twice in a day, is carried out in a peculiar way in a low to medium saline phase of production cycle during June to October and harvesting takes place by the end of October. In later months, i.e. during November to April, traditional fishing is taking place, in the high saline phase (Chandramohanan and Mohanan, 2012).

At present Kuthir and Orkazhama are the two traditional varieties used in Kaipad rice fields. Earlier Orthadiyan, Mundonand, Kuttusan were planted. Some new varieties were developed by Kerala Agricultural University Pilicode, and the varieties are Ezhome I (2010) (Tolerant to medium salinity and flooding which is resistant to gall midges, leaf folders, case worms and moderately resistant to whirl maggot, sheath blight and bacterial leaf blight), Ezhome II (2010) (No major incidence of pests and diseases under Kaipad system), Ezhome III (2013) (Medium duration variety tolerant to medium salinity; high yielding in both Kaipad and Pokkali soils during Kharif and Rabi seasons, unlike other Kaipad high yielding varieties, which are high yielding only in Kaipad Kharif season), Ezhome IV (2015) (HY long duration paddy suitable for Kaipad lands; non lodging, white kernels)(<http://www.kau.in/basic-page/varieties-released>).

Area of the Present Study

Kerala, the Southernmost narrow strip shaped state of India is spread over 38,855 km² with a population of 33,387,677 (censusindia.gov.in). Apart from being the main food source for 90% of the population, it has significant role in the culture of the state. There are at least 60 types of Kerala delicacies and food specialties in which rice is the key ingredient. The width of the Kerala State varies between 15 and 120 km and costal belt may extend up to 580 km in length, and conventionally differentiated into three climatically separate regions, the eastern highlands (*Malanadu*), the central midlands (*Idanaddu*), and the western lowlands (*Theera Desam*). The state's landmass is also distinguished into 13 agro-climatic zones based on altitude, rainfall pattern, soil type and topography.



Kannur district lies between latitudes 11 degree 40 minutes to 12 degree 48 minute North and longitudes 74 degree 52 minutes to 76 degree 07 minutes East. The district is bound by the Western Ghat in the East (Coorg district of Karnataka state), Kozhikode and Wayanad districts in the South, Lakshadweep Sea in the West

and Kasaragod, the northern most district of Kerala, in the north. The district has a total area of 2,966 sq.k.m.

Kaipad rice cultivation methods (Plate IV-VIII)

Rice cultivation related activities begin by April by draining out saline water completely from the Kaipad field, later left to dry for one month. After that, small mounds (locally called “Potta” or “Koon”) of approximately 45cm diameter and approximately 60 cm height are prepared (Plate V.3).

These preliminary works will be over by the 2nd week of May, and when the South-West monsoon starts and strengthens the rain wash out/removes saline content of the soil in the prepared mounds. Later, the water outlets of the bunds are opened when there is sufficient fresh water flow in the river. The germinated seeds are sown on the mounds (Plate VI.2), and the seedlings become mature enough for after one-and-a-half months of growth. Later, those seedlings are uniformly dismantled and leveled in the same field using spade/shovel (Plate X.2). During the entire crop duration, neither organic nor chemical fertilizers nor pesticides are used. Normally harvesting month of the crop is end of October before salinity increases in the river. During harvesting, only panicles are cut, and remaining plant parts are left in the field itself, which are used by the fish/prawn as their oviposition sites and for feeding. After prawn filtration/ fish cultivation in next cycle (November-April), the excreta and other wastes act as a mineral rich organic fertilizer for the Kaipad rice.

The major Kaipad areas seen in North Malabar are Chengottukkavu (11°25'31.8"N 75°43'34.9"E), Ulleri (11°26'11.0"N 75°44'18.5"E), Koyilandi (11°26'55.2"N 75°43'26.6"E), Pilicode (12°11'18.2"N 75°09'10.3"E), Padanna (12°10'42.7"N 75°08'25.9"E), Thrikkariapur (12°08'53.1"N 75°09'20.8"E), Udma (12°26'42.3"N 75°00'54.7"E), Kumbala (12°36'04.5"N 74°56'38.4"E), and Manjeswar (12°42'43.1"N 74°53'18.5"E).

Kaipad rice fields selected for the present study.

Six Kaipad rice fields are selected for the survey, and the phases of rice cultivation in Kaipad is shown in the plates IV to XIII.

Ezhome (12°01'58.8"N 75°17'30.3"E)

Ezhome known as “A jewel of North Malabar”, is a Village in Payyannur Block in Kannur District. It is located 24 km towards North from District head quarters Kannur. Pariyaram (4 km), Cherukunnu (4 km), Cheruthazham (6 km), Madayi (7 km), Mattool (7 km) are the nearby Villages to Ezhome.

Munderikkadavu (11°56'22.6"N 75°25'54.2"E)

Munderi Kadavu is a rich wetland region which is a suburb of Kannur and is famous for migratory birds. This area is a part of Katampally Wetlands which incorporates nearly 4000 acres of marshland, and a recent study describes the place as a ‘biodiversity treasure house’. It is estimated that thousands of birds including around 60 species of migrant birds are present at Munderi Kadavu Bird Sanctuary. This wetland is located 14 km away from Kannur

Kaitheel (12°00'10.5"N 75°19'21.0"E)

Kaitheel is a located in Keezhara region of Kannapuram Panchayath, Kannur, in the route which connecting Cherukunnu Thara and Vellikkeel. Kaitheel area is also famous for many native and migratory birds.

Vellikkeel (12°00'28.2"N 75°20'16.5"E)

The Vellikkeel is located in Morazha Village in Pattuvam Grama Panchayath, 5 km from Dharamshala which falls on the route from Kannur to Taliparamba. The rice fields sampled for the present study is near to the Vellikkeel ecopark, which is very famous for mangrove-wetland tourism. The rice fields are connected to the Kuttikol river which is passing near to the rice fields. Like Munderikkadavu and Kaitheel, this place is also famous for native and migratory

wetland birds, because of the richness of wetland tracts and different species of mangroves.

Mulloom (12°00'43.2"N 75°19'24.0"E)

Mulloom is a wetland area enriched with fauna and flora in Pattuvam Grama panchayath in Kannur district. Mulloom also famous for Fish capture, Mangroves and Wetland birds.

Pattuvam (12°01'14.5"N 75°18'36.9"E)

Pattuvam is also located in Pattuvam Grama Panchayatha of Kannur District and is noted for mangroves and wetland birds.

Conventional rice fields selected for the Present study.

Six Conventional rice fields are selected for the survey, and the rice cultivation phases in Conventional rice fields are given in the plates I to III.

Kaiveli (12°02'59.3"N 75°19'38.9"E)

The rice fields in Kaiveli is situated between Narikodu and Onaparambu in Kannur district. The survey in Kaiveli rice fields is took as control field to the nearest Kaipad rice field, Ezhome (4.2 km away).

Munderimotta (11°56'24.6"N 75°26'48.5"E)

The Munderimotta is located in between Idaiylppedika and Maniyur in Melechoova- Kolacherimukku route, and the rice fields selected for this study is situated in the Munderimotta-Kudukkimotta route in Munderi Grama Panchayath. the nearest Kaipad rice field, Munderi Kadavu is located 1.2 km away.

Keezhara (11°59'56.7"N 75°19'33.1"E)

Keezhara is located in Kannapuram Panchayath, Kannur and this Conventional rice field is located near the Kaipad rice field in Kaitheel.

Periyadu (11°59'43.8"N 75°20'44.1"E)

The Conventional rice field selected in Periyadu is in Morazha–Ozhakrome route. This Conventional rice field is used for the survey as control to the Kaipad rice field, Vellikkeel, which is 2.5 km away.

Kuthirappuram (12°00'53.9"N 75°19'32.4"E)

The Conventional rice field in Kuthirappuram is used as control survey fields to the Kaipad field, Mullool, and is located in Pattuvam Grama Panchayath.

Mangalassery (12°01'46.4"N 75°19'03.4"E)

Mangalassery is located in Pattuvam – Taliparamba road. This rice field is used as the control rice field, parallel to the Kaipad rice field, Pattuvam which is 1.5 km away.

PLATE I



1. Prepared land for rice cultivation in conventional rice fields



2. Preparation of bunds and final field setting in conventional rice fields



3. Fixing and spreading of rice seedlings in the fields

PLATE II



1. Seedling fixing and spreading in the final stage



2. Conventional rice fields after the completion of seedling spreading



3. Early tillering stage of rice in Conventional fields

PLATE III



1. Middle tillering stage of rice



2. Reproductive stage of rice



3. Ripening stage of rice prior to the harvest

PLATE IV



1. Kaipad lands making dry prior to the mound preparation



2. Land preparing to start mound preparation



3. Preparation of mounds

PLATE V



1. Preperation on mounds in large area



2. Prepared mounds



3. A single mound

PLATE VI



1. Germinated seeds to fix in mounds



2. Spreading of germinated seeds on mounds



3. Germinated seeds on mound

PLATE VII



1. Covering the germinated seeds using thin layer of mud



2. Germinated seeds covering to protect seeds from flocks of birds



3. Seedlings on the mound

PLATE VIII



Figs 1, 2, 3 : Early growth stages of rice in Kaipad

PLATE IX



Figs 1, 2, 3: Growth satges

PLATE X



1. Weed removal in Kaipad rice fields



2. Dismantling and spreading of rice plant hills from mounds



3. Lush Vegetative growth of rice after dismantling

PLATE XI



1. Late tillering stage of rice



2. Reproductive stage of rice



3. Ripening stage of rice

PLATE XII



Figs 1, 2 & 3- Harvesting stage of Kaipad rice

PLATE XIII



Figs 1, 2 & 3- Different phases of Kaipad rice harvesting

CHAPTER 1

TO COMPARE THE PHYSICAL AND CHEMICAL PARAMETERS OF WATER, SOIL AND LEAF IN SELECTED KAIPAD AND CONVENTIONAL RICE FIELDS OF NORTH KERALA

In this chapter we are dealing with introductory part, review of literature and methodology regarding the first objective, i.e. the comparative study of physico-chemical parameters of water, soil and leaf in selected Kaipad and Conventional rice fields of North Kerala.

The Parameters compared between Kaipad and Conventional rice fields were Atmospheric humidity, Atmospheric temperature, Water Surface Temperature, Water Bottom Temperature, Water pH, Water Salinity, Water Electrical conductivity, Water Dissolved Oxygen, Water Chemical Oxygen Demand, Water Total Hardness, Water Turbidity, Water Nitrate, Water Phosphate, Water Potassium, Water Calcium, Water Magnesium, Water Sulfate, Soil pH, Soil Electrical conductivity, Soil available Nitrogen, Soil available Phosphorus, Soil available Potassium, Soil available Calcium, Soil available Magnesium, Soil available Sulfur, Soil available Iron, Soil available Manganese, Soil available Zinc, Soil available Copper and Soil available Boron, Leaf total Nitrogen, Leaf total Phosphorus, Leaf total Potassium, Leaf total Calcium, Leaf total Magnesium, Leaf total Sulfur, Leaf total Iron, Leaf total Manganese, Leaf total Zinc, Leaf total Copper and Leaf total Boron.

INTRODUCTION

Rice is sensitive to low and high temperature stresses and the optimal temperature for the rice cultivation is 25–35 °C, and low and high temperatures instead of optimal adversely affects the growth, physiology, and yield of rice. High temperature (>35 °C) negatively affects the root-shoot growth, hampers pollination, leads to poor anther dehiscence, and spikelet sterility further. These responses vary with the extent of temperature increase and its duration. In

addition, low temperature ($<20^{\circ}\text{C}$) delays rice germination and seedling establishment, hampers tiller formation, affects flowering, causes panicle sterility, and finally leads to lower grain yield (Hussain et al., 2019).

Lower humidity in light and higher humidity in darkness increase the rate of leaf emergence, plant height, leaf area, leaf blade length, the number of roots, total root length and dry matter production as compared with low humidity in both light and dark periods (Hirai et al., 2000).

The optimum rice production is totally dependent on physical, chemical and biological qualities of water. So it is necessary to check the quality of water used for rice cultivation (De Datta., 1993). A variety of pesticides, hormones, herbicides, antibiotics, and chemical fertilizers, have been used in rice agricultural production systems of Kerala and this may cause contamination of water.

For paddy rice, water temperature is a major determinant of growth and yield and it is higher than the air temperature, and this difference significantly affects production, especially in cool climates (Shimono et al., 2007).

Perhaps the most important direct effect of soil pH on rice growth is the effect on the chemical equilibria of sulfides and ferrous iron, both of which are toxic to rice when present in large amounts (Yu, 1991). Water electrical conductivity also plays an important role in rice cultivation, and it varies with changes in the salinity (Scardaci et al., 2002).

The rice fields are most vulnerable to salinity, and it may develop during longer water holding periods and in closed irrigation systems (Scardaci et al., 2002). Rice is very sensitive to salinity during early seedling (Maas, 1990) and pollination stages (Khatun and Flowers, 1995). The salinity during the seedling stage causes a reduction in stand density and seedling biomass (Shannon et al., 1998). During pollination, salinity may cause panicle blanking (sterile florets) or sterility, leading to a reduction in grain yield. Rice is more tolerant of salinity at other growth stages, and salinity stress during these periods has less impact on yield (Grattan et al., 2002). The rice yields decrease 12% for every unit (dS/m) increase above 3.0 dS/m

(Maas and Grattan, 1999; Hanson et al., 1999), and it also significantly reduced seedling growth and seedling survival (Zeng and Shannon, 2000).

The enhanced dissolved oxygen content and combined ammonium-nitrate nitrogen source have positive effects on root growth and nitrogen accumulation of rice plants (Zhao et al., 2011).

The survival of paddy seedlings after complete submergence in water is decreased with increased duration of submergence, increased depth, temperature, and water turbidity. Their durability is increased with high light intensity (Palada and Vergara, 1972). Turbid water also resulted in lower under water photosynthesis because of poor light transmission, chlorophyll retention and silt deposition and ultimately poor survival (Gautam et al., 2015).

Nitrogen is a key plant nutrient being a constituent of amino acids, nucleic acids, nucleotides, chlorophyll, enzymes, and hormones, and it promotes rapid plant growth and improves grain yield and grain quality through higher tillering, leaf area development, grain formation, grain filling, and protein synthesis. Nitrogen is also highly mobile within the plant and soil (IRRI, 2000 - <http://www.knowledgebank.irri.org/training/fact-sheets/nutrient-management/item/nitrogen>). The additional supply of nitrogen from irrigation water before the panicle initiation stage of rice leads to increased tillering and total grain number, and so higher grain yields, especially in the case of ammonium nitrogen (Ikeda and Watanabe, 2002), but did not result in an appreciable increase of the nitrogen content of grains (Ikeda et al., 2001).

Nitrogen supplied from water irrigated during the reproductive growth period did not affect appreciably the yields of rice with a moderate number of grains; it is possible that it could lead to a substantial increase in the concentration of nitrogen in rice grains. and high nitrogen content of rice grains is favorable for nutrition, but adversely affects the taste of boiled rice (Ikeda and Watanabe, 2002).

Potassium is required for significant plant functions, like osmoregulation, enzyme activation, regulation of cellular pH, cellular cation-anion balance,

regulation of transpiration by stomata, and the transport of the products of photosynthesis (Dobermann and Fairhurst, 2000). They also improve root growth and plant vigor, prevent lodging and improve resistance to adverse climatic conditions, amplify crop resistance to pests and diseases, improve tillering and shoot and root dry matter manufacture, enhance the number of filled grains and grain weight, minimize the environmental pollutant concentration in rice grain, reduce Na^+ concentration and increase availability of K^+ in saline soils (Maryam and Amiri, 2014; Zain et al., 2014; Zaman et al., 2015).

Aslam et al., (2001) observed that the Calcium improved all growth characteristics, like tillering capacity, shoot and root lengths, shoot and root weights.

Magnesium (Mg) is an important element for crops, and its deficiency affects photosynthesis and carbohydrate partitioning (Farhat et al., 2016), reduces sustainability of agricultural production and development, and leads to long-term negative impacts on human and animal health (Robert and Helen, 2004; Jeroen et al., 2015). Unfortunately, the major symptoms of its deficiency frequently occur especially at their critical developmental stage with rapid carbohydrate accumulation, grown in acidic soils widely distributed across the world (Cakmak et al., 1994; Farhat et al., 2016). Wang et al., (2011) noted that, Magnesium enhances crop performance by improving yield or resulting in favorable physiological outcomes, providing great potentials for integrated Mg management for higher crop yield and quality. Zinc application increases the crop growth rate of rice (Saeed, 2011). Several enzyme activities in plants, including carbon dioxide (CO_2) assimilation and protein synthesis, and the cellular pH and the cation-anion balance activation are affected by magnesium deficiency in plants. And it may reduce grain quality (% milled rice, protein, and starch content) also. This phenomenon is not frequently noticed in the field because sufficient amounts are usually supplied in irrigation water, but it is common in rainfed lowland and upland rice where soil Mg has been depleted because of the continuous removal of Mg without recycling crop residues or replacing removed Mg with mineral fertilizer, and

many rainfed rice soils are naturally deficient in Mg (Dobermann and Fairhurst, 2000).

Many species of rice can grow effectively at soil pH 5.5, and its rhizosphere pH is lower than that of the bulk soil. Possibly the most dominant direct effect of soil pH on its growth is the effect on the chemical equilibria of sulfides and ferrous iron, both of which are toxic to rice when available in huge amounts and the pH_2S and pS^{2-} values are related to pH nearly linearly (Yu ., 1991). During the whole rice growth periods, soil pH increased from the transplanting stage to the heading stage. However, it decreased again at the ripening stage (Li et al., 2008).

The electrical conductivity of the soil is directly proportional to the concentration of the nutrient and inversely proportional to the soil depth. Besides, its values reflect the salinity of the soil where, the higher the EC value, the higher the soil salinity and vice versa (Othaman et al., 2020).

Phosphorous (P) is essential for root development, tillering, early flowering, and ripening and it is mobile within the plant, but not in the soil (IRRI, 2000). The production of rice is majorly affected by soil phosphorus (P) deficiencies in many areas of the world (Fageria et al., 2011) and its uptake by rice varied with soil available P.

The symptoms of iron toxicity in rice are the developments of yellowing of leaves, dark brown spots followed by reddish brown coloration, and it negatively affects rice crop growth and productivity (Barthakur and Baruah, 1990).

Copper, among trace metals, essential for plant growth, but high concentration of the element in soil shows highly toxic effect to plant, such as growth inhibition and oxidative damage by generating reactive oxygen radicals (Adrees et al., 2015; Thounaojam et al., 2012; Wu et al., 2010).

Leaf analysis is also called stem leaf analysis, tissue analysis or foliar analysis, and is the most precise method of monitoring nutrient levels of any plant species. While soil analysis shows the levels of soil nutrients, leaf analysis shows the grower exactly what the plant has successfully absorbed. This kind of analysis

can be helpful in detecting nutrient deficiencies before they affect plant health and yield.

The rice plant has been known to have a high tolerance to manganese and tissues found to contain as much as 4.000 ppm Mn without any harmful effects (Tanaka and Navasero, 1966). On the other hand, others have reported manganese toxicity in tissues containing 2.000 ppm Mn (Tanaka and Navasero, 1966). Under water culture conditions, 10 ppm Mn was reported to be the upper critical level in the culture solution for maintaining normal rice growth; at this level, the straw contained 1.000 ppm Mn (Ishizuka et al., 1961). Toxicity symptoms started to develop at 30 ppm Mn in culture solution (Kasugai, 1939).

Low levels of Fe and Mn were necessary for better growth of plant and efficient utilization of these nutrients by rice plants. Antagonistic effects were observed only when one of the nutrients was seen in higher quantities in the rice field (Alam, 1985).

Sulfur (S) deficiency affects chlorophyll production, protein synthesis, and plant function and structure. It can lead to delayed plant development and maturity. If deficiency occurs at vegetative stage, it can affect yield (Anonymous, 2014).

Zinc (Zn) deficiency is the most widespread micronutrient disorder in rice (Wissuwa et al., 2006), and its deficiency leads to diverse symptoms that usually appear 2 to 3 weeks after transplanting rice seedlings. The leaves develop brown blotches and streaks that may fuse to cover older leaves fully, plants remain stunted and in severe cases may die, while those that recover will show substantial delay in maturity and reduction in yield (Yoshida and Tanaka, 1969; Van Breemen and Castro, 1980; Neue and Lantin, 1994). Its deficiencies usually associated with concentrations of less than 20 ppm, and toxicities will occur when its concentration exceeds 400 ppm (Tisdale et al., 1993).

The rice grain yield will decrease significantly with the increase of soil Copper levels (Xu et al., 2005). The reasons of rice yield reductions due to Copper stress were the decrease of panicle number (Hu and Schmidhalter, 2002; Zhang et

al., 1997), unfilled grain number (Yang and Li, 1990) or reduction of both panicle number and 1000-grain weight (Kang et al., 1999; Su and Yuang, 1997; Chen et al., 1995).

The total biomass will decrease significantly with rising soil Cu levels (Kang et al., 1999; Su and Yuan, 1997). The biomass responses to soil Cu stress are probably associated with its inhibition of photosynthesis, because excessive Cu could restrain chlorophyll synthesis or result in chlorophyll decomposition (Ouzounidou, 1994).

Boron (B) is a nonmetal essential micronutrient for normal growth and development of plants, including rice (Gupta, 1979), and its deficiency was reported in rice-growing soils (Cakmak and Romheld 1997; Rashid et al., 2004 and 2007) and flooded lowland rice grown in calcareous soils (Rashid et al., 2004 and 2007) and it causes considerable yield losses. Its deficiency in rice induces sterility of panicle due to poor development of pollen and anther and failed pollen germination and alters cell wall pectin in pollen tubes (Yang et al., 1999) which reduces the number of grains per panicle and, hence, grain yield (Nieuwenhuis et al., 2002; Gowri, 2005). Moreover, Boron deficiency in rice also damages grain quality (Rashid et al., 2004 and 2007). Conversely, B toxicity has also been seen in rice (Ponnamperuma and Yuan, 1966) with symptoms including interveinal chlorosis in older leaves and dark brown elliptical spots on infected plant parts.

Boron deficiency reduces chlorophyll and soluble protein contents in the leaves, and the resultant loss in photosynthetic enzyme activity obstructs the Hill reaction (Sharma and Ramchandra, 1990; Cakmak and Romheld, 1997) and the ability of the plant to capture light, which decreases photosynthetic activity (Cakmak and Romheld, 1997). Its deficiency during the reproductive stage cause abnormal stomata and distorted guard cells (Blevins and Lukaszewski, 1998; Huang et al., 2000).

The iron toxicity symptoms in rice are as a result of an immoderate uptake of Fe^{2+} by the rice roots and its acropetal translocation into the fleaves where an elevated production of toxic oxygen radicals can damage cell structural components

and impair physiological processes, and the visual symptom associated with these processes is the “bronzing” of the rice leaves and substantial associated yield losses (Becker and Asch, 2005). Potassium content in leaf has solid effect on enzyme activation, protein synthesis, photosynthesis, stomatal movement and water relations in plants (Marschner, 1995).

Soil analysis is the way to observe the Nutrient availability in agriculture systems to develop sustainable management strategy for conservation of soils. The Kaipad soil is characterized by unique saline hydromorphic soil, and is very rich in organic matter content which may influence the biological properties of soil and with high production potential.

Aim of this chapter is to analyse and interpret the water, soil and leaf parameters of Kaipad and other conventional rice fields, and to determine the major differences in quality of those parameters within and between these two categories of rice fields.

REVIEW OF LITERATURE

Many studies were conducted on qualitative and quantitative analysis of water, soil and plant/leaf in river, lakes, ponds, streams, and rice agro-ecosystems all over the world. In rice fields, weather parameters, water parameters, soil parameters and leaf parameters may play an important role in growth of rice plants, and its interaction with its pests, parasitoids, and predators.

Climate change may influence all organisms, including plants, insects and their interactions among weather, plants and herbivores. It also affects the insect physiology, behavior, development, and species distribution. On the other hand, the population abundance of an insect species is manipulated by the host plant, natural enemies or extreme weather conditions.

Weather and climatic conditions are known to significantly affect the insect pest population dynamics (Kennedy and Storer, 2000). Soultani et al., (2012) also stated that the climatic factors such as temperature and humidity could influence the abundance of insect populations. In 1990, Mulford and Dugdale suggested that the

knowledge of abiotic conditions such as temperature, day length, rainfall and relative humidity can be used as important components in forecasting and predicting the severity of insect pest population. Knowledge of insect pest population dynamics is essential for developing sustainable crop protection methods and for interpreting and forecasting the response of taxonomic groups to weather patterns varying on a daily, seasonally or as a long term consequence of global climate change (Denholm et al., 2001).

Insects are ectothermic and sensitive to precipitation, so they can be easily affected by climate change (Bale et al., 2002). These effects can be direct, through the influence of climatic factors on the insect's physiology and behavior (Bale et al., 2002; Cannon 1998; Harrington et al., 2001), or indirectly mediated by host plants, competitors or natural enemies (Bale et al., 2002; Harrington et al., 2001).

Temperature is probably the most important environmental factor influencing insect's behavior, distribution, development, survival and reproduction (Chu and Chao, 2000). Studies suggested that higher temperatures will favor parasitoids rather than their host insects (Davis et al., 1998; Kiritani, 2006). In extreme conditions, higher abundance of insect pests may partly be due to parasitoids's lower activity (Hance et al., 2007) or to disturbed parasitoid-pest relationship and decreased controlling ability of parasitoids.

Jaypal et al., (2018) observed minimum number of dead hearts at the maximum temperature. But highest increase in infestation level was indicated at a minimum temperature.

The humidity also plays a significant role in insect pest population dynamics. Maximum relative humidity also showed a negative correlation with per cent infestation, and maximum percent of dead heart was observed at a higher relative humidity (Jaypal et al., 2018).

Khaliq et al., (2014) reported that climatic factors such as temperature and relative humidity greatly influence the outbreak of insect population. The investigation by Animesh and Rajendra (2018) revealed that rainfall, rate of change

of rainfall, temperature difference, rate of change of temperature, limited difference of relative humidity, wind speed, duration of sunshine has a remarkable influence on the fluctuations of Yellow stem borer.

Studies by Mishra et al., (2019) revealed that a non significant relationship between various weather parameters and abundance of various pests like, Rice gundhi bug, *Leptocorisa acuta* (Thunberg), Green leaf hopper, *Nephotettix virescens* (Distant), Army worm, *Mythimna separata* (Walker), Rice leaf folder, *Marasmia patnalis*= *Cnaphalocrocis medinalis* (Guene). But there was a significant positive correlation with maximum temperature and abundance of Rice butterfly, *Melanitis leda ismene* Cramer and Short horn grasshopper, *Tetrix subulate* Linnaeus. Abundance of Field cricket, *Euscyrtus concinnus* (de Haan), Mole cricket, *Gryllotalpa orientalis* Burmeister were significantly positively correlated with maximum temperature and evaporation.

Physico- chemical analysis of water.

The physico-chemical characteristics of water play a significant role in abundance, diversity and distribution of insects in the paddy field (Norazliza et al., 2014). Xu et al., (2012) reported that the water quality parameters, like, Water nitrate, Water phosphorus, Water dissolved oxygen (DO), Water pH and Water chemical oxygen demand (COD) are responsible for changes in water temperature. Water temperature can be influenced by environmental factors such as rainfall, temperature, and vegetative shading around the sampling area (Environmental Protection Agencies, 2012). The concentration of pesticides and fertilizers application also influences the Water Temperature (Gossum et al., 2009).

Lee et al., (2019) conducted a study on water and soil properties in organic and conventional paddies throughout the rice cultivation cycle in South Korea. Their results showed that water content (WC), electrical conductivity (EC), organic matter (OM), and available phosphorus (P₂O₅) in soil varied significantly ($p < 0.01$) depending on the farming method (Lee et al., 2019).

A study conducted by Saranya and Dhanalakshmi (2017) in Valapattanam and Munderi Kadavu river near Kaipad areas indicated that the hydrological parameters of the rivers were maximum during pre monsoon in upper stream of rivers and minimum during post monsoon season in the downstream of rivers.

The Pokkali cultivation system with alternate rice and prawn/crab cultivation in their respective periods of salinity, hardness, alkalinity, chlorinity and other conditions provide a habitat for rich and dense forms of biota of both invertebrates and vertebrates, differs in their dominance and availability. The gradual and cyclical fluctuations in the various physico-chemical parameters of the Pokkali fields during the different facets of cultivation make it rich with diverse flora and fauna (Mumthaz and Jhon George, 2017).

Rice is usually grown in flooded conditions with a water depth of 0–10 cm (Bouman et al., 2007), about 70% or more of rice crops are grown in irrigated fields (Fischer et al., 2014). Therefore, the growth processes for irrigated rice are strongly influenced by water temperature.

Water temperature affects growth rate and yield of rice plants (Matsushima et al., 1964; Roel et al., 2005) through various biological processes, e.g., leaf photosynthesis (Shimono et al., 2004), phenological development (Collinson et al., 1995; Fukui et al., 2015; van Oort et al., 2011), root water uptake (Murai et al., 2008), and fertilization of the spikelet (Julia and Dingkuhn, 2013; Shimono et al., 2005).

The rice spikelet sterility induced by heat stress (Jagadish et al., 2007; Satake and Yoshida, 1978) and the decline in grain quality and yield with high temperature (Mohammed and Tarpley, 2009; Peng et al., 2004) are worldwide concerns with ongoing global warming. Grain damage is affected by both air and water temperatures (Usui et al., 2016) and there have been several attempts to reduce heat stress during critical stages using appropriate field water management (Morita et al., 2016). In the rice fields of Malaysia, water temperature ranged between 27 to 40.1°C (Ali, 1990), and Ghosh (1992) reported a range of 27 to 29°C in rice fields.

Sugiyama and Hama (2013) found that high water temperature catalyzes the absorption of phosphorus in sediment. In 2012, Chen et al., found that low absorption of phosphorus will lead to slow down of the rate of leaf emergence and thus, later slow down the growth of the plant. Therefore, as the water temperature decreased, the growth of plant also will be decreased. Water temperature fluctuation may be due to surrounding water/air temperature and shading by rice plants which also maintains the water favorable for activities.

The determination of pH may serve as an index of other environmental factors like quantity of CO₂, O₂ and dissolved solids (Kumar and Gupta, 2002). Chandramohan and Mohanan (2012) reported Water pH between 6.71 and 7.45 in April and from 6.15 to 6.71 in July in Kaipad rice fields. Chowdhury et al., (2000) observed that pH values of water in rice fields ranged between 5.63 to 8.20 in all treatments with an average value 6.63. which is slightly lower than the value of 7.3 obtained by Uddin (1998) in his experiments on rice fish culture. Arun (1996) noticed that the water pH of the Pokkali wetland varied from 6 to 8.7.

During a study in Pokkali areas by Deepa (2014) reported maximum water pH during December (7.4). Generally, the water pH was maximum during the prawn culture period (January to May) during the different years.

Even at ECe as low as 3.5 dSm⁻¹, rice loses about 10% of its yield, and 50% yield loss was recorded for rice at ECe 7.2 dSm⁻¹ (Umali, 1993).

By 2050, the world's population is predicted to reach 9.6 billion people and food production needs to increase approximately 70% by 2050 or 44 million metric tons annually to provide sufficient food for this population. This is a challenge because there is very little potential for future expansion of arable lands, whereas environmental stresses affecting crop production are increasing (Tester and Landgridge, 2010; Eckardt, 2009; Cominelli et al., 2013).

Asia accounts for 90% of the world's production and consumption of rice (Virmani and Ahmed, 2011; Khush, 2005) but Sea-level rise is already increasing

rice-killing salinity in the deltas of Asian rivers, the richest rice-growing areas of the world (Dayton, 2014).

Salinity and water deficit were listed as the two most critical factors that limit global crop production (Munns, 2011). Soil and water salinisation are the most important abiotic stresses that many rice cultivation areas have to face worldwide (Motos et al., 2017). About 20% of the agricultural land and 50% of the cropland worldwide suffer from salinity according to the United Nations Environment Programme (UNEP) (Othman et al., 2006).

Various environmental stresses viz. soil salinity, high winds, extreme temperatures, drought and flood have affected the production and cultivation processes of agricultural crops, among this soil salinity is one of the most devastating environmental stresses, which causes major reductions in cultivated land area, crop productivity and quality (Yamaguchi and Blumwald, 2005; Shahbaz and Ashraf, 2013).

Almost all Agricultural crops shows a spectrum of responses under salt stress. Salinity not only decreases the agricultural production of most crops, but also, effects soil physicochemical properties, and ecological balance of the area. Low agricultural productivity, low economic returns and soil erosions are the few salinity impacts (Hu and Schmidhalter, 2002). Salinity effects are the results of complex interactions among morphological, physiological, and biochemical processes including seed germination, plant growth, and water and nutrient uptake (Akbarimoghaddam et al., 2011; Singh and Chatrath, 2001). Soil salinity imposes ion toxicity, osmotic stress, nutrient (N, Ca, K, P, Fe, Zn) deficiency and oxidative stress on plants, and thus limits water uptake from soil. Soil salinity significantly reduces plant phosphorus (P) uptake because phosphate ions precipitate with Ca ions (Bano and Fatima, 2009). In a study conducted by Fogliatto et al., 2019, germination percentage, germination speed, seedling root and shoot length were affected by increasing the salt concentration in all tested populations and varieties.

Matoh et al., (1986) suggested that the growth reduction in the rice plants subjected to salt stress was mainly due to excess of ions, while Castillo et al., (2004)

suggested that the effect of salt on rice is mainly caused by the osmotic component. Rice is very sensitive to salinity stress and is currently listed as the most salt sensitive cereal crop with a threshold of 3 dSm⁻¹ for most cultivated varieties (USDA, 2016).

In rice, previous studies have shown that salinity acts mainly on delaying seed germination than reducing germination percentage; moreover, salt tolerance in rice increases with time, being lowest during the early seedling stage (2–3 leaf stage) with a certain variability amongst different rice varieties (Pearson et al., 1966); Mondal and Borromeo, 2016). A previous study found that, beside the variability among varieties, only few were slightly affected by a salinity level of 12 dS m⁻¹ at the seedling stage (Mondal and Borromeo, 2016). The salinity level tolerated by rice during germination seems not to be correlated with salinity tolerance at other growth stages (Shi et al., 2017).

Rice plants have evolved various mechanisms to cope with salinity stress including: (i) biosynthesis and accumulation of osmolytes for osmoprotection; (ii) ion homeostasis and compartmentation; (iii) antioxidants—ROS detoxification; and (iv) programmed cell death (Hoang et al., 2016). Rice is also recommended as a desalinization crop due to its ability to grow well in flooded conditions and the standing water in rice paddy can leach the salts out of the topsoil to make salt-affected land suitable for the subsequent crops (Bhumbla and Abrol, 1978).

Dissolved oxygen is one of the most important and critical chemical factors in rice fishculture system. Ghosh et al., (1984) recorded the range of dissolved oxygen in the water of rice fields was 3.5 to 6.17 mg/l. Later, Ghosh (1992) reported the dissolved oxygen content of the water in the rice fields ranged from 3.2 to 4.5 mg/l in monsoon and 2.2 to 2.9 mg/l in summer. The range of dissolved oxygen content were 3.7 to 6.0 mg/l recorded by Uddin (1998) in his experiment conducted on rice-fish culture.

Varoius autthers reported nitrate values of 0.22 to 0.23 mg/l (Ali, 1992), 1.30 to 3.20 mg/l (Chowdhury et al., 2000), 0.02 to 2.60 mg/l (Ghosh, 1992), 0.06 to 0.1 mg/l (Bhuiyan, 1970) in rice.

Phosphorus in the form of phosphate ($\text{PO}_4\text{-3}$) is an essential plant nutrient. Erosion and runoff can result in large amounts of phosphates in bodies of water and lead to eutrophication, the depletion of oxygen from excessive aquatic growth. These are some of the primary reasons that the monitoring of phosphate levels in water is extremely important. Phosphate-phosphorus concentration in water has been considered very important in aquatic productivity. Ghosh (1992) reported that the concentration of phosphate-phosphorus ranged from 0.03 to 0.09 ppm in his experiment on rice fish culture.

Potassium deficiency normally proceeds through a series of leaf color changes including yellow, reddish brown, and eventually a tan/ brown color, depending on cultivar, resulting from leaf death. Premature leaf death and accompanying color changes often are a result of increased damage from various rice diseases (Slaton et al., 1995).

Rice plants will grow well only when they receive an adequate supply of sulfur and other nutrients throughout much of their growing period. This sulfur may come from the soil, irrigation, or rain water, by absorption from the atmosphere or from applied manures or fertilizers. Rice plants remove between 8 and 17 kg S ha⁻¹ from a paddy soil, depending on variety, to yield between 4 and 9 tonnes of grain per hectare (Freney et al., 1982).

Tarunkumar et al., (2014) observed that the Physico-chemical characteristics of soil and water are very significant in Paddy cum Fish culture field which in general controls the productivity of water bodies.

Krishnani et al., (2011) revealed that organic carbon in soil was higher during Pokkali paddy crop *vis a vis* extensive shrimp culture, and soil was acidic during both the crops. There was no difference in other soil parameters such as electrical conductivity and redox potential. Water parameters like salinity, ammonia and nitrite values were marginally higher during extensive shrimp culture than during paddy crop. However, pH, chemical oxygen demand, phosphates and total phosphorous were not different between the two crops. The soil and water

parameters, except soil pH, were observed to be within optimum range for shrimp farming.

Victory et al., (2018) revealed that ammonia, nitrate-nitrogen, nitrite-nitrogen are strongly correlated positively and thus significant to rice growth. They also noted that the pH have a low correlation; and the relationship between rice growth, dissolved oxygen and temperature had negative correlation and hence not significant.

Rosly et al., (2014) showed that there are significant correlations between beneficial insects in paddy field and water temperature, salinity, turbidity, pH, dissolved oxygen, biological oxygen demand, chemical oxygen demand, ammonia and total suspended solids. Also the plant height, insect pest, temperature, rainfall and humidity were found to be good predictors on the abundance of beneficial insects.

Soil Parameters analysis in Agro ecosystems

The quality of paddy soil is highly related to human health and ecological environment. In recent decades, heavy metal contamination, nutrient loss and microbial imbalance in paddy fields had a significant negative impact on food security (Deng et al., 2019).

The soil quality analysis includes an analysis of parameters and processes which influences the ability of soil to operate efficiently as a component of an ecosystem (Tale and Sangita, 2015). Soil quality may include a capacity for water retention, carbon sequestration, plant productivity, waste remediation, and other functions, or it may be defined more narrowly.

Micronutrients play a vital role in crop growth, crop productivity, soil fertility and human nutrition (Patel et al., 2015). Magdoff and Van (2000) revealed that the farming practices that cause nutrition imbalances can minimize pest resistance. Meyer (2000) proposed that soil nutrient availability not only affects the amount of damage by herbivores on plants but also the ability of plants to recover from those herbivores.

Hasegawa and Horie (1997) developed a dynamic crop growth model to analyse irrigated paddy rice (*Oryza saliva* L.) productivity as determined by climatic factors and N availability. The model consists of submodels related to soil N processes, rice N-uptake, developmental processes, photosynthesis, dry matter production and spikelet formation. Soil N processes include N mineralization, expressed as a function of temperature and soil moisture before flooding. The balance between soil N supply and crop N demand determines rice N-uptake.

Manure and organic fertilizers are more effective than chemical fertilizer to induce rice growth and tolerance to insect pests and other diseases. Their effects increase plant height, number of tillers, SPAD index and decreases population/incidence of Stem Borer, Brown Plant Hopper, Leaf Folder etc. (Chau and Heong, 2005).

Chau and Heong (2005) stated that the low content of nitrogen and phosphate and high content of potassium in rice plant are the main mechanism of defense in rice, and the application of manure and organic fertilizers are effective method to protect natural enemies under field condition.

Findings of Madhavi et al., (2018) on soil analysis revealed that significant changes were observed in physico-chemical properties such as Soil Texture, pH, Organic Carbon (OC), Nitrogen (N), Phosphorous (P), Alkalinity, Acidity, Micronutrients (Cu & Zn) and total Microbial Counts (TMC). Soil Micronutrients of Copper (Cu), Zinc (Zn) and Microbial Growth were slightly in higher quantities during Middle cropping period.

Soil chemical properties are typically related to variability in crop yield and their degradation will result in a decrease of soil fertility and nutrients (Gray and Morant, 2003; Yamagishi et al., (2003). Understanding field spatial variation and the relationships with crop response may substantially increase the input effectiveness and average crop yield (Virgilio et al., 2007).

Lee et al., (2019) observed higher organic matter, electrical conductivity, and P_2O_5 of soil in the conventional paddies than in the organic paddies of South Korea.

All soil properties, except pH and ammonium, depended on seasonal variation. Their cluster analysis revealed that soil properties in May were distinctly separated from those in other seasons mainly due to basal fertilization. The principal component analysis distinguished the soil properties in different seasons, but they did not observe such a distinction between the soil properties in organic and conventional paddies. Low contents of Water Content, Organic Matter, and total N were observed in March. High concentrations of nitrate and total P were observed in May, but these were low in August and October. The soils from October were also characterized by high concentrations of EC and P_2O_5 .

Low levels of Nitrogen may be the major factors limiting rice production due to their positive effects on rice yield. Crop production and quality is affected due to deficient micronutrients (B & Zn) all over the world (Rashid and Ryan, 2004; Rafique et al., 2008).

Paddy soils are naturally heterogeneous in their physico-chemical properties, so can impact on rice productivity. This means that uniform management of fields will often result in over-application of inputs in areas with high nutrient levels and under-application in areas with low nutrient levels (Ferguson et al., 2002). Better agricultural crop practices can be achieved only if soil and nutrient variations within a farm are understood and properly managed (Omonode and Vyn, 2006).

Rani and Latha, (2017) observed that total uptake of Boron, Calcium and Magnesium had positive and significant correlation with yield whereas negative correlation existed between Fe uptake and yield in Kole lands.

The various physical and chemical properties of soil samples such as bulk density, textural analysis, pH, electrical conductivity, organic carbon, available N, P, K, Ca, Mg, S, Fe, Zn, Cu, Mn, B, Si, exchangeable Na and Al and cation exchange capacity were estimated by Santhi et al., (2016) using the standard procedures. Their results revealed that the macro and micro nutrient status of Kaipad soils was generally very high except in case of Magnesium, and the high Cation Exchange Capacity observed in these soils might be due to the high organic matter content of these soils.

Salinity affects the rice crop by reducing plant growth measured in terms of biomass production or plant height, thousand grain weight and number of spikes, ultimately leading to grain yield reduction. Salt stress is also known to affect the quality and composition of rice grain by hampering the physico-biochemical processes during the grain filling stage. Salt-induced changes occurring during the vegetative stage of the rice plant may also affect the rice grain composition and quality (Razzaq et al., 2020).

Velmurukan et al., (2016) also documented that the effects of salinity on crops are multiple, such as the reduction of growth due to high osmotic potential and ion toxicity, photosynthesis inhibition by decreased CO₂ availability and pigment content, diminished nutrient and water uptake, and root damage; all of these phenomena eventually result in yield reduction. One of the crop growth stages most affected by salinity is seed germination, a phase in which plants are generally quite sensitive to salt stress (Ibrahim, 2016).

The most important criterion for analysis and sustainability of soil ecosystems is to maintain or enhance the soil quality (Schoenholtz, 2000). Several authors have found that linear correlations between yield and soil properties, or between two soil properties, vary greatly both within and between fields (Drummond et al., 1995; Khakural et al., 1999; Pierce et al., 1994; Lamb et al., 1997) and can also exhibit strong temporal variability (Lark et al., 1997). The rice production is affected by available soil-Phosphorus (P), exchangeable soil-Potassium (K), soil pH and soil Electrical Conductivity (EC) and are highly variable in nature mainly due to the variability in water availability (Rathnayake et al., 2015).

Soil pH is the most significant property of soil, and it affects all other soil parameters. Therefore, pH is considered while analysing any kind of soil (Kekane et al. 2015). It may increase or decrease according to soil nature which will ultimately affect the availability of nutrients (Liu, 1996). Soil pH influence soil microorganisms as well as availability of nutrients to plants (Fageria et al., 2011). In acidic wetland soils, usually pH increases because of flooding (Sahrawat, 2012).

Electrical conductivity is also a very important property of the soil, it indicates the quality of the soil. It is a measure of ions present in solution (Tale and Sangita, 2015). Soil is considered saline if it has an ECe (electrical conductivity of its saturation extract) above 4 dSm⁻¹ (Rengasamy, 2006). Even at ECe as low as 3.5 dSm⁻¹, rice loses about 10% of its yield, and 50% yield loss was recorded for rice at ECe 7.2 dSm⁻¹ (Umali, 1993).

Understanding the relationships between rice yield and soil properties such as bulk electrical conductivity is of critical importance in precision farming. The Apparent Electrical Conductivity of soil (ECa) is influenced by a combination of physico-chemical properties including soluble salts, clay content and mineralogy, soil water content, bulk density, organic matter and soil temperature (Ezrin et al., 2010).

Rice production is limited by soil Phosphorus (P) deficiencies in many parts of the world. Phosphorus is second most significant plant nutrient after nitrogen. It is often necessary to apply phosphorus for rice production to meet our food security in future. Increase in P accumulation enhances a potential loss of P through soil erosion and/or leaching in paddy rice field (Ooya et al., 2007) as well as in the other agricultural crop lands. Impacts of long-term fertilization regimes on rice productivity and soil P availability is largely unknown (Lan et al., 2012).

Potassium plays an important role in different physiological processes of plants, and is one of the important elements for the plant development (Solanki and Chavda, 2012). Fageria et al., (2011) reported that Calcium and Magnesium deficiencies are rare in lowland rice and changes in their concentrations are extremely small amount in flooded soils. Biswas et al., (2019) reported that the Basic cations viz., Calcium (Ca), Magnesium (Mg) and Potassium (K) play an important role in maintenance of good quality soil and in sustainable crop production. Their uptakes do not depend only on their concentrations in soil but also on their ratios, although ratio changes because of many factors. Voogt (1987) reported that the Calcium, Phosphorus and Magnesium strongly interfere with each

other during uptake process, and Magnesium deficiency may occur when soil Ca: Mg ratio is high (Bergmann, 1992).

Sulfur (S) is important throughout the growth cycle of the crops. Plant tissues must contain sufficient concentrations of Sulfur, only then the plants can produce carbohydrates, proteins, oils and vitamins to their full potential (Tandon and Messick, 2007). Sulfur is important in rice nutrition for the synthesis of amino acids and proteins, which account for approximately 90% of organic S in the plant, and the Sulfur requirement of rice varies according to the Nitrogen supply. When S becomes limiting, addition of N does not change the yield or protein level of plants. If it is limiting during early growth, then tiller number and therefore final yield will be reduced. Although the concentration of Sulfur in rice grain is higher than in rice straw, there is less remobilization of S to the grain than for Phosphorus.

Significant negative relationships were observed in results of the earlier studies between Sulfur, Zinc and Potassium nutrient contents of rice foliage and incidence of brown planthopper (BPH). Zinc and Sulfur content in foliage was positively correlated with leaf folder incidence (Dash et al., 2007). Whereas Phosphorus showed significantly positive correlations with BPH only and Nitrogen showed positive correlation with both BPH and leaf folder.

Bhindhu et al., (2018) reported that the acid tropical soils of Kerala are characterized with low levels of basic cations and high levels of acidic cations like Iron and Manganese. Higher iron content in the rhizosphere has antagonistic effect on uptake of essential nutrients leading to reduction of rice yield.

The combined role of Iron and Manganese in plant nutrition is much more important than their individual roles (Karim and Mohsin, 1964; Chiu, 1967; Patel et al., 1977; Alam, 1982). The low levels of Fe and Mn were essential for better plant growth and efficient utilization of these nutrients by rice plant (Alam, 1985).

Zinc deficiency continues to be one of the key factors in determining rice production in several parts of the country (Chaudhary et al., 2007), and it has been reported in lowland rice of India also (Mandal et al., 2000).

Among trace metals, the redox-active element Copper is an essential micronutrient for crops (DalCorso et al., 2013), and plays an important role in the crop growth by increasing the tillering and pollen viability of the crop (Das, 2014). But excessive amount of the same in soil shows highly toxic effect to plant, such as growth inhibition and oxidative damage by generating reactive oxygen radicals (Adrees et al., 2015), and can cause toxic effects on most organisms (Elguindi et al., 2011). Copper acts as a structural element in regulatory proteins and involves in photosynthesis electron transport, mitochondrial respiration, stress responses, cell wall metabolism and hormone signaling. The cereal crops show white tips as Cu deficiency symptoms and the deficiency of such micronutrient has been identified as the main limiting factor for crop yield, food quality and human health (Alloway, 2008).

Shukla et al., (2014) reported that Indian soils are extensively deficient in micronutrients and 5.4 per cent soils of India recorded Cu deficiency. The total Cu content in Indian soils ranged from 1.8 to 960 mg kg⁻¹ and the available Cu content ranged from 0.10 to 378 mg kg⁻¹. More than 25 per cent of Cu deficiency recorded high in the soils of Tamil Nadu. The rice crop also needs adequate amount of Cu for obtaining high yield which cannot be achieved by applying the NPK fertilizers alone.

Ahamad et al., (2009) reported that presence of Boron in plant relate to sugar transport, flower production, retention, pollen tube elongation, its germination and translocation of carbohydrate and sugars to reproductive organs, which in turn improved the spikelet number and fertility that influenced the yield and productivity.

Leaf Parameters analysis in Rice Agro ecosystems

Nitrogen (N) and Potassium (K) are two elements that are required in great quantities for rice growth and yield formation (Oosterhuis et al., 2014). Hou et al., (2020) revealed that the increased K rates decreased leaf greenness but increased grain yield, and they proposed that the increase of K rates decreased leaf N and Mg concentrations due to the antagonistic relationships between K⁺ and NH₄⁺ as well

as Mg^{2+} , or the increase of K rates promoted leaf development, which diluted the leaf N and Mg concentrations.

Schimansky, (1981) revealed that the reduction in plant growth at higher Ca rates may be due to antagonism of Ca with NH_4 , K, and Mg, and number of micro-nutrients such as Fe, B, Cu, Mo, Mn, and Zn, and Flowers et al., (1991) reported that another important reason for declined growth at higher external Ca concentration could be the extra cellular salt (Ca) accumulation i.e. osmotic effect: a primary factor in salinity damage.

Magnesium (Mg) is a macronutrient required by plants for growth and metabolism, and Mg is a component of chlorophyll and is involved in photosynthesis and protein synthesis. It activates several enzymes and regulates cellular pH and cation-anion balance. In rice plants, Mg deficiency that can be exacerbated by Fe toxicities can result in reduced spikelet number, reduced grain weight and reduced grain quality (Marschner, 2012). A critical deficiency level of 1 cmolc kg⁻¹ soil is recommended for rice (Fairhurst et al., 2007).

Correlation coefficients between the soil sulfate fractions extracted with phosphates and the sulfur concentrations of rice plants grown in fields were around 0.71 (significant at 5 % level)(Suzuki,1978).

Yoshida and Chaudhry (1979) revealed that the visible symptoms of Sulfur deficiency were characterized by pronounced elongation of roots followed by a general yellowing of upper leaves, yellowing that spread to lower leaves, and finally yellowing of the whole plant. Reduced tiller number and stunted growth, delayed flowering and high percentages of unfilled grains were also observed.

Silva et al., (2003) reported that the Iron toxicity is a widespread nutritional disorder of rice grown on irrigated soil, characterized by yellowing or bronzing of leaf, severe growth retardation at the beginning of the vegetative phase, and a high degree of sterility in the reproductive phase resulting up to 88% production losses. So Iron deficiency is a yield-limiting factor with major implications for crop

production in numerous agricultural regions of the world (Hansen et al., 2006). Rice plants are especially susceptible to low Fe supply, (Takahashi et al., 2001).

Leaf Manganese is an essential micronutrient beneficial for the growth of rice plants, and needed by plants in a small amount, but its existence could stimulate the growth of plants substantially. According to Mousavi et al., (2011) Mn plays a role in the biosynthesis of chlorophyll, and its availability maintained the greenness of leaves to delay senescence in photosynthesizing (Agustina, 2011).

Under water culture conditions, 10 ppm Mn was reported to be the upper critical level in the culture solution for maintaining normal rice growth; at this level, the straw contained 1.000 ppm Mn (Ishizuka et al., 1961). Toxicity symptoms started to develop at 30 ppm Mn in culture solution (Kasugai, 1939).

Zinc is an important trace element, essential for the healthy crop growth and metabolism (Alloway, 2008). In rice though it is required only in small quantity, its deficiency has an adverse effect on healthy crop growth and yield may reduce up to 30 percent (Hafeez et al., 2015). It is essential for several biochemical processes in the rice plant, such as cytochrome and nucleotide synthesis, auxin metabolism, chlorophyll content, enzyme activation and membrane integrity (IRRI, 2000).

After Nitrogen (N), Phosphorus (P) and Potassium (K), widespread Zinc (Zn) deficiency has been found responsible for yield reduction in rice (Fageria et al., 2002; Quijano-Guerta et al., 2002). Chaudhary et al., (2007) reported that Zinc plays a significant role in the growth and development of rice. Among the seventeen essential nutrient elements, Zn is the fourth most deficient nutrient element in Indian soils (Shukla and Behera, 2011). Various biochemical and metabolic process in rice such as synthesis of cytochromes and nucleotides, auxin metabolism, production of chlorophyll, activation of several enzymes, membrane integrity, metabolism of carbohydrate, cell wall development, gene expression and respiration are controlled by Zinc (IRRI, 2000; Broadley et al., 2007).

The main factors affecting the Zn availability to the rice plant are soil pH, concentration of Zn, Fe, Mn and P in the soil solution, organic matter content,

bicarbonate content, high Ca to Mg ratio, moisture content in the soil and redox potential of the soil.

Copper (Cu) is a micronutrient in plants and functions are related to respiration and photosynthesis in conjunction with a large number of enzymes (Marschner, 1995; Yruela et al., 2000). Excess Cu causes the impaired growth of the roots and shoots, nutrient deficiency, chlorosis, and tissue necrosis and plant death will happen in severe cases (Marschner, 1995; Kopsell and Kopsell 2007).

The Boron requirement is much higher for reproductive growth than for vegetative growth in most plant species. Boron uptake correlated well with the concentration of H_3BO_3 in the soil solution. Boron plays a major role in rice on metabolic involvement in the metabolic pathways involved in cell division and cell elongation, calcium utilization, flowering/fruitletting, disease resistance, water relations and act as catalyst for several reactions. It is also very much essential for the metabolism of carbohydrate, transport of sugars, synthesis of nucleotide, respiration and pollen viability (Suman and Sheeja, 2018). The application of Boron through different sources either through soil or foliar spray was found to be beneficial in stimulating plant growth and in increasing yield of rice (Jawahar and Vaiyapuri, 2008).

Very few studies were conducted earlier in Kaipad rice fields regarding the Physico- chemical parameters of Water, Soil and leaf. This study may help farmers and researchers to understand the variation in the physico-chemicals parameters in Kaipad rice fields and how it compares with these parameters in conventional rice fields.

MATERIALS AND METHODS

Analysis for Water Parameters

For the analysis of physical and chemical parameters of the water sample, we have selected six Kaipad and six conventional rice fields. The sample collection was done for five rice cultivating months, i.e., June, July, August, September, and October in 2015, 2016 and 2017. The samples were collected in white jerry cans (2

Litre). The jerry cans were cleaned well using forced water, and shade dried. The water was collected by dipping the jerry can without creating any air bubbles inside it and without any muddy substances also. After the collection, the jars were closed well and covered the top area with plastoseal to avoid the leakage of water during transportation. The details like Place of Collection, Type of Rice field, Date of collection, Time of Collection and Name of Collector were given in printed data label sheet. The labels were again laminated with transparent cello-tape to avoid the missing of data label during transportation. The collected water samples were brought to water analyzing laboratory, Water quality division, Centre for Water Resources, Development and Management, Kunnammangalam, Kozhikode. Some physical parameters test and whole chemical parameters tests were done from the laboratory.

Water Physical Parameter Analysis

The physical parameters like Water Surface Temperature, Water Bottom Temperature, Water pH, Water Salinity, Water Electrical Conductivity, Water Dissolved Oxygen, Water Chemical Oxygen Demand, Water Total Hardness and Water Turbidity were tested.

Water Surface Temperature

The water surface temperature was tested using glass thermometer by touching its long tip (mercury bulb) on water surface until the liquid column in the thermometer stopped moving and stable value reached (normally one minute). The thermometer was held at eye level, and the value noted.

Water Bottom Temperature

The thermometer was dipped into the water up to 10 cm, and kept for one minute or until the movement of liquid column stops. Checked the value by holding the thermometer at eye level. The results were noted in field notebook.

Water pH Analysis

The pH of a solution is the negative common logarithm of hydrogen ion activity,

$$\text{pH} = -\log_{10} (\text{aH}^+)$$

pH of the samples was measured using Systronics digital pH meter. The instrument is calibrated using pH 4, 7 and 10 buffer solutions.

Water Salinity Analysis

Water Salinity refers to the concentration of soluble salts in water sample. Water salinity was measured using Systronics Salinity meter. The Meter was prepared according to manufactures directions, and calliberated using a standard solution. The probe was rinsed using distilled or deionized water. Later the probe was placed into the sample water and conductivity of the water sample noted.

Water Electrical conductivity Analysis

The ability of water to conduct an electric current is known as conductivity or specific conductance and depends on the concentration of ions in solution, Conductivity is also temperature-dependent; thus, the temperature of the sample should be measured and recorded.

Electrical conductivity of water is directly proportional to its dissolved mineral matter content. Several factors influence conductivity – amongst them, temperature, ionic motilities', and ionic values. It is the overall concentration of ions present in water that influences conductivity the most. Conductivity becomes an indicator of dissolved ions present in any water sample. It is a rapid method of estimating the concentration of total dissolved solids. And it is measured in millisiemens per metre ($1 \text{ mS m}^{-1} = 10 \text{ } \mu\text{S cm}^{-1} = 10 \text{ } \mu\text{mhos cm}^{-1}$). The measurement should be made in situ, or in the field immediately after a water sample has been obtained, because conductivity changes with storage time.

Determination of Electrical Conductivity:

EC were measured using Systronics conductivity meter.

Reagents:

1. **Conductivity water** – The conductivity of the water was less than 1 mhos /cm.
2. **Standard KCl solution (0.01M)**: Dissolved 745.6 mg anhydrous KCl in conductivity water and made up to 1000 ml at 25 °. Specific conductance of this solution was 1413 $\mu\text{S}/\text{cm}$.

Conductivity measurement procedure:

The Cell was rinsed with one or more portions of the sample to be analyzed. Then the conductance was directly measured from the conductivity meter. The cell constant was taken as unity.

Water Dissolved Oxygen Analysis

Dissolved Oxygen was estimated volumetrically by the Winkler method with Azide modification.

$\text{DO, mg/l} = (\text{Normality of thio} \times \text{Volume of thio} \times 8 \times 1000) / \text{volume of sample.}$

Water Chemical Oxygen Demand Analysis

It is a measure of oxygen consumed to oxidize organic matter by boiling with potassium dichromate and concentrated Sulfuric acid for two hours. For most organic compounds, the oxidization is 95 to 100 percent complete with this method.

Method: Open Reflux

Apparatus:

- Reflux Flasks, consisting of 250ml flask with flat bottom and with 24/40-ground flask neck

- 30cm jacket Liebig or equivalent condensers with 24/40 ground glass joint, Hot plate or gas burner having sufficient heating surface.

Reagents:

1. **Standard Potassium dichromate solution (0.25N):** Dissolved 12.259g $K_2Cr_2O_7$, primary standard grade, previously dried at $103^\circ C$ for 2 hours, in distilled water and dilute to 1000ml.
2. **Sulfuric Acid reagent:** Added 5.5g $Ag_2 SO_4$, technical or reagent grade, per kg of conc. H_2SO_4 , keep for a day or two to dissolve.
3. **Ferroin indicator solution:** Dissolved 1.485g 1, 10- phenanthroline monohydrate and 695mg $FeSO_4 \cdot 7H_2O$ in distilled water and dilute to 100ml.
4. **Standard ferrous ammonium Sulfate (FAS) 0.25N:** Dissolved 98g $FeSO_4 (NH_4)_2 SO_4 \cdot 6H_2O$ in distilled water, add 20ml Con $H_2 SO_4$, cool and dilute to 1000ml.
5. **Mercuric sulfate, $Hg SO_4$, Powder.**

Procedure:

Took 50 ml of sample plus 50 ml distilled water in a 500 ml-refluxing flask, added 1g $HgSO_4$, few glass beads, and 5 ml H_2SO_4 reagent, mixed and cooled. Added 25 ml of 0.25N $K_2Cr_2O_7$, solution, and mix. Connected the flask to the condenser and turned on cooling water, added additional 70 ml of sulfuric acid reagent through open end of condenser, with swirling and mixing. Refluxed for 2 hours, cooled, washed down condenser with distilled water to double the volume of contents, cool. Added 2 drops of Ferroin indicator, titrated with FAS until a colour change from bluish green to reddish brown occurs. Also refluxed and titrated a distilled water blank with reagent.

Standardization of FAS:

Diluted 10 ml standard $K_2Cr_2O_7$ to about 100ml, add 30ml con H_2SO_4 , cool. Added 2 drops of Ferroin indicator and titrated with FAS.

Calculation:

$$\text{Normality of FAS} = \frac{0.25 \times \text{Volume of } 0.25N \text{ } K_2Cr_2O_7, \text{ ml}}{\text{Volume of FAS used, ml}}$$

$$\text{COD, mg /l} = \frac{(A - B) N \times 8000}{\text{ml sample used}}$$

Where

A = FAS used for blank, ml

B = FAS used for sample, ml

N = Normality of FAS

Water Total Hardness Analysis

Determination of Total Hardness

Calcium and Magnesium are principal cations causing hardness. Calcium and Magnesium ions react with EDTA to form soluble complexes and the completion of the reaction is indicated by the colour change of a suitable indicator such as Eriochrome black T. Calcium and Magnesium form a complex of wine red colour. Therefore, by adding EDTA solution, the complex is broken, and a new complex is formed and gives blue colour.

Reagents:

1. **Standard EDTA solution (0.01M):** Weigh 3.723 g analytical reagent grade Disodium Ethylenediamine Tetraacetate Dihydrate, dissolve in distilled water and dilute to 1000 ml.
2. **Buffer solution (Ammonium Hydroxide + Ammonium Chloride):** Dissolve 16.9g NH_4Cl in 143ml conc. Ammonium hydroxide.

3. **Erichrome black T indicator:** Mix 0.5g dye and 100g NaCl to prepare a dry powder mixture.

Procedure:

About 25 ml of the sample was taken in a conical flask. Added about 1 ml of ammonium hydroxide buffer solution and titrated against 0.01M EDTA using Erichrome Black T as indicator. At the end point of the reaction colour changes from wine red to blue.

$$\text{Total hardness} = \frac{M \times V \times 1000 \times 100 \text{ mg/l}}{25}$$

M – Molarity of EDTA

V- Volume of EDTA used

Water Calcium Hardness

pH is maintained at 10. As Mg can be first precipitated as $\text{Mg}(\text{OH})_2$, titer value give the amount of Calcium only. Murexide indicator forms a pink colour with Ca and become complex ion change from pink to purple.

Reagents:

1. **Standard EDTA solution (0.01M):** Weigh 3.723 g analytical reagent grade Disodium Ethylenediamine Tetra Acetate Dehydrates, dissolve in distilled water and dilute to 1000ml.
2. **Buffer solution** (Sodium hydroxide 1N).
3. **Murexide indicator:** Mix together 0.5g dye and 100g NaCl to prepare a dry powder mixture.

About 25 ml of the sample was taken in a conical flask Added 1 ml of sodium hydroxide buffer solution and titrate against 0.01 M EDTA using Murexide indicator. At end point colour changes from pale pink to sweet violet.

$$\text{Calcium hardness} = \frac{M \times V \times 1000 \times 100}{25}$$

M = Molarity of EDTA

V = Volume of EDTA used

Calcium in ppm = Calcium hardness x 0.4

Water Magnesium Hardness

Like calcium, magnesium is abundant and a major dietary requirement for humans (0.3- 0.5g/day). It is the second major constituent of hardness and it generally comprises 15-20 per cent of the total hardness expressed as CaCO₃. Its concentration is very significant when considered in conjunction with that of sulfate.

Total hardness- Calcium hardness = Magnesium hardness

Magnesium in ppm = Magnesium hardness x 0.243.

Water Turbidity Analysis

Turbidity is an important parameter for characterizing water quality. Water turbidity is mostly due to colloidal and extremely fine dispersion of suspended matter such as clay, silt, and finally divided organic and inorganic matter. Plankton and other microorganisms also contribute to turbidity. Raw water turbidity can vary from less than 1 NTU to greater than 1000NTU.

Determination of Turbidity:

Turbidity is measured using the instrument called digital Nephelo turbidity meter.

Reagents:

1. **Solution I:** Dissolved 1.00gm hydrazine sulfate, (NH₂)₂.H₂SO₄, in distilled water and diluted to 100ml.
2. **Solution II:** Dissolved 10.00gm hexamethylenetetramine, (CH₂)₆N₄ in distilled water and diluted to 100ml.

3. **Solution III (Stock turbidity suspension):** mixed 5ml of solution I with 5ml of solution II; allowed to stand for 24 hrs and diluted to 100ml. This solution will have a turbidity of 400 NTU.
4. **Solution IV (Standard turbidity Suspension):** diluted 10ml of solution III as prepared above to 100 ml to have a solution with turbidity of 40 NTU.

Prepared calibration graph in the range 0 to 40 units by carrying out appropriate dilutions of solutions III and IV above and taking readings on turbidity meter. Once this instrument is calibrated using the standard solutions the turbidity of the sample can either read directly from the instrument or can be read from the calibration curve.

Water Chemical Parameter Analysis

The water chemical parameters preferred for the analysis are Water Nitrate, Water Phosphate, Water Potassium and Water Sulfate.

Water Nitrate Analysis

Determination of Nitrate-N:

Method: Cadmium Reduction Technique – Spectrophotometer

Apparatus:

- Reduction column.
- Spectrophotometer for use at 543 nm.

Reagents:

1. **Ammonium chloride:** Dissolved 100g NH_4Cl in 500ml distilled water.
2. **Diluted NH_4Cl solution:** Diluted 50 ml Conc. NH_4Cl solution to 2000 ml with distilled water. Amalgamated Cd fillings: Filed sticks of pure Cd metal with a coarse metal hand file and collect the fraction that passes a sieve with 2mm opening and is retained in a sieve with 0.5mm opening. Stirred about

300g filling with 3ml of HgCl_2 solution (1g HgCl_2 /100 ml) for 3mts (for 6 reduction columns). Decanted the liquid. Washed the amalgamated fillings with distilled water and then with diluted HCl (1+99). Washed with DW until no nitrite was detected in the supernatant fluid. Stored the filings in the dark in NH_4Cl solution.

3. **Sulphanilamide:** Dissolved 5g sulphanilamide in a mixture of 50 ml Con.HCl and about 300 ml distilled water and diluted to 500ml. The solution is stable for many months.
4. **N- (1-Naphthyl) Ethylene diamine dihydro chloride (NED) solution:** Dissolved 500mg NED in 500 ml distilled water. Stored in dark bottle. Renewed the solution once a month.
5. **Stock Nitrate solution:** Dissolved 721.8mg anhydrous potassium nitrate, KNO_3 in distilled water and diluted to 1000 ml. This solution contains 100mg/l $\text{NO}_3\text{-N}$.

Procedure:

Preparation of reduction of column:

Packed a plug of glass wool in the bottom of a reduction column and filled the column with distilled water. Poured in sufficient amalgamated cadmium filings to produce a column 30 cm long. Washed the column thoroughly with dilute NH_4Cl solution. Used a flow rate not greater than 8 ml/min. If the rate is too fast, slow it by constricting the end of the outlet siphon, packing more glass wool at the base of the column, or attaching a piece of tubing to the column outlet and using a pinch clamp to control the flow rate. If pH of the sample is above 9, adjust to between 8 and 9, using a pH meter and dilute HCl. Placed 80 to 90ml of the sample in a conical flask and added 2 ml of con. NH_4Cl solution. Mixed and poured the sample from the flask in to the column until the marked level in the top part of the column is reached. Placed 50ml graduated cylinder under the outlet to collect the effluent. Discarded the first 25 to 30 ml effluents.

Within 15 minutes of sample collection added 1.0 ml of Sulphanilamide solution. After 2 minutes, but not exceeding 8 min added 1.0ml NED solution and mixed immediately. After 10 minutes and within 2 hrs measured the absorbance of the solution at a wavelength of 543 nm.

The standard stock solution was passed through the column and a series of standards were prepared in concentration 0.2, 0.4, 0.6, 0.8 and 1ppm with proper dilution. The reagents were added and the absorbance's were determined at 543nm using spectrophotometer. A graph was plotted taking concentration along X- axis and absorbance's along Y- axis.

Similarly, the absorbance's of each sample was taken and from the standard straight line, the concentrations of each sample were determined.

Water Phosphate Analysis

The presence of phosphate in water and waste water is of great significance as large quantities in fresh water indicates pollution, through sewage and industrial waste.

Determination of Phosphate:

Method: Ammonium Molybdate spectrophotometry.

Principle:

Ammonium Molybdate reacts with phosphate to form molybdophosphoric acid, which is reduced to blue coloured complex '*Molybdenum blue*' by the addition of stannous chloride.

Reagents:

1. **Ammonium Molybdate solution:** Dissolved 25.0 g Ammonium Molybdate tetra hydrate in about 175 ml distilled water. Carefully add 280 ml con. Sulfuric acid to 400 ml distilled water and cool. Added the Molybdate solution to the diluted acid and dilute to 1000 ml.

2. **Stannous chloride solution:** Dissolved 2.5g stannous chloride, $\text{SnCl}_2 \cdot 2\text{H}_2\text{O}$ in 100ml glycerol and heat in a water bath. Mixed by stirring with a glass rod. This reagent is stable and requires no special storage.
3. **Phosphate stock solution:** Dissolved 439.0 mg anhydrous potassium dihydrogen phosphate, KH_2PO_4 in distilled water and made up to 1000 ml in a volumetric flask. 1ml = 100 microgram phosphorous.

Procedure:

Took 50 ml sample; added 2ml Ammonium Molybdate solution and 5 drops of stannous chloride solution. After 10 minute to 12 minute measured the colour using Spectrophotometer at 690 nm. Prepared standard graph by diluting appropriate volumes of phosphate working solution.

Determination of Potassium:

Method: Flame Emission Photometry.

Reagents:

1. **Stock potassium solution:** weighed 1.907g KCl, dried at 110°C and cooled in desiccators, transferred to 1 liter volumetric flask and made up with distilled water, 1 ml - 1.00mg K
2. **Intermediate potassium solution:** diluted 10ml stock potassium solution with water to 100 ml. 1 ml = 0.1 mg K,
3. **Standard potassium solution:** Diluted 10ml intermediate solution with water to 100ml, 1ml = $10\mu\text{g}$ K.

Procedure:

Prepared a blank and potassium calibration standard in any of the applicable ranges 0-100, 0-10 or 0-1mg K/l. The instrument reading was adjusted to 100 using 10ppm potassium solution, checked with 5ppm. Then sample was aspirated.

Water Sulfate Analysis

Determination of Sulfate:

Principle:

Sulfate ion is precipitated in an acid medium with Barium Chloride in such a manner as to fix barium sulfate crystals of uniform size. Turbidity meter measures the absorbance of barium sulfate suspension and the sulfate ion concentration is determined by comparison of the reading with a standard curve.

Sulfate concentration of the samples is determined using Systronics Nephelo Turbidimetric meter or spectrophotometrically at 420nm and a light path of 4 to 5cm. The instrument was calibrated using 40 ppm sulfate solution.

Reagents:

1. **Conditioning reagent:** Mixed 50 ml glycerol with a solution containing 30 ml con. HCl, 300 ml distilled water, 100 ml 95% ethyl or isopropyl alcohol and 75 g NaCl.
2. **Barium chloride crystals**
3. **Standard sulfate solution:** Dissolved 147.9 mg anhydrous sodium sulphate, Na_2SO_4 in distilled water and diluted to 1000 ml, 1 ml=100 μg SO_4

Procedure:

Took 30 ml sample in a 100ml conical flask. Added 1.25 ml conditioning reagent and mix. Added a pinch of BaCl_2 crystals and shook well for 1 minute. Immediately after the stirring period has ended, poured some of the solution to the absorption cell of the photometer and measured the turbidity at 30 sec intervals for 4 minutes.

Used 0-40 ppm standard sulfate solutions for calibrating the instrument

Analysis of Soil Parameters

Soil Physical Parameter Analysis

For the analysis of physical and chemical parameters of the soil sample, we have selected six rice fields from Kaipad area and six rice fields from conventional area. The sample collection was done for five rice cultivating months, i.e., June, July, August, September and October in 2015, 2016 and 2017. The clay soil samples were collected using scoop, and filled a particular quantity of soil into the large Zip-lock transparent covers. The details like Place of Collection, Date of collection, Time of Collection, Type of field and Name of Collector were labeled on the zip lock cover to avoid confusion. The collected soil samples were brought to the laboratory, and spread out in a paper, and shade dried for some days (depends on the water content of the collected soil). The shade dried soil was sieved through small mesh sized net, kept the same in another zip lock cover with label, and further used for the physical and chemical parameter analysis of soil samples. The Soil analysis were done under the guidance of Dr. Moosa from Regional Rice Research station, Pattambi and under the super vision of Dr. Hamza, Indian Institute of Spices Research, Kozhikode.

Soil pH Analysis

The pH is defined as the negative logarithm of hydrogen ion activity or simply the log of the reciprocal of the hydrogen ion activity.

$$\text{pH} = \log (\text{H}^+) = \log 1/(\text{H}^+)$$

Apparatus: pH meter, balance, 100 ml beaker, glass rods, buffer solution (pH 4.0, 7.0 and 9.2).

Procedure:

20 g air-dried soil (Pre Sieved through 2mm) were weighed and transferred to a clean 100 ml beaker. 40 ml distilled water were added to this. The content was stirred using a glass rod intermittently and allowed to stand for half an hour. The pH meter electrode was washed carefully with a distilled water jet and wiped dry

using a piece of filter paper. Soil suspension was stirred again just before taking the reading. The electrodes were dipped into the beaker containing the soil water suspension and meter value were recorded (Sawarkar, 2011).

Soil Electrical Conductivity Analysis

Principle:

The electrical conductivity is measured with the help of Soulbridge. The instrument is calibrated and cell constant is determined with the help of 0.1 N KCl solution.

Procedure:

Took 20g of soil in 100 ml beaker, added 40 ml of distilled water and shook intermittently for 30 minutes. Kept this solution overnight to settle the soil particles. Determined the conductivity of supernatant liquid with help of conductivity meter and values were recorded (Sawarkar, 2011).

Soil Chemical Parameter Analysis

Analysis of Soil Available Nitrogen (Alkaline Permanganate Method).

The estimation of Soil Available Nitrogen was done using the procedure given by Subbiah and Asija, (1956).

Analysis of Soil Available Phosphorus (Bray I Method)

The determination of Soil Available Phosphorus was done using the procedure using Bray- No.1 method. The procedure is given by Olsen et al., (1954).

Soil Available Potassium, Calcium and Magnesium (Neutral Ammonium Acetate Extraction).

The estimation of Available Potassium, Calcium and Magnesium was done using the procedure given by Black (1965).

Analysis of Soil Available Sulfur (Morgan's method)

The estimation of Soil Available Sulfur was done using the procedure given by Arora and Bajwa (1994).

Analysis of Soil Available Iron, Manganese, Zinc and copper (DTPA method)

The analysis of Soil available Iron, Manganese, Zinc and Copper was done using the procedure given by Lindsay and Norvell (1978).

Analysis of Soil available Boron (Hot Water Soluble- Curcumin oxalic acid method)

The determination of Soil available Boron was done using the procedure given by Berger and Truog (1939) and Dible et al., (1954).

Analysis of Leaf Parameters

Leaf Chemical Parameter Analysis

Processing of plant samples

Decontamination: The collected leaves were washed in running tap water and then washed in 0.1 % detergent solution, 0.1 N HCl single distilled water and double distilled water.

Drying and Storage:

After washing the samples, excess water sticking on the surface was removed with blotting paper and put in paper cover after proper labeling. Then shade dried the sample for 48 hours, later in hot air oven at 60°C to 70°C for 48 hours or till they obtain a constant weight.

Powdering:

After drying the samples, ground them in a mixie (stainless steel jar) or grinding mill free of metal contamination.

Wet oxidation of plant tissue

Apparatus: Fume cupboard, hot plate, balance, acid dispenser.

Reagents:

1. **Acid mixture (HNO₃.HClO₂, 9:4):** Took 1.8 liters of conc. Nitric acid in a 3-liter bottle, added 800 ml, conc. Perchloric acid, mixed well and stored.

Procedure:

Weighed 1g powdered sample into 100 ml volumetric flask (which is rinsed with 0.1 N HCl, distilled water, double distilled water and dried). Added 10 ml of diacid mixture and kept for 2 hours for cold digestion (to avoid frothing). Then heated slowly for 1 hour and then strongly by adjusting the thermostat of hot plate till a clear white solution/emulsion obtained at the bottom of the flask. Cooled the flask and made up the volume to 100 ml. This solution were used for estimation of total elements like P, K,Ca, Mg, S, Fe, Mn, Zn, Cu, B, etc.

A. Dry/wet ashing method

Apparatus: Thoroughly cleaned all glassware by pre-rinsing with 20% HNO₃ to avoid metal contamination. Rinsed with distilled water followed by double distilled water. Used silica crucible capable of with standing temperature upto 700°C.

1. **Atomic Absorption Spectrophotometer:** Equipment was well maintained and capable of producing 0.200 absorbance or above for 4mg/l copper solution.
2. **Muffle furnace:** With pyrometer to control temperature range of 500-600°C.

Reagents:

1. **Standard stock solution:** Certified AA standards of metal solutions of 1000µg/ml traceable to NIST. USA (E-Merck standards). Prepared working standard solutions to cover linear range of calibration curve (1:2:4 or 1:3:6).
2. **Nitric acid:** Use Ultrapure.
3. **Lanthanum oxide.** 99.99% purity: AAS quality.

Lanthanum chloride solution.1% (w/v): Weighed 11.7(+100 mg) La_2O_3 and transferred to 1 L volumetric flask. Added enough water to wet powder and then slowly added 50 ml Conc.HCl. When powder got dissolved and then diluted to volume with water and mixed well. Lanthanum chloride solution is stable up to 6 months when stored at room temperature.

4. **Cesium chloride solution 1% (w/v):** Weighed 12.7 g CsCl and transferred to 100 ml volumetric flask. Diluted to volume with water and mixed.

Wet ashing:

Weighed the prepared and finely powdered sample (1-2g) and transferred to a 100 ml capacity round bottom flask. Added Conc. nitric acid (10 ml) and perchloric acid (1 ml). Connected to the water-cooled condenser via a middle piece unit. Turned the stopcock provided in the middle piece clockwise (open position). Heated the contents of the flask to boil. Trapped the traces of nitric acid vapours coming out of the condenser with a water suction pump. Heat refluxed till the digestion is completed and the solution is clear. Now turned the stopcock clockwise ('close' position) and continued heating. The nitric acid distillate started collecting in the middle piece. Reduced the volume of nitric acid in the round bottom flask to almost 2ml. (While concentrating care was taken to prevent any explosion due to Perchloric acid). Stopped heating and cooled the entire assembly. Made up the digested solution to a known volume (20 or 30 ml).

Analysis of Leaf total Nitrogen

Leaf total Nitrogen is estimated by the micro-Kjeldhal method as per procedure suggested by AOAC (1995).

Analysis of Leaf total Phosphorus (Vanado Molybdate Method)

The estimation of total Phosphorus was done using the procedure given by Koenig and Johnson (1942).

Analysis of Leaf total Potassium, Leaf total Calcium and Leaf total Magnesium

The estimation of Leaf total Potassium, Leaf total Calcium and Leaf total Magnesium was done using the procedure given by Black (1965).

Analysis of Leaf total Sulfur

The determination of leaf total Sulfur was done using the procedure by given Arora and Bajwa (1994).

Analysis of Leaf total Iron, Leaf total Manganese, Leaf total Zinc and Leaf total Copper

The analysis of Leaf total Fe, Leaf total Mn, Leaf total Zn and Leaf total Cu of leaves was done using the procedure given by Lindsay and Norvell (1978).

Analysis of Leaf total Boron (Curcumin oxalic acid method Method)

The determination of Leaf total Boron was done using the procedure given by Berger and Truog (1939) and Dible et al., (1954).

Monitoring of Plant health

The visit to the selected rice fields were conducted fortnightly to observe the adverse effects in plants due to deficiency of nutrients. The following symptoms were checked:

- Yellowing of leaves and subsequent light brown necrosis.
- Plants with thin stem and overly green leaves.
- Dark green plants with a margin of yellowish brown color and/or necrotic spots on tip of older leaves; wilting, rolling and early senescence. Presence of large number of sterile unfilled spikelets.
- Yellowing and withering of younger leaves; split or rolled leaf tips, stunted plant growth.

- Orange-yellow interveinal chlorosis on older leaves.
- Uniform pale green discoloration in young leaves, followed by complete yellowing.
- Interveinal chlorosis of emerging leaves.
- Young leaves with interveinal chlorosis; pale yellow to whitish discoloration in top leaves.
- Tiny brown spots starting from tips and spreading towards the base
- Pale yellow to whitish interveinal chlorosis in young leaves.
- Stunted plants and less tillering; brown spots on leaf blade and sheath.
- Slightly chlorotic leaves with dark brown to reddish brown spots; older leaves with bronze tint coloration starting from margin.
- Narrow leaves; chlorotic stripes and wilting leaf tips with brown necrotic lesions.
- Reduced plant size; white and rolled leaf tips; emerging leaves with progressing chlorosis.
- Chlorosis along the margins of older leaves.

Data analysis

The relation of Atmospheric, Water, Soil and leaf parameters between months in Kaipad and Conventional rice fields.

Atmospheric –Water – Soil and Leaf Parameters of different months in Conventional and Kaipad rice fields were compared using One-Way ANOVA, and checked whether they are significantly different or not.

Relation between Atmospheric parameters, Water and Soil Parameters, Soil and Leaf Parameters within Kaipad and Conventional rice fields.

We tested relation between Atmospheric Parameters, Atmospheric parameters and Water Physical parameters, Water and Soil Parameters, Soil and Leaf Parameters within Kaipad and Conventional rice fields using linear modeling.

Relation of atmospheric, Water, Soil, Leaf parameters between the Kaipad and Conventional Rice fields.

We used generalized linear model to study the effect of rice field type on Atmospheric, Water, soil and Leaf parameters. We did that for Atmospheric parameters (Atmospheric maximum temperature, Atmospheric minimum temperature, Atmospheric Humidity), Water Parameters (Surface water temperature, Bottom water temperature, Water pH, Water Salinity, Water Electrical conductivity, Water dissolved oxygen, Water Chemical oxygen demand, Water total hardness, Water Turbidity, Water nitrate, Water phosphate, Water Potassium, Water Calcium, Water Magnesium and Water sulfur), Soil Parameters (Soil pH, Soil Electrical conductivity, Available nitrogen, Available phosphorus, Available Potassium, Available Calcium, Available Magnesium, Available sulfur, Available Iron, Available Manganese, Available Zinc, Available Copper and Available Boron), Leaf Parameters (total Nitrogen, total Phosphorus, total Potassium, total Calcium, total Magnesium, total Sulfur, total Iron, total Manganese, total Zinc, total Copper and total Boron). Rice field type was the independent variable and Parameters of the respective group (Atmospheric, Water, Soil and Leaf) as the dependent variable. We used Poisson distribution as the error factor, and log as a link function.

RESULTS

The relation of Atmospheric parameters between months in Kaipad and Conventional rice fields.

The minimum temperature in Kaipad rice fields ($p=0.534$)(Fig.1.1)(Tab.1.1), and Conventional rice fields ($p=0.181$)(Fig.1.2)(Tab.1.2) are not significantly

different between months. Similarly, no significant difference in Atmospheric Humidity in Kaipad rice fields ($p=0.552$)(Fig.1.3)(Tab.1.1) and Conventional rice fields ($p=0.0662$)(Fig.1.4)(Tab.1.2) across months was observed. But the Maximum temperature in Kaipad rice fields ($p=0.0139$ *) (Fig.1.5)(Tab.1.1) and Conventional rice fields ($p=0.0261$ *) (Fig.1.6)(Tab.1.2) shows significant difference between months.

Fig.1.1: Box Plot showing Month v/s Atmospheric Minimum Temperature in Kaipad Rice Fields

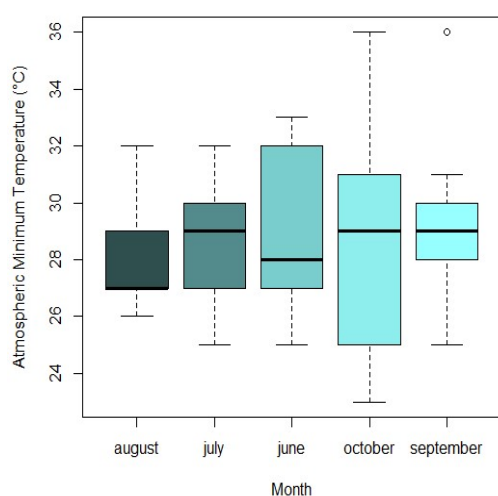


Fig.1.2: Box Plot showing Month v/s Atmospheric Minimum Temperature in Conventional Rice Fields

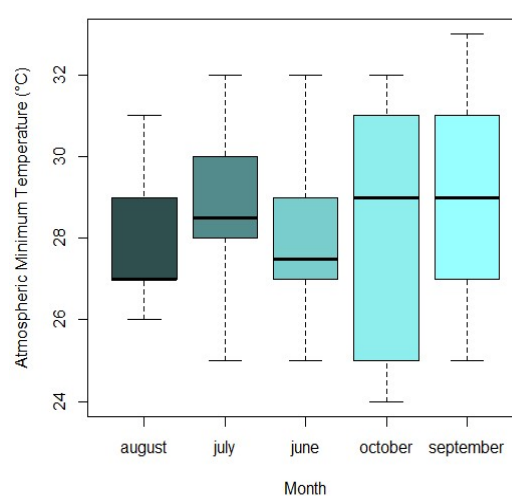


Fig.1.3: Box Plot showing Month v/s Atmospheric Humidity in Kaipad Rice Fields

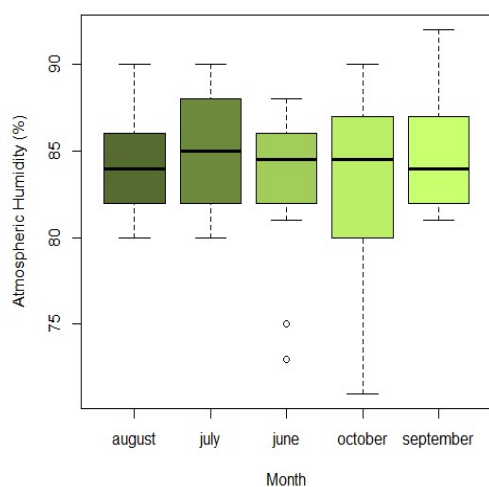


Fig.1.4: Box Plot showing Month v/s Atmospheric Humidity in Conventional Rice Fields

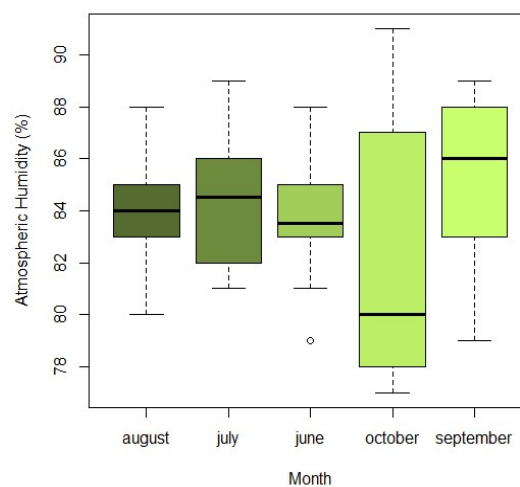


Fig.1.5: Box Plot showing Month v/s Atmospheric Maximum Temperature in Kaipad Rice Fields

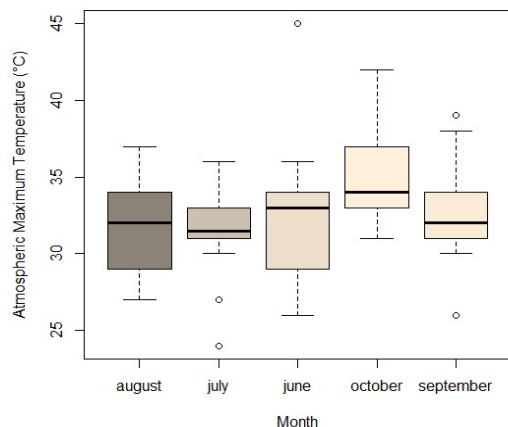
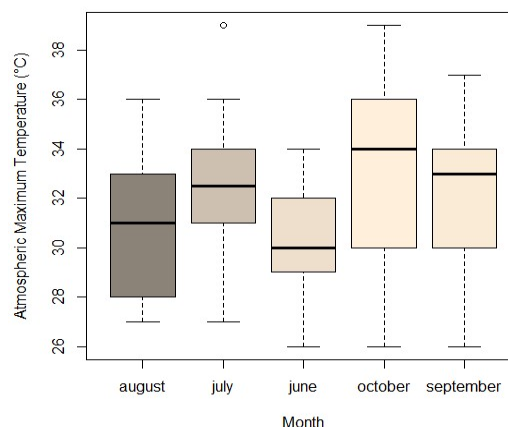


Fig.1.6: Box Plot showing Month v/s Atmospheric Maximum Temperature in Conventional Rice Fields



The relation of Water physical parameters between months in Kaipad and Conventional rice fields

The surface water temperature ($p=0.0423$ *) (Fig.1.8), bottom water temperature ($p=0.0322$ *) (Fig.1.10), water pH ($p=0.016$ *) (Fig.1.12), water salinity ($p=0.0121$ *) (Fig.1.14) and water electrical conductivity ($p=0.0212$ *) (Fig.1.16) in Conventional rice fields are significantly different between months (Tab.1.2). The surface water temperature ($p=0.00572$ **) (Fig.1.7), bottom water temperature ($p=0.0099$ **) (Fig.1.9) and water salinity ($p=0.00583$ **) (Fig.1.13) are significantly different between months in Kaipad rice fields (Tab.1.1).

Fig.1.7: Box Plot showing Month v/s Surface Water Temperature in Kaipad Rice Fields

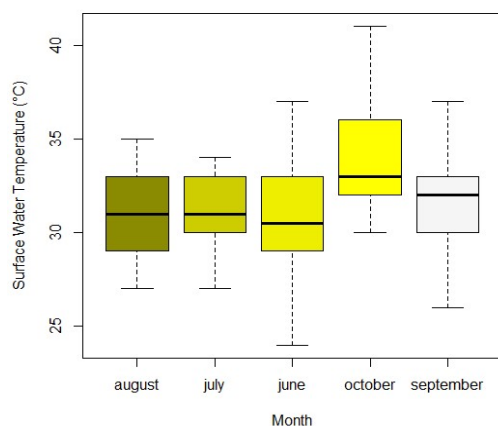


Fig.1.8: Box Plot showing Month v/s Surface Water Temperature in Conventional Rice Fields

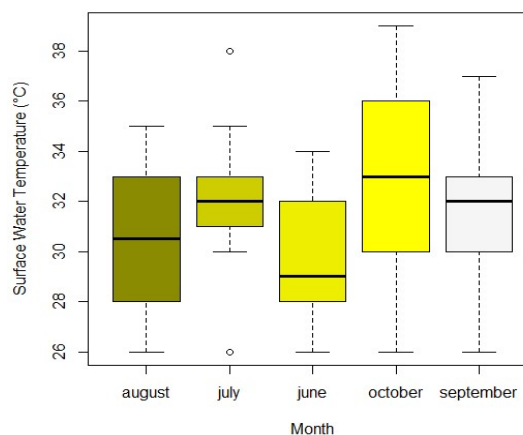


Fig.1.9: Box Plot showing Month v/s Bottom Water Temperature in Kaipad Rice Fields

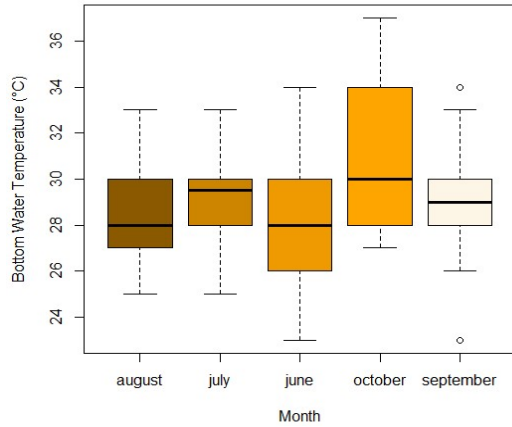


Fig.1.10: Box Plot showing Month v/s Bottom Water Temperature in Conventional Rice Fields

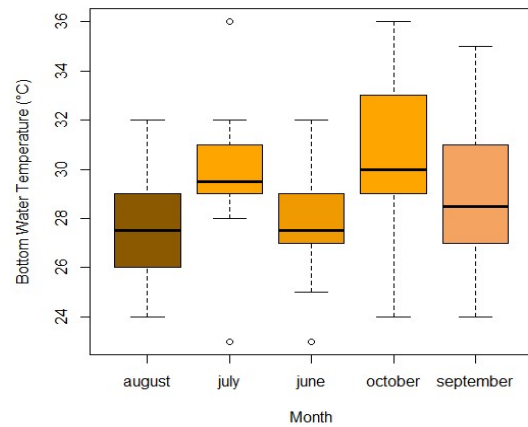


Fig.1.11: Box Plot showing Month v/s Water pH in Kaipad Rice Fields

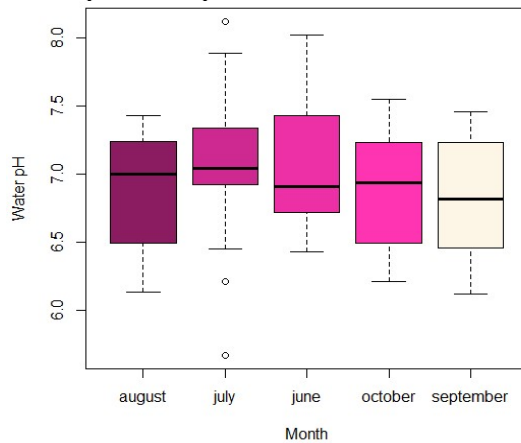


Fig.1.12: Box Plot showing Month v/s Water pH in Conventional Rice Fields

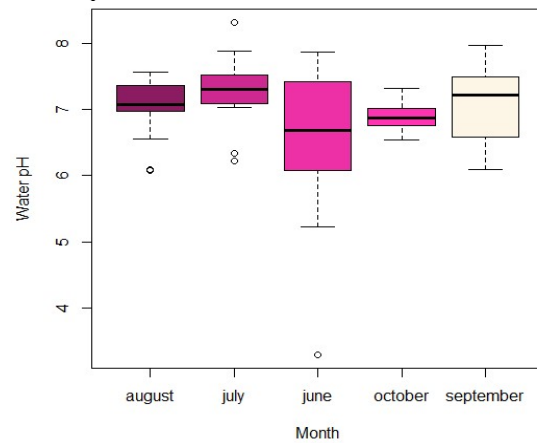


Fig.1.13: Box Plot showing Month v/s Water Salinity in Kaipad Rice Fields

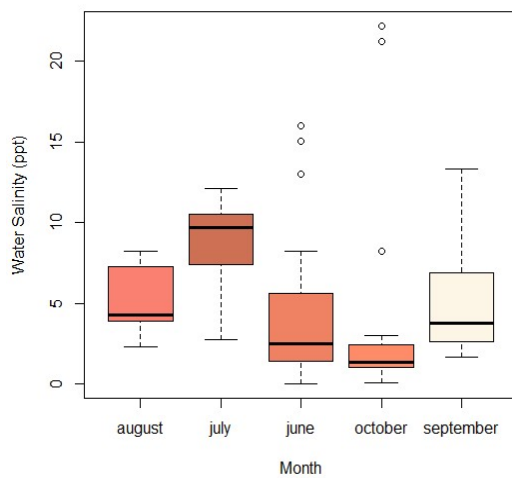
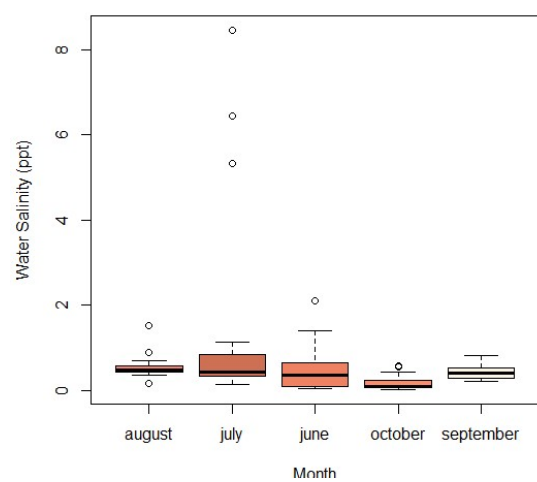


Fig.1.14: Box Plot showing Month v/s Water Salinity in Conventional Rice Fields



The water electrical conductivity ($p < 2e-16$ ***) (Fig.1.15), water chemical oxygen demand ($p < 2e-16$ ***) (Fig.1.19) and water total hardness ($p = 2.42e-14$ ***) (Fig.1.21) in Kaipad rice fields (Tab.1.1); and water chemical oxygen demand ($p = 1.75e-08$ ***) (Fig.1.20) and water turbidity ($p = 7.61e-05$ ***) (Fig.1.24) in Conventional rice fields are significantly different (Tab.1.2).

Fig.1.15: Box Plot showing Month v/s Water Electrical Conductivity in Kaipad Rice Fields

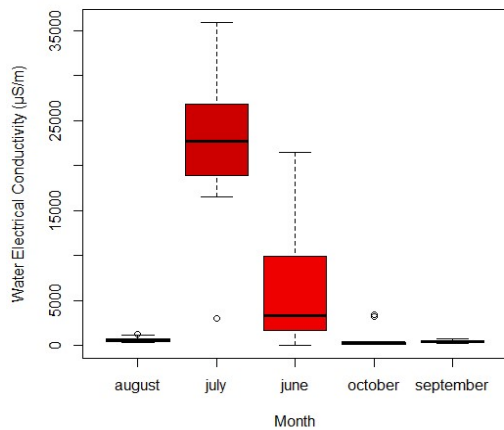


Fig.1.16: Box Plot showing Month v/s Water Electrical Conductivity in Conventional Rice Fields

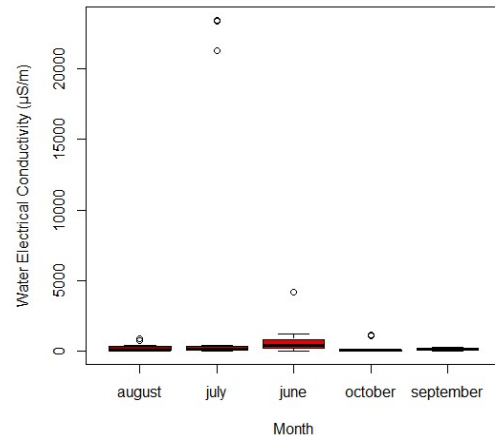


Fig.1.17: Box Plot showing Month v/s Water Dissolved Oxygen in Kaipad Rice Fields

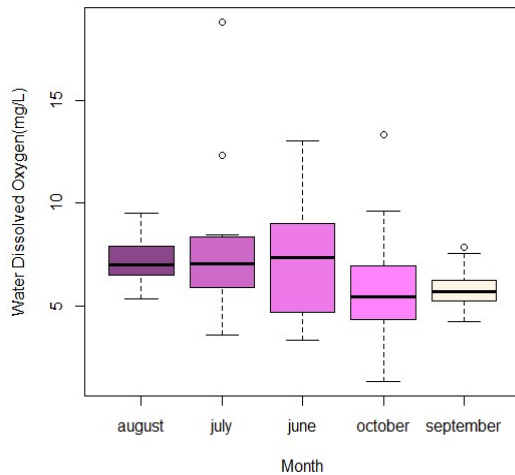


Fig.1.18: Box Plot showing Month v/s Water Dissolved Oxygen in Conventional Rice Fields

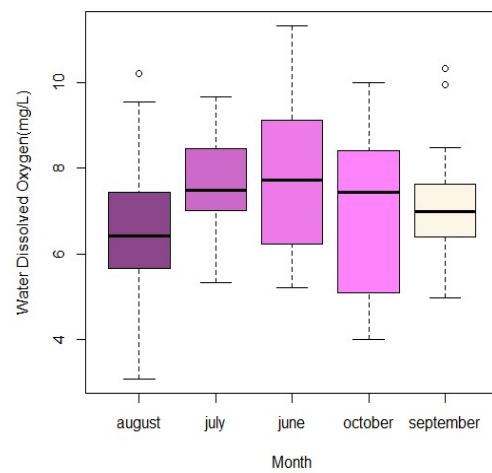


Fig.1.19: Box Plot showing Month v/s Water Chemical Oxygen Demand in Kaipad Rice Fields

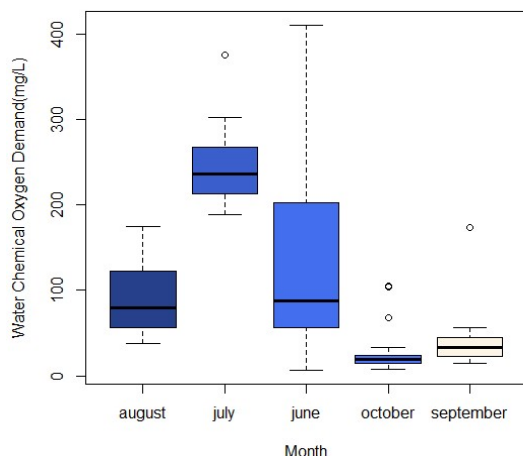
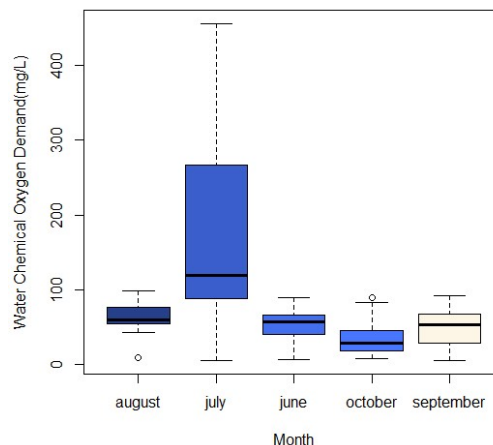


Fig.1.20: Box Plot showing Month v/s Water Chemical Oxygen Demand in Conventional Rice Fields



The water pH ($p=0.466$)(Fig.1.11), water dissolved oxygen ($p=0.0516$)(Fig.1.17) and water turbidity ($p=0.0842$)(Fig.1.23) in Kaipad rice fields (Tab.1.1) and water dissolved oxygen ($p=0.197$)(Fig.1.18) and water total hardness ($p=0.234$)(Fig.1.22) in Conventional rice fields (Tab.1.2) are not showing any significant difference between months.

Fig.1.21: Box Plot showing Month v/s Water Total Hardness in Kaipad Rice Fields

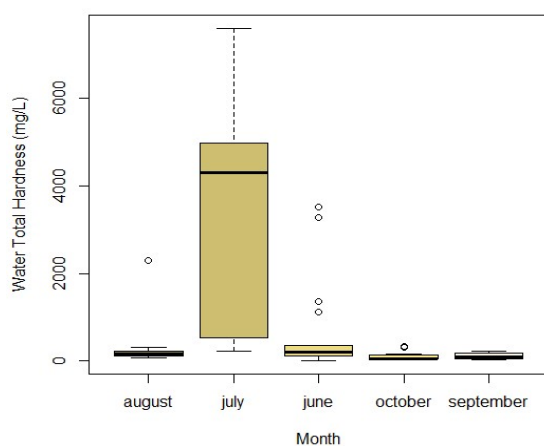


Fig.1.22: Box Plot showing Month v/s Water Total Hardness in Conventional Rice Fields

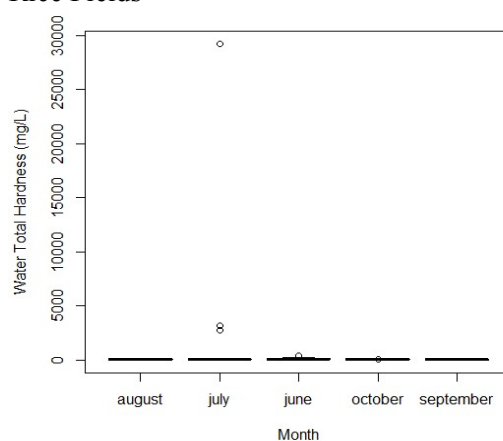


Fig.1.23: Box Plot showing Month v/s Water Turbidity in Kaipad Rice Fields

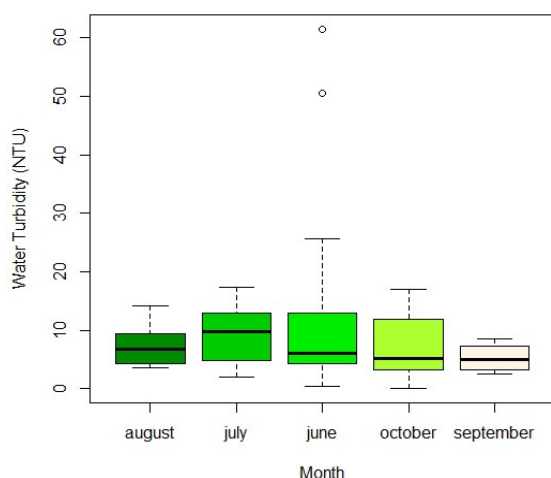
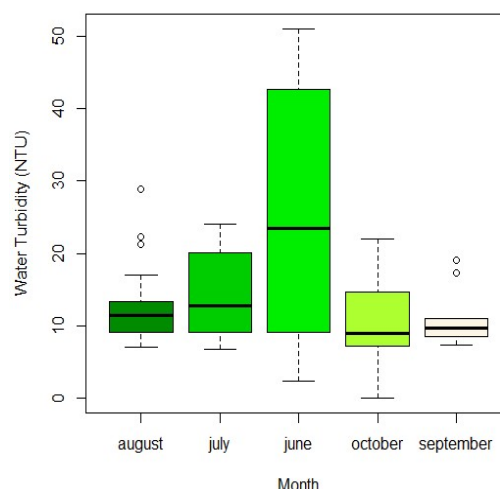


Fig.1.24: Box Plot showing Month v/s Water Turbidity in Conventional Rice Fields



The relation of Water Chemical parameters between months in Kaipad and Conventional rice fields

The Potassium ($p=4.03e-11$ ***) (Fig.1.29), Calcium ($p=<2e-16$ ***) (Fig.1.31), Magnesium ($p=3.62e-12$ ***) (Fig.1.33), Sulfate ($p=3.12e-09$ ***) (Fig.1.35) in Kaipad rice fields (Tab.1.1); and Potassium ($p=3.44e-16$ ***) (Fig.1.30), Sulfate ($p=1.07e-12$ ***) (Fig.1.36) in conventional rice fields (Tab.1.2) are showing significant difference between months. Likewise, Nitrate ($p=0.00667$ **) (Fig.1.26), Phosphate ($p=0.00234$ **) (Fig.1.28) and Calcium ($p=0.0289$ *) (Fig.1.32) in Conventional rice fields are also significantly different between months (Tab.1.2). But, Nitrate ($p=0.943$) (Fig.1.25), and Phosphate ($p=0.0793$) (Fig.1.27) in Kaipad rice fields (Tab.1.1); and Magnesium ($p=0.14$) (Fig.1.34) in Conventional rice fields (Tab.1.2) do not show any significant difference between months.

Fig.1.25: Box Plot showing Month v/s Water Nitrate in Kaipad Rice Fields

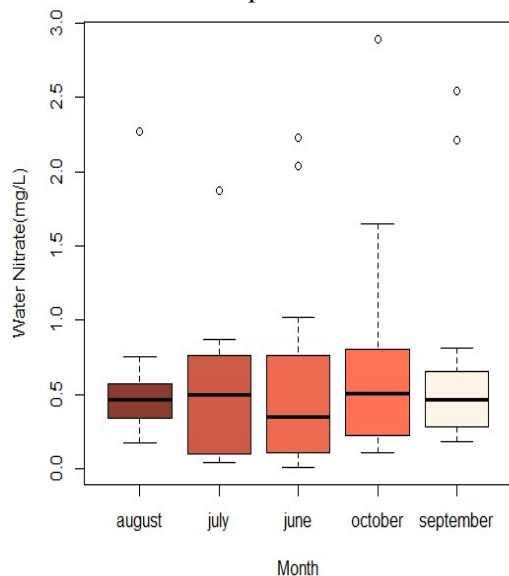


Fig.1.26: Box Plot showing Month v/s Water Nitrate in Conventional Rice Fields

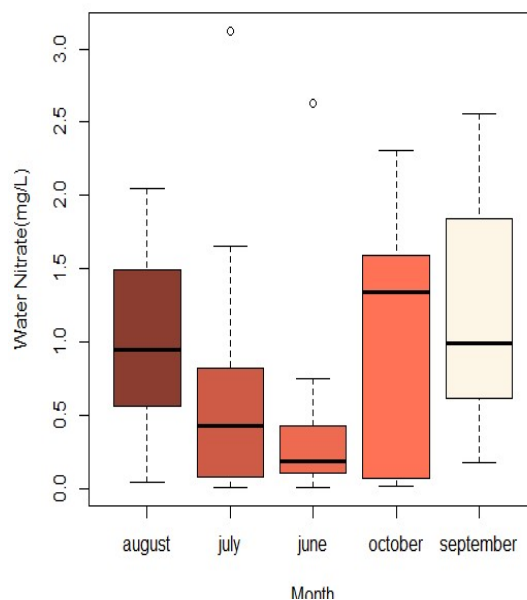


Fig.1.27: Box Plot showing Month v/s Water Phosphate in Kaipad Rice Fields

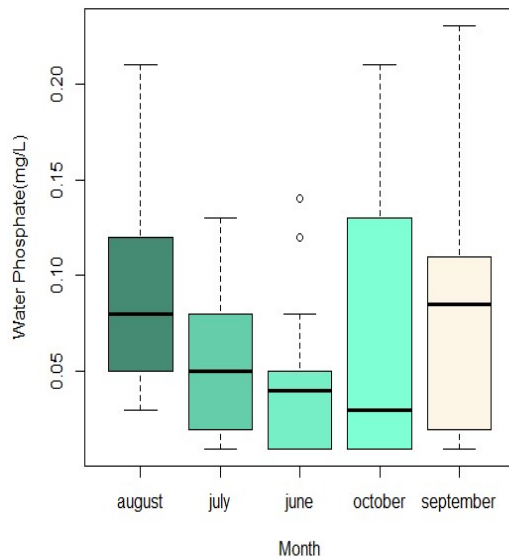


Fig.1.28: Box Plot showing Month v/s Water Phosphate in Conventional Rice Fields

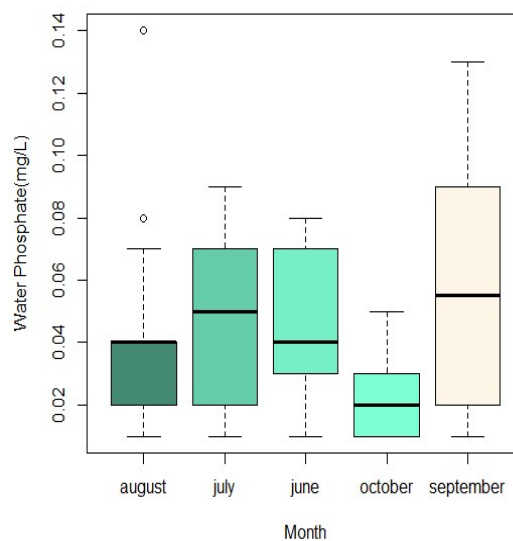


Fig.1.29: Box Plot showing Month v/s Water Potassium in Kaipad Rice Fields

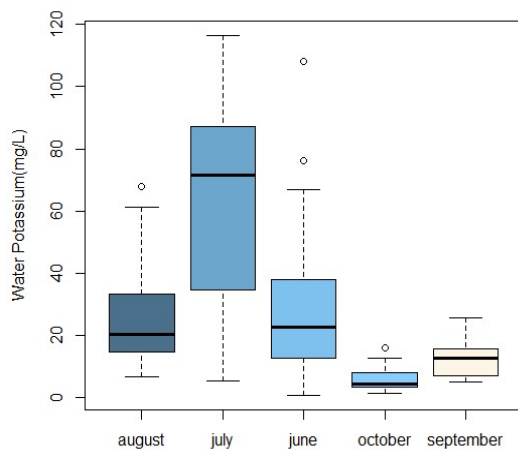


Fig.1.30: Box Plot showing Month v/s Water Potassium in Conventional Rice Fields

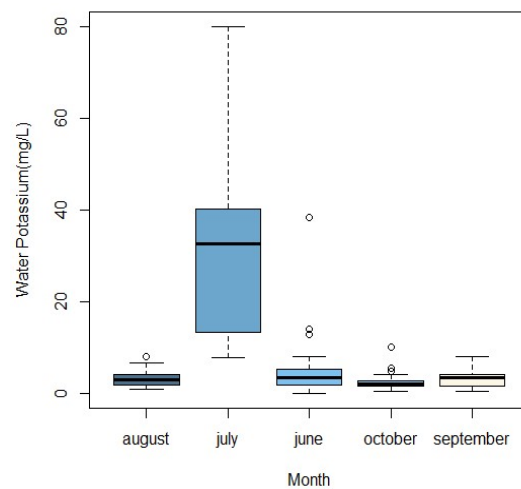


Fig.1.31: Box Plot showing Month v/s Water Calcium in Kaipad Rice Fields

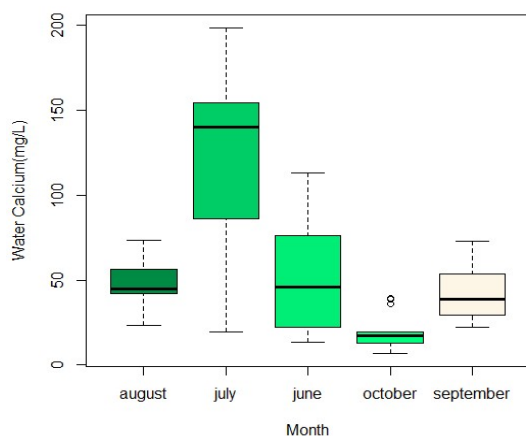


Fig.1.32: Box Plot showing Month v/s Water Calcium in Conventional Rice Fields

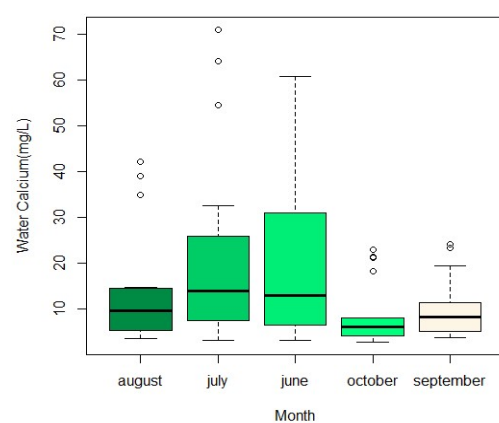


Fig.1.33: Box Plot showing Month v/s Water Magnesium in Kaipad Rice Fields

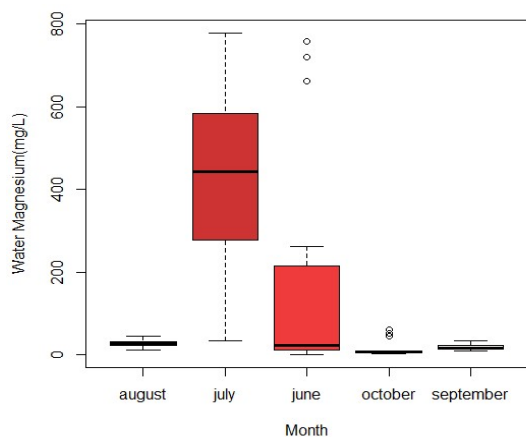


Fig.1.34: Box Plot showing Month v/s Water Magnesium in Conventional Rice Fields

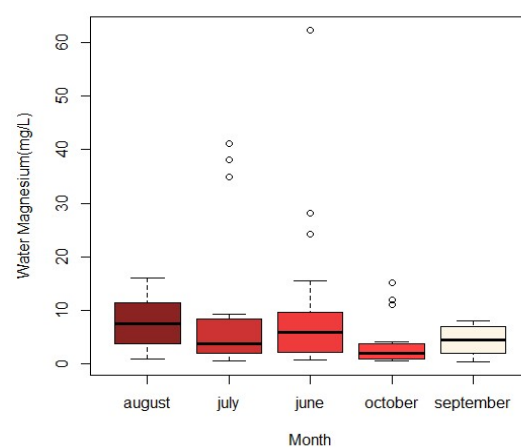


Fig.1.35: Box Plot showing Month v/s Water Sulfate in Kaipad Rice Fields

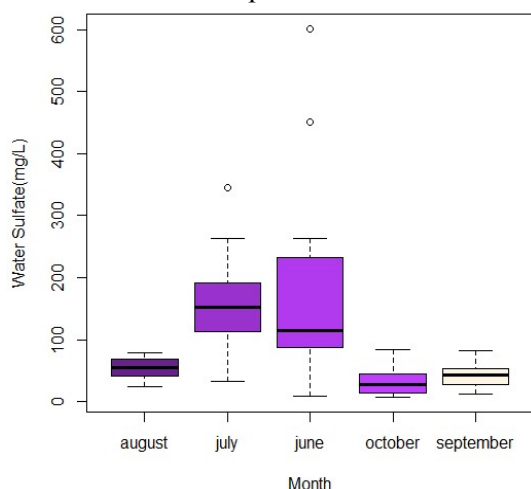
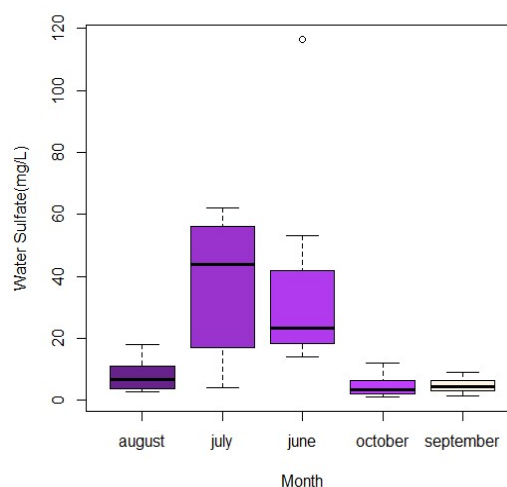


Fig.1.36: Box Plot showing Month v/s Water Sulfate in Conventional Rice Fields



The relation of Soil physical parameters between months in Kaipad and Conventional rice fields

The soil pH and soil electrical conductivity ($p=0.764$ and $p=0.122$ respectively) in Kaipad (Fig.1.37 and Fig.1.39)(Tab.1.1) and in Conventional rice fields ($p=0.315$ and $p=0.957$ respectively)(Fig.1.38 and Fig.1.40)(Tab.1.2) are not showing any significant difference between months.

Fig.1.37: Box Plot showing Month v/s Soil pH in Kaipad Rice Fields

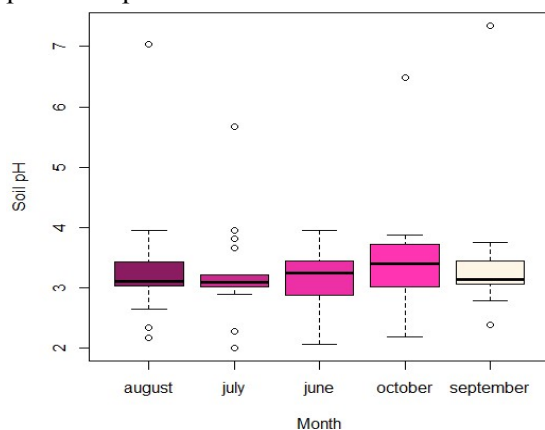


Fig.1.38: Box Plot showing Month v/s Soil pH in Conventional Rice Fields

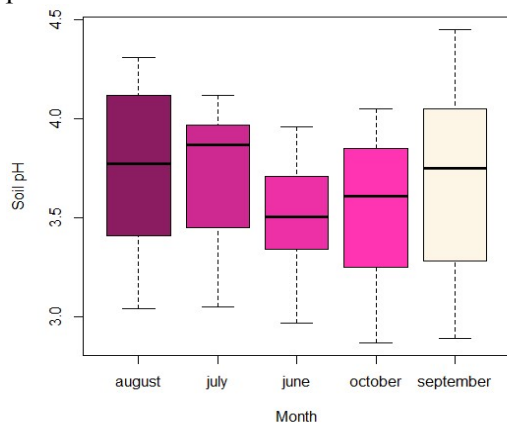


Fig.1.39: Box Plot showing Month v/s Soil Electrical Conductivity in Kaipad Rice Fields

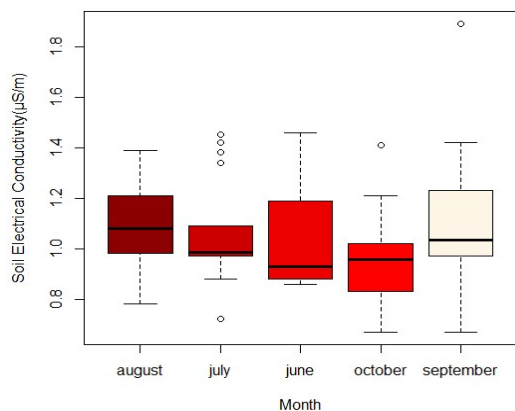
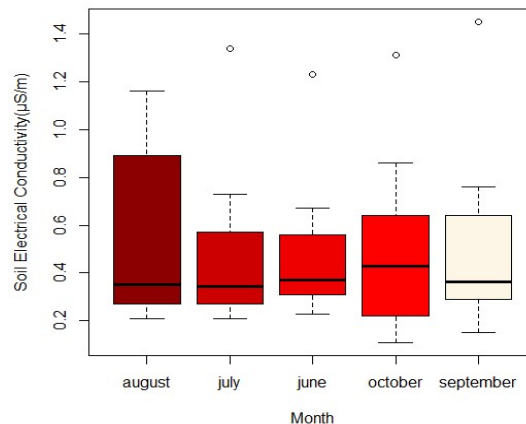


Fig.1.40: Box Plot showing Month v/s Soil Electrical Conductivity in Conventional Rice Fields



The relation of Soil chemical parameters between months in Kaipad and Conventional rice fields.

The Nitrogen ($p=0.754$)(Fig.1.41), Phosphorus ($p=0.47$)(Fig.1.43), Potassium ($p=0.25$)(Fig.1.45), Calcium ($p=0.265$)(Fig.1.47), Magnesium ($p=0.207$)(Fig.1.49), Sulfur ($p=0.879$)(Fig.1.51), Manganese ($p=0.275$)(Fig.1.55), Zinc ($p=0.409$)(Fig.1.57), Copper ($p=0.128$)(Fig.1.59) and Boron ($p=0.319$)(Fig.1.61) in soils of Kaipad rice fields are not showing any significant difference between months (Tab.1.1).

Fig.1.41: Box Plot showing Month v/s Soil available Nitrogen in Kaipad Rice Fields

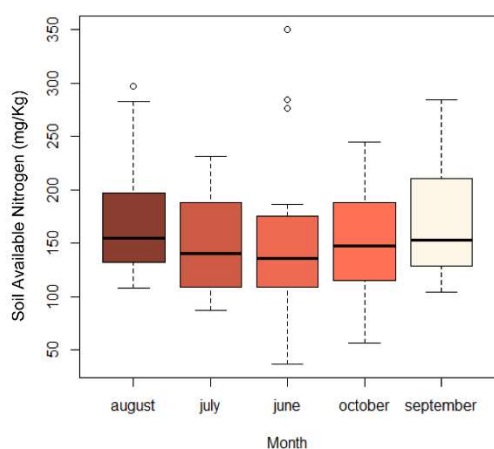


Fig.1.42: Box Plot showing Month v/s Soil available Nitrogen in Conventional Rice Fields

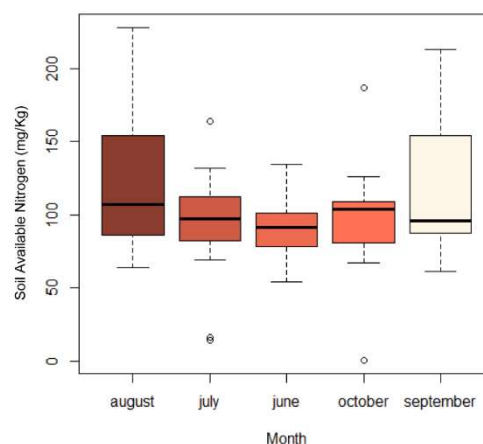


Fig.1.43: Box Plot showing Month v/s Soil available Phosphorus in Kaipad Rice Fields

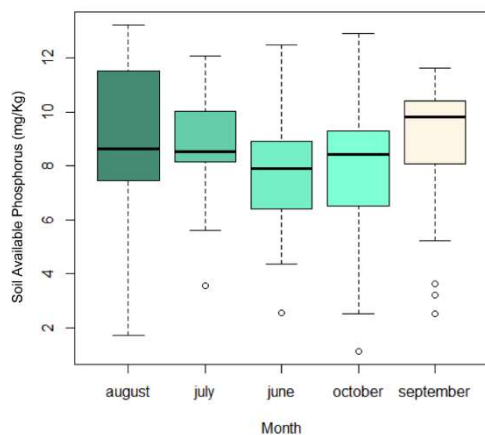


Fig.1.44: Box Plot showing Month v/s Soil available Phosphorus in Conventional Rice Fields

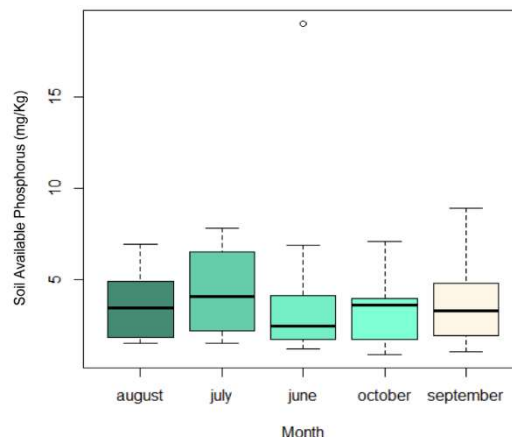


Fig.1.45: Box Plot showing Month v/s Soil available Potassium in Kaipad Rice Fields

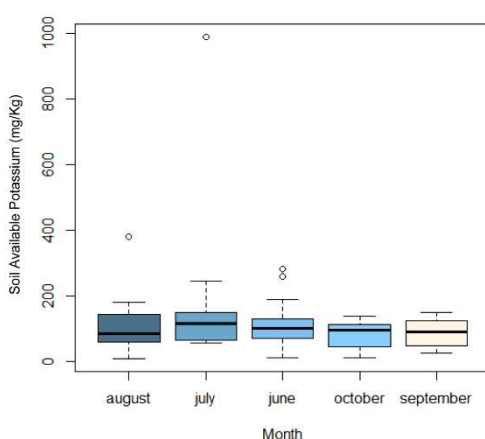
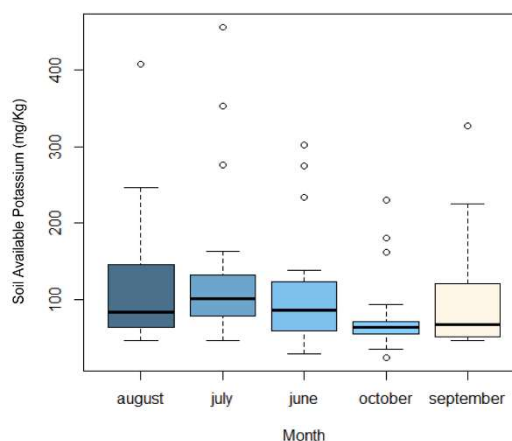


Fig.1.46: Box Plot showing Month v/s Soil available Potassium in Conventional Rice Fields



In soils of Conventional rice fields, the Nitrogen ($p=0.0929$)(Fig.1.42), Phosphorus ($p=0.847$)(Fig.1.44), Potassium ($p=0.334$)(Fig.1.46), Calcium ($p=0.803$)(Fig.1.48), Magnesium ($p=0.942$)(Fig.1.50), Sulfur ($p=0.841$)(Fig.1.52), Iron ($p=0.529$)(Fig.1.54), Manganese ($p=0.722$)(Fig.1.56), Zinc ($p=0.961$)(Fig.1.58), Copper ($p=0.408$)(Fig.1.60) and Boron ($p=0.481$)(Fig.1.62) are also not showing any significant difference between months (Tab.1.2). But Iron ($p=0.000948$ ***) shows a significant difference between months in Kaipad rice fields (Tab.1.2).

Fig.1.47: Box Plot showing Month v/s Soil available Calcium in Kaipad Rice Fields

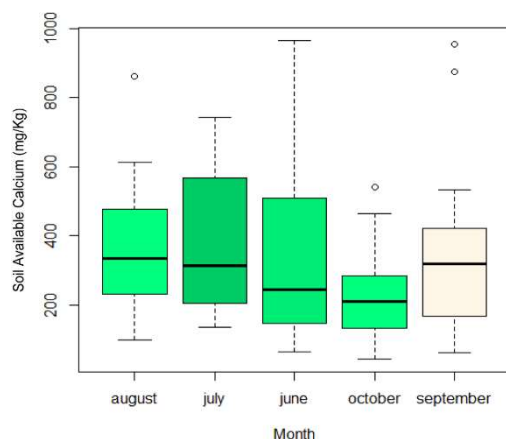


Fig.1.48: Box Plot showing Month v/s Soil available Calcium in Conventional Rice Fields

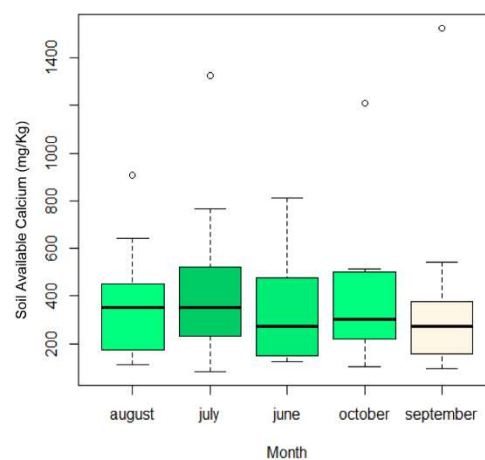


Fig.1.49: Box Plot v/s Soil available Magnesium in Kaipad Rice Fields

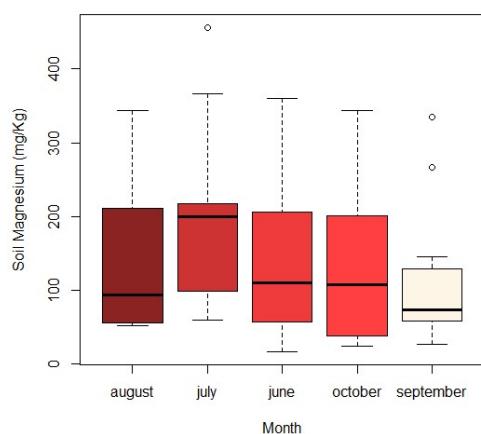


Fig.1.50: Box Plot showing Month v/s Soil available Magnesium in Conventional Rice Fields

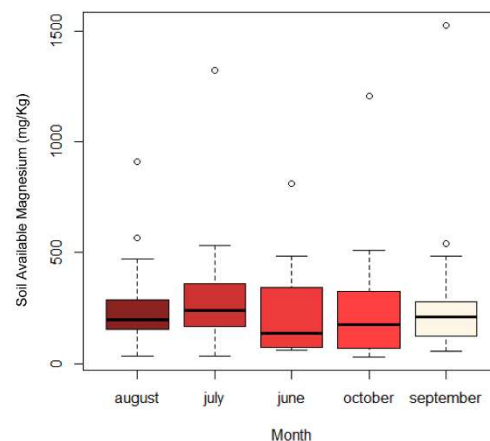


Fig.1.51: Box Plot showing Month v/s Soil available Sulfur in Kaipad Rice Fields

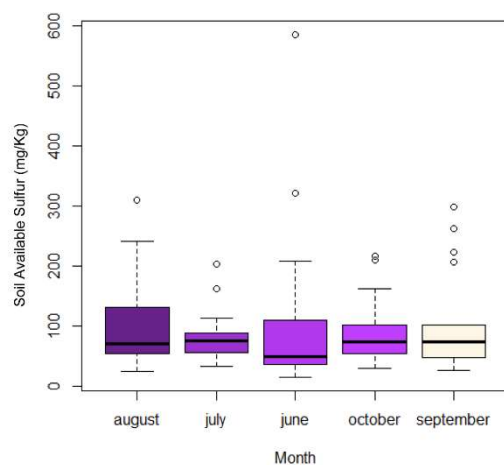


Fig.1.52: Box Plot showing Month v/s Soil available Sulfur in Conventional Rice Fields

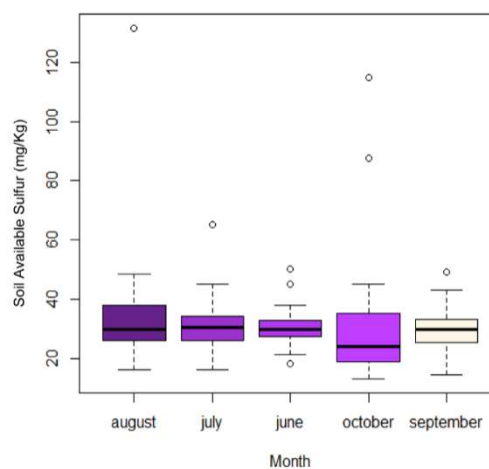


Fig.1.53: Box Plot showing Month v/s Soil available Iron in Kaipad Rice Fields

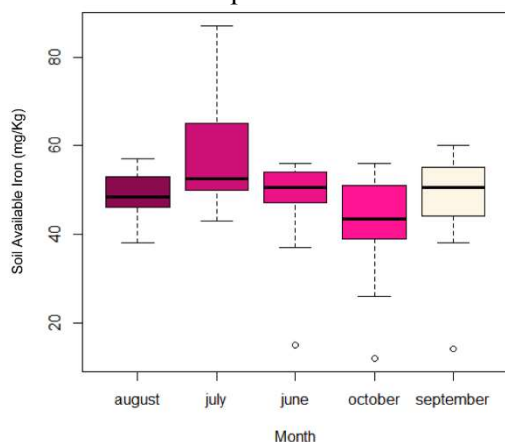


Fig.1.54: Box Plot showing Month v/s Soil available Iron in Conventional Rice Fields

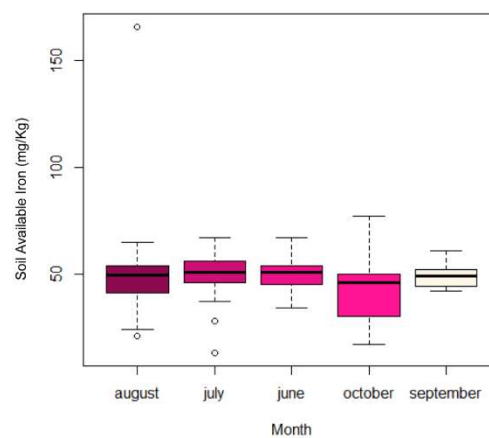


Fig.1.55: Box Plot showing Month v/s Soil available Manganese in Kaipad Rice Fields

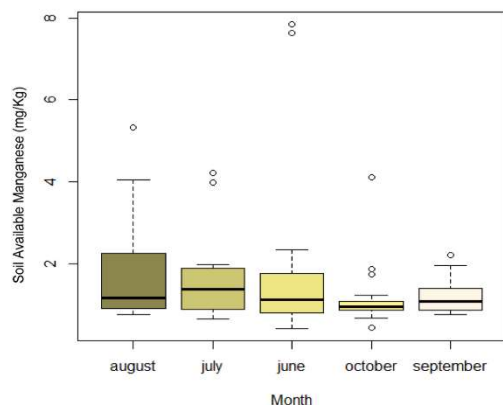


Fig.1.56: Box Plot showing Month v/s Soil available Manganese in Conventional Rice Fields

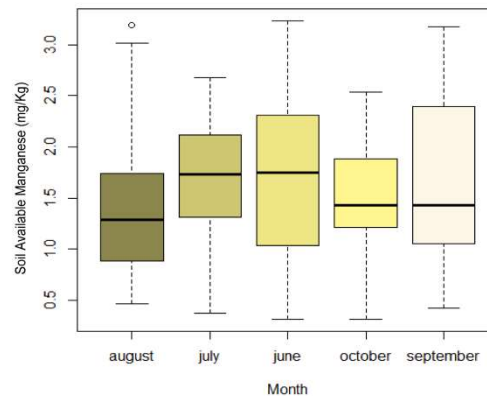


Fig.1.57: Box Plot showing Month v/s Soil available Zinc in Kaipad Rice Fields

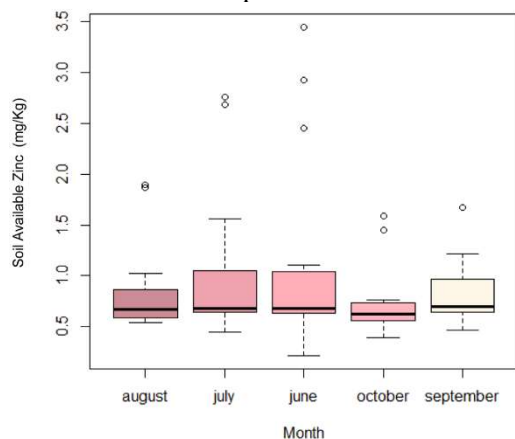


Fig.1.58: Box Plot showing Month v/s Soil available Zinc in Conventional Rice Fields

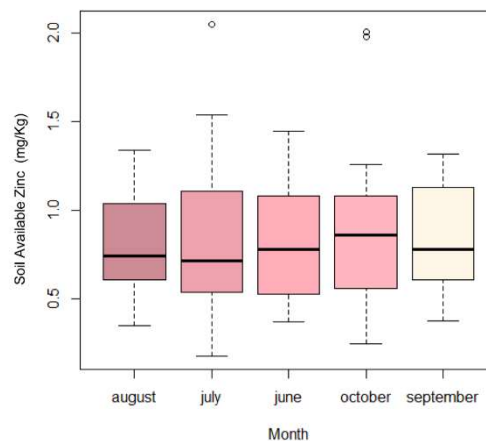


Fig.1.59: Box Plot showing Month v/s Soil available Copper in Kaipad Rice Fields

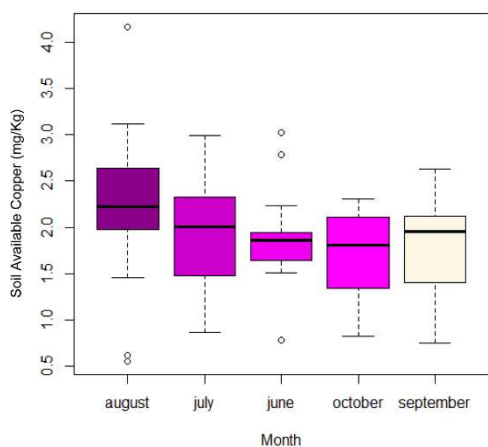


Fig.1.60: Box Plot showing Month v/s Soil available Copper in Conventional Rice Fields

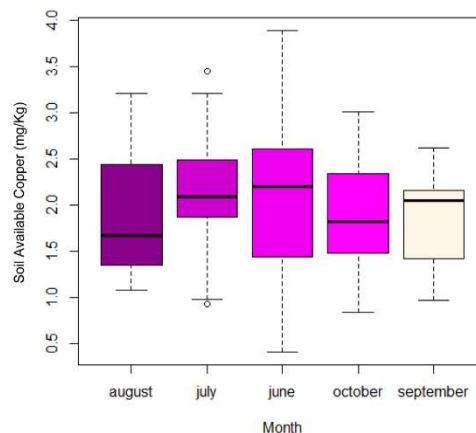


Fig.1.61: Box Plot showing Month v/s Soil available Boron in Kaipad Rice Fields

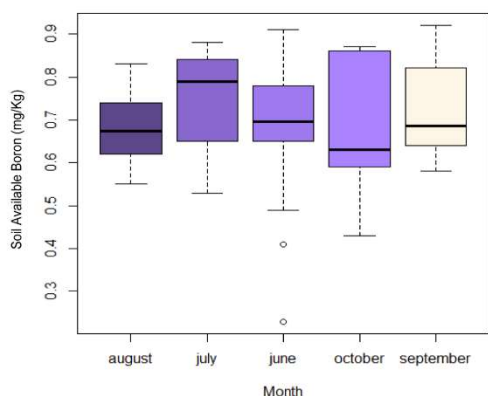
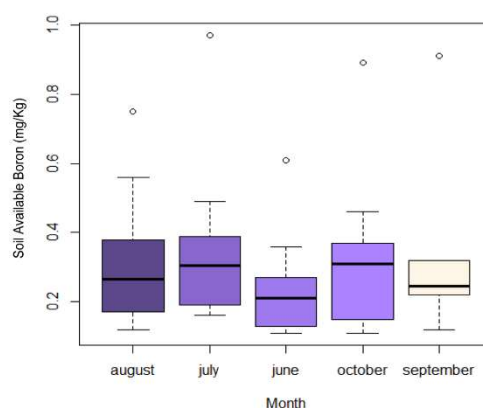


Fig.1.62: Box Plot showing Month v/s Soil available Boron in Conventional Rice Fields



The relation of Leaf parameters between months in Kaipad and Conventional rice fields.

In Kaipad rice fields, Nitrogen ($p=0.873$)(Fig.63), Phosphorus ($p=0.807$)(Fig.1.65), Potassium ($p=0.262$)(Fig.1.67), Calcium ($p=0.515$)(Fig.1.69), Magnesium ($p=0.17$)(Fig.1.71), Sulfur ($p=0.658$)(Fig.1.73), Manganese ($p=0.254$)(Fig.1.77), Zinc ($p=0.076$)(Fig.1.79) and Copper ($p=0.309$)(Fig.1.81) in leaves between months are not significantly different (Tab.1.1). But Iron ($p=0.0394$ *) (Fig.1.75) and Boron ($p=0.0139$ *) (Fig.1.83) in leaves shows significant difference (Tab.1.1).

Fig.1.63: Box Plot showing Month v/s Leaf total Nitrogen in Kaipad Rice Fields

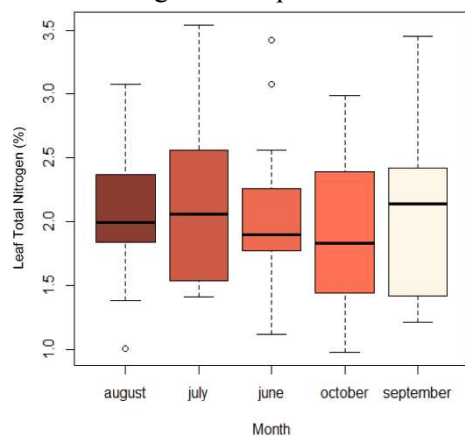


Fig.1.64: Box Plot showing Month v/s Leaf total Nitrogen in Conventional Rice Fields

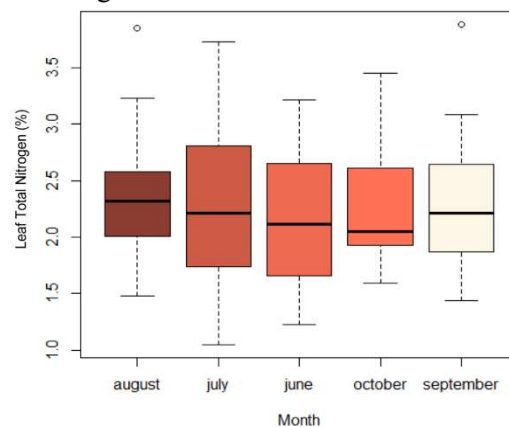


Fig.1.65: Box Plot showing Month v/s Leaf total Phosphorus in Kaipad Rice Fields

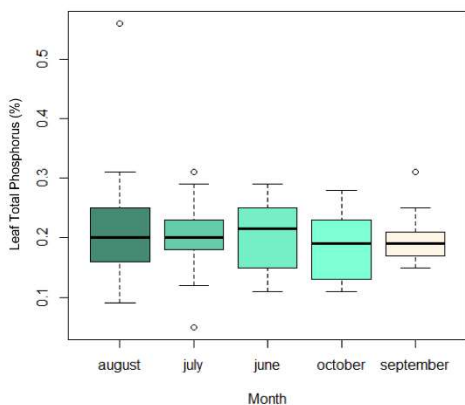


Fig.1.66: Box Plot showing Month v/s Leaf total Phosphorus in Conventional Rice Fields

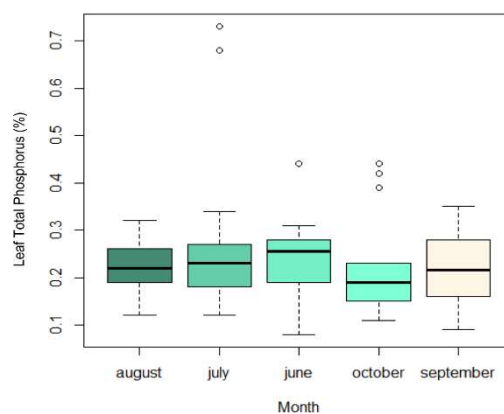


Fig.1.67: Box Plot showing Month v/s Leaf total Potassium in Kaipad Rice Fields

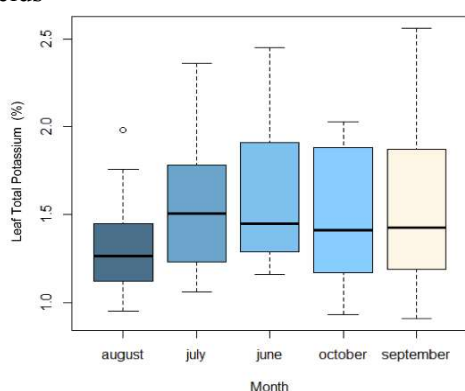
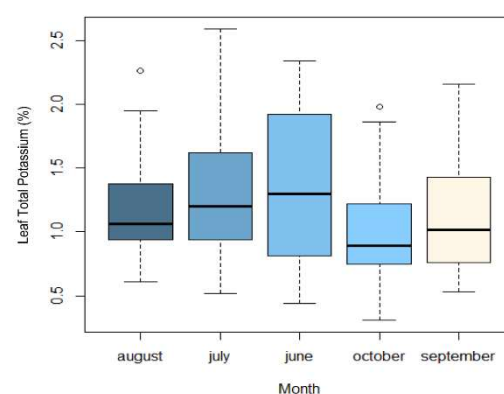


Fig.1.68: Box Plot showing Month v/s Leaf total Potassium in Conventional Rice Fields



In Conventional rice fields, Nitrogen ($p=0.945$)(Fig.1.64), Phosphorus ($p=0.437$)(Fig.1.66), Potassium ($p=0.244$)(Fig.1.68), Calcium ($p=0.106$)(Fig.1.70), Magnesium ($p=0.918$)(Fig.1.72), Sulfur ($p=0.825$)(Fig.1.74), Iron

($p=0.727$)(Fig.1.76), Manganese ($p=0.805$)(Fig.1.78), Zinc ($p=0.594$)(Fig.1.80), Copper ($p=0.594$)(Fig.1.82) and Boron ($p=0.913$)(Fig.1.84) in leaves are not significantly different between the months of rice cultivation (Tab.1.2).

Fig.1.69: Box Plot showing Month v/s Leaf total Calcium in Kaipad Rice Fields

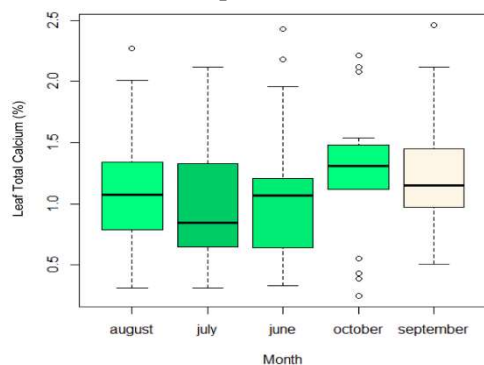


Fig.1.70: Box Plot showing Month v/s Leaf total Calcium in Conventional Rice Fields

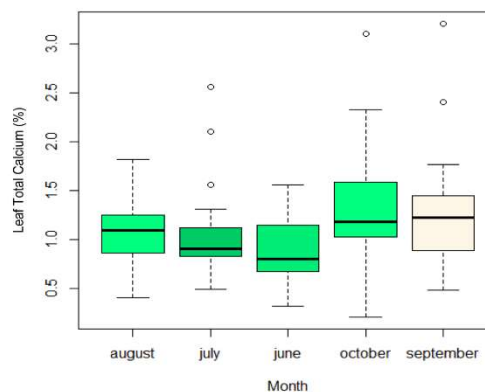


Fig.1.71: Box Plot showing Month v/s Leaf total Magnesium in Kaipad Rice Fields

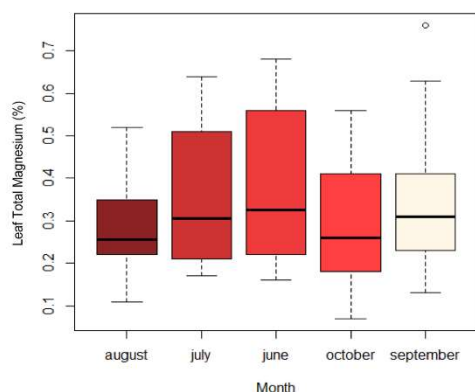


Fig.1.72: Box Plot showing Month v/s Leaf total Magnesium in Conventional Rice Fields

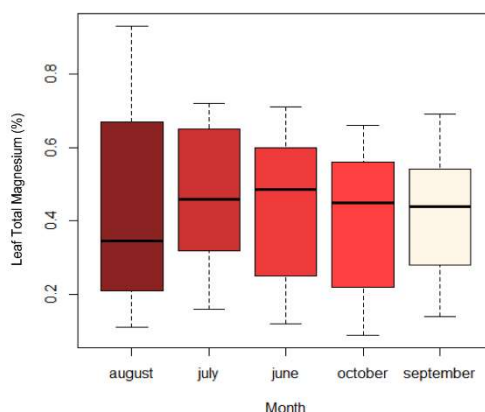


Fig.1.73: Box Plot showing Month v/s Leaf total Sulfur in Kaipad Rice Fields

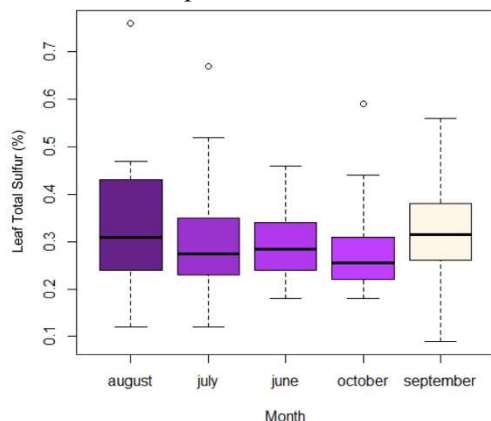


Fig.1.74: Box Plot showing Month v/s Leaf total Sulfur in Conventional Rice Fields

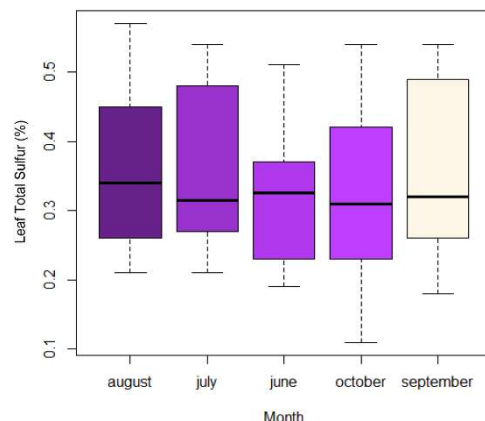


Fig.1.75: Box Plot showing Month v/s Leaf total Iron in Kaipad Rice Fields

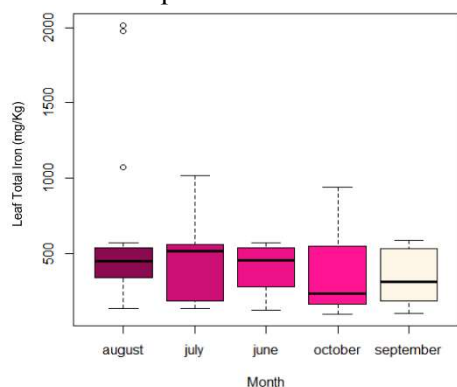


Fig.1.76: Box Plot showing Month v/s Leaf total Iron in Conventional Rice Fields

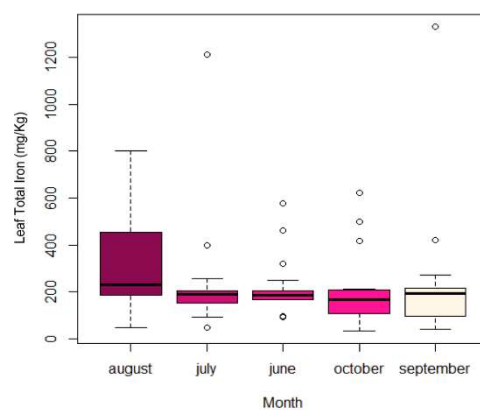


Fig.1.77: Box Plot showing Month v/s Leaf total Manganese in Kaipad Rice Fields

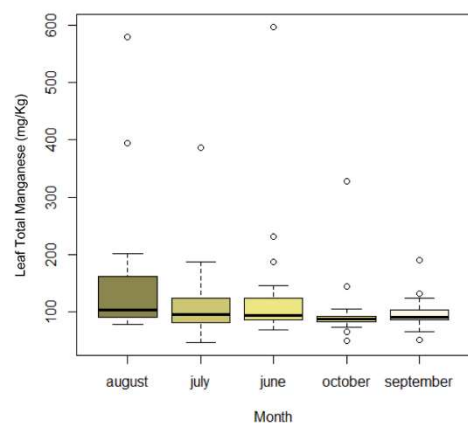


Fig.1.78: Box Plot showing Month v/s Leaf total Manganese in Conventional Rice Fields

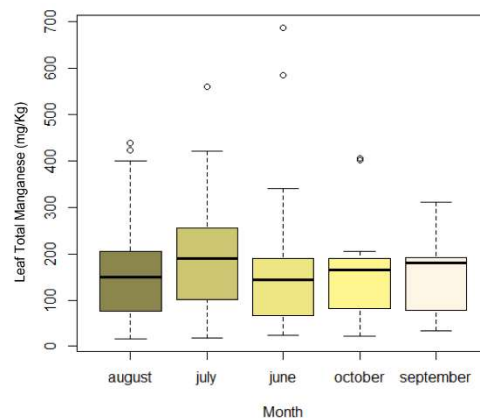


Fig.1.79: Box Plot showing Month v/s Leaf total Zinc in Kaipad Rice Fields

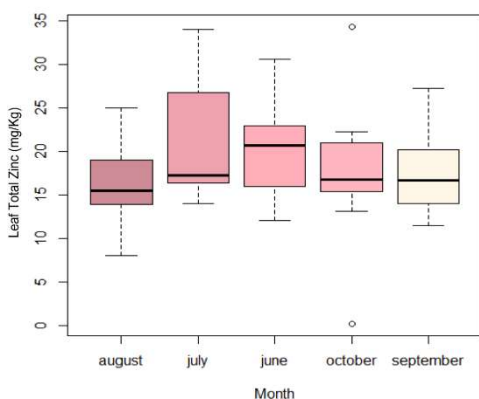


Fig.1.80: Box Plot showing Month v/s Leaf total Zinc in Conventional Rice Fields

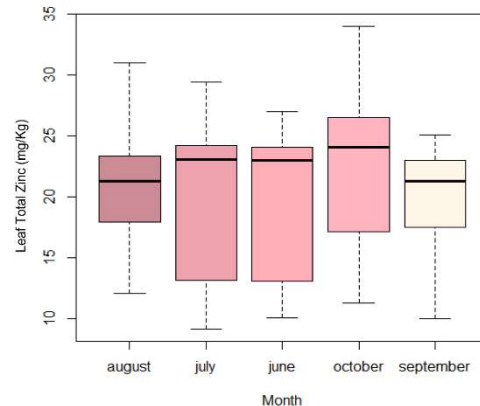


Fig.1.81: Box Plot showing Month v/s Leaf total Copper in Kaipad Rice fields

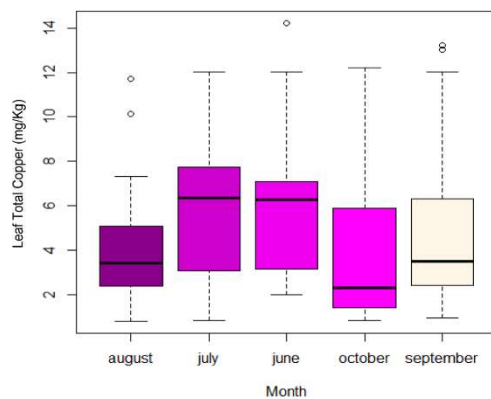


Fig.1.83: Box Plot showing Month v/s Leaf total Boron in Kaipad Rice Fields

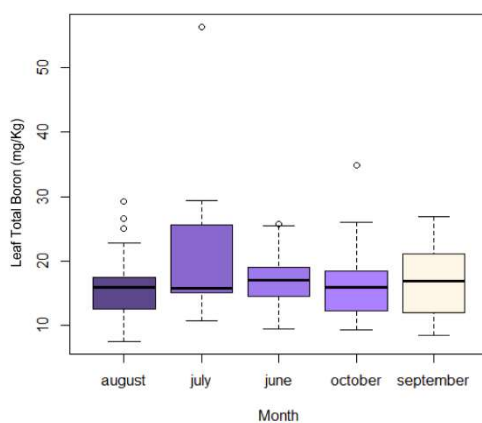


Fig.1.82: Box Plot showing Month v/s Leaf total Copper in Conventional Rice Fields

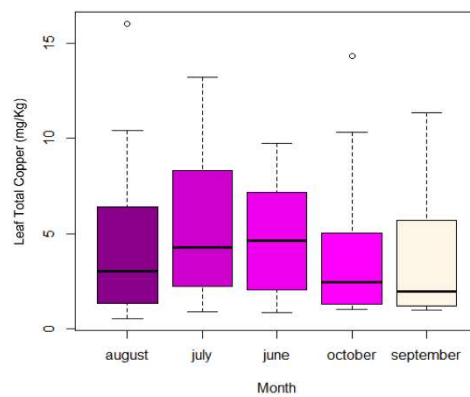


Fig.1.84: Box Plot showing Month v/s Leaf total Boron in Conventional Rice Fields

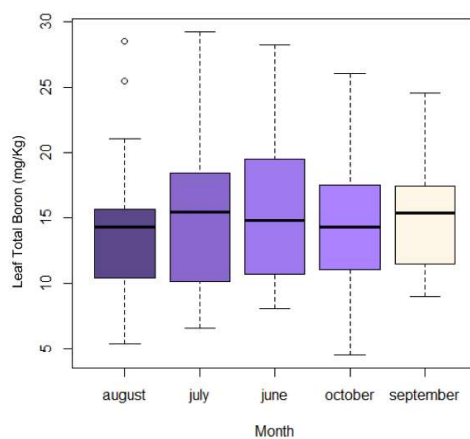


Table 1.1: The ANOVA table of Atmospheric, Water, Soil and Leaf parameters between months in Kaipad rice fields

Sl.No	Parameter	Df	Sum sq	Mean Sq	F Value	Pr(>F)
1	Atmospheric Minimum temperature	4	21.8	5.456	0.792	0.534
2	Atmospheric Maximum temperature	4	145.0	36.26	3.331	0.0139 *
3	Atmospheric humidity	4	42.5	10.62	0.764	0.552
4	Surface water temperature	4	117.0	29.261	3.92	0.00572 **
5	Bottom water temperature	4	97.5	24.378	3.555	0.0099 **
6	Water pH	4	0.751	0.1879	0.903	0.466
7	Water Salinity	4	286.9	71.72	3.907	0.00583 **
8	Water EC	4	6.628e+09	1.657e+09	80.73	<2e-16 ***
9	Water DO	4	54.2	13.558	2.458	0.0516
10	Water COD	4	579609	144902	33.98	<2e-16 ***
11	Water Total Hardness	4	152320595	38080149	26.67	2.42e-14 ***
12	Water Turbidity	4	594	148.4	2.129	0.0842
13	Water Nitrate	4	0.265	0.0664	0.191	0.943
14	Water Phosphate	4	0.02402	0.006004	2.169	0.0793
15	Water Potassium	4	37827	9457	18.84	4.03e-11 ***
16	Water Calcium	4	109779	27445	35.91	<2e-16 ***
17	Water Magnesium	4	2134190	533547	21.24	3.62e-12 ***
18	Water Sulfate	4	339789	84947	14.83	3.12e-09 ***
19	Soil pH	4	1.42	0.3552	0.461	0.764
20	Soil EC	4	0.331	0.08285	1.879	0.122

21	Soil available Nitrogen	4	6379	1595	0.475	0.754
22	Soil available Phosphorus	4	24.9	6.228	0.896	0.47
23	Soil available Potassium	4	65770	16443	1.375	0.25
24	Soil available Calcium	4	237160	59290	1.33	0.265
25	Soil available Magnesium	4	56841	14210	1.509	0.207
26	Soil available Sulfur	4	9425	2356	0.297	0.879
27	Soil available Iron	4	1926	481.5	5.127	0.000948 ***
28	Soil available Manganese	4	9.33	2.333	1.304	0.275
29	Soil available Zinc	4	1.34	0.3349	1.006	0.409
30	Soil available Copper	4	2.76	0.6897	1.843	0.128
31	Soil available Boron	4	0.0789	0.01973	1.194	0.319
32	Leaf total Nitrogen	4	0.47	0.1184	0.306	0.873
33	Leaf total Phosphorus	4	0.0072	0.001811	0.401	0.807
34	Leaf total Potassium	4	0.674	0.1686	1.34	0.262
35	Leaf total Calcium	4	0.993	0.2483	0.822	0.515
36	Leaf total Magnesium	4	0.1638	0.04096	1.647	0.17
37	Leaf total Sulfur	4	0.0346	0.008646	0.608	0.658
38	Leaf total Iron	4	949100	237275	2.638	0.0394 *
39	Leaf total Manganese	4	45549	11387	1.361	0.254
40	Leaf total Zinc	4	266.9	66.72	2.198	0.076
41	Leaf total Copper	4	58.1	14.53	1.218	0.309
42	Leaf total Boron	4	145.0	36.26	3.331	0.0139 *

Table 1.2: The ANOVA table of Atmospheric, Water, Soil and Leaf parameters between months in Conventional rice fields

Sl.No	Parameter	Df	Sum sq	Mean Sq	F Value	Pr(>F)
1	Atmospheric minimum temperature	4	28.6	7.146	1.604	0.181
2	Atmospheric maximum temperature	4	97.1	24.284	2.915	0.0261 *
3	Atmospheric humidity	4	86.7	21.687	2.292	0.0662
4	Surface water temperature	4	81.8	20.460	2.591	0.0423 *
5	Bottom water temperature	4	78.8	19.695	2.774	0.0322 *
6	Water pH	4	5.37	1.3425	3.237	0.016 *
7	Water Salinity	4	18.36	4.589	3.422	0.0121 *
8	Water EC	4	1.882e+08	47062214	3.053	0.0212 *
9	Water DO	4	18.86	4.715	1.543	0.197
10	Water COD	4	220023	55006	13.39	1.75e-08 ***
11	Water Total Hardness	4	54159443	13539861	1.423	0.234
12	Water Turbidity	4	2425	606.2	6.889	7.61e-05 ***
13	Water Nitrate	4	7.23	1.807	3.82	0.00667 **
14	Water Phosphate	4	0.01399	0.003498	4.521	0.00234 **
15	Water Potassium	4	11338	2834.4	31.99	3.44e-16 ***
16	Water Calcium	4	2158	539.5	2.845	0.0289 *
17	Water Magnesium	4	649	162.21	1.783	0.14
18	Water Sulfate	4	18971	4743	22.6	1.07e-12 ***
19	Soil pH	4	0.743	0.1857	1.205	0.315
20	Soil EC	4	0.057	0.01435	0.161	0.957
21	Soil available Nitrogen	4	11676	2919	2.063	0.0929
22	Soil available Phosphorus	4	9.6	2.411	0.345	0.847

23	Soil available Potassium	4	33098	8274	1.162	0.334
24	Soil available Calcium	4	108570	27143	0.407	0.803
25	Soil available Magnesium	4	54739	13685	0.191	0.942
26	Soil available Sulfur	4	457	114.2	0.354	0.841
27	Soil available Iron	4	935	233.8	0.799	0.529
28	Soil available Manganese	4	1.31	0.3281	0.519	0.722
29	Soil available Zinc	4	0.089	0.02229	0.153	0.961
30	Soil available Copper	4	1.97	0.4914	1.008	0.408
31	Soil available Boron	4	0.1026	0.02565	0.878	0.481
32	Leaf total Nitrogen	4	0.276	0.0690	0.186	0.945
33	Leaf total Phosphorus	4	0.0403	0.01008	0.954	0.437
34	Leaf total Potassium	4	1.423	0.3558	1.39	0.244
35	Leaf total Calcium	4	2.225	0.5561	1.974	0.106
36	Leaf total Magnesium	4	0.042	0.01058	0.235	0.918
37	Leaf total Sulfur	4	0.0215	0.00537	0.376	0.825
38	Leaf total Iron	4	93798	23450	0.512	0.727
39	Leaf total Manganese	4	27873	6968	0.405	0.805
40	Leaf total Zinc	4	87.2	21.81	0.7	0.594
41	Leaf total Copper	4	87.2	21.81	0.7	0.594
42	Leaf total Boron	4	29.1	7.27	0.243	0.913

Relation between Atmospheric parameters within the Kaipad rice fields

The relation between atmospheric minimum temperature and water surface temperature ($p=1.66e-10$ ***) (Fig.1.85), atmospheric maximum temperature and water surface temperature ($p=<2e-16$ ***) (Fig.1.86), atmospheric minimum temperature and bottom water temperature ($p=4.44e-10$ ***) (Fig.1.87) and atmospheric maximum temperature and bottom water temperature ($p=<2e-16$ ***) (Fig.1.88) within the Kaipad rice fields are significant (Tab.1.3).

Fig.1.85: Scatter Diagram showing Atmospheric Minimum Temperature v/s Water Surface Temperature within Kaipad Rice Fields

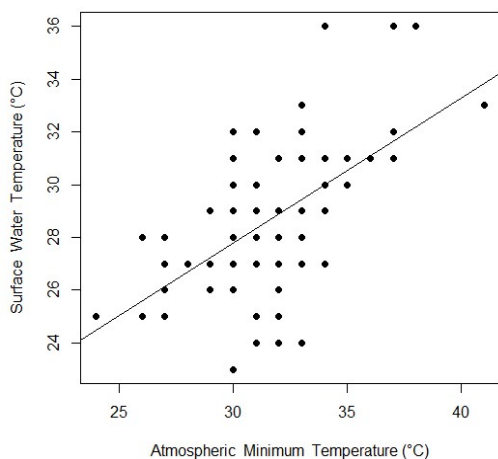


Fig.1.86: Scatter Diagram showing Atmospheric Maximum Temperature v/s Water Surface Temperature within Kaipad Rice Fields

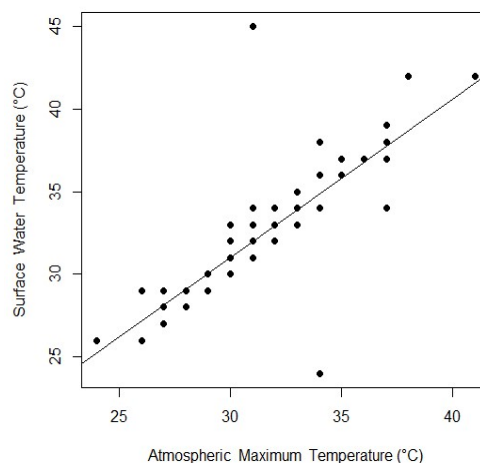


Fig.1.87: Scatter Diagram showing Atmospheric Minimum Temperature v/s Bottom Water Temperature within Kaipad Rice Fields

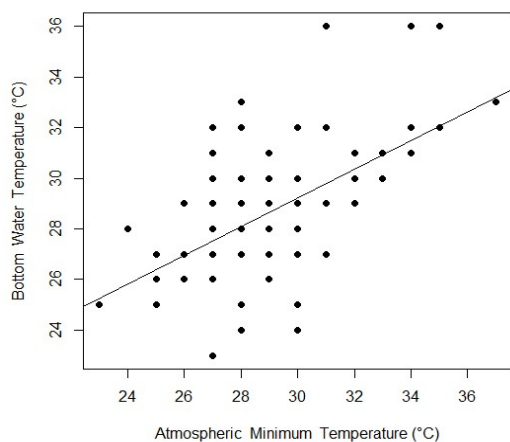
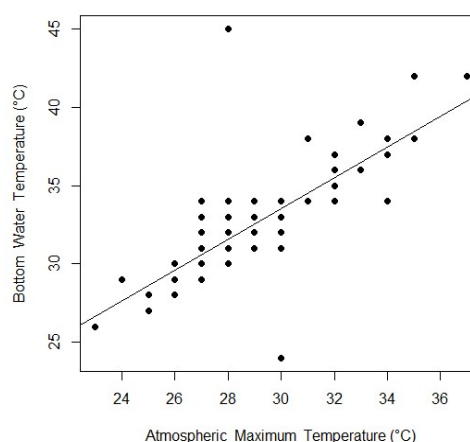


Fig.1.88: Scatter Diagram showing Atmospheric Maximum Temperature v/s Bottom Water Temperature within Kaipad Rice Fields



Relation between Water and Soil parameters within the Kaipad rice fields.

Within the Kaipad rice fields, the relation between Water pH and Soil pH ($p=0.378$)(Fig.1.89); and Water electrical conductivity and soil electrical conductivity ($p=0.255$)(Fig.1.90) are not significant (Tab.1.3).

Fig.1.89: Scatter Diagram showing Water pH v/s Soil pH within Kaipad Rice Fields

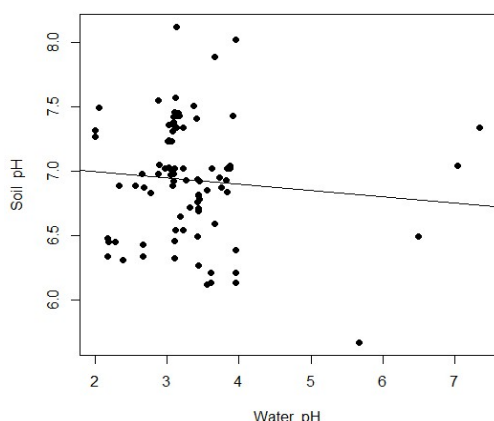
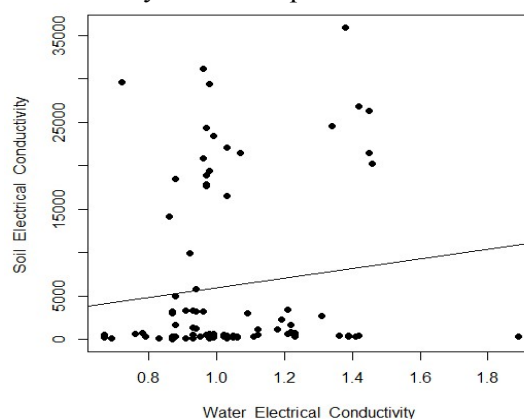


Fig.1.90: Scatter Diagram showing Water Electrical Conductivity v/s Soil Electrical Conductivity within Kaipad Rice Fields



There is a positive relation between water Phosphate and soil Phosphorus ($p=0.0255$ *) (Fig.1.91), water Calcium and soil Calcium ($p=0.00715$ **) (Fig.1.92), and water Magnesium and soil Magnesium ($p=0.0469$ *) (Fig.1.93), and the relations are significant (Tab.1.3). But the relation between water Nitrate and soil Nitrogen ($p=0.3865$)(Fig.1.94), water Potassium and soil Potassium ($p=0.109$)(Fig.1.95) and water Sulfate and soil Sulfur ($p=0.581$)(Fig.1.96) are not significant (Tab.1.3).

Fig.1.91: Scatter Diagram showing Water Phosphate v/s Soil available Phosphorus within Kaipad Rice Fields

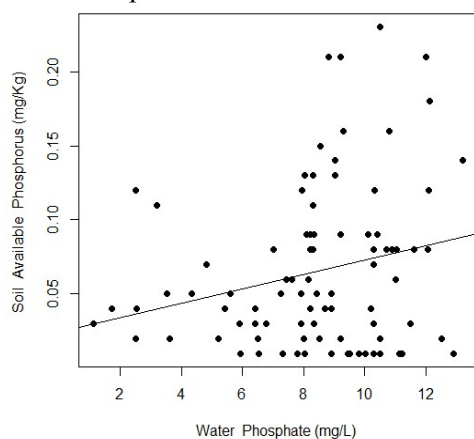


Fig.1.92: Scatter Diagram showing Water Calcium v/s Soil available Calcium within Kaipad Rice Fields

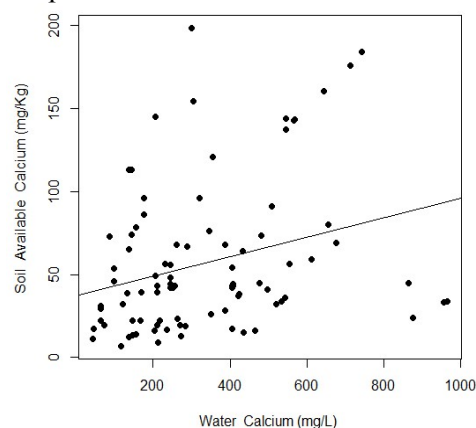


Fig.1.93: Scatter Diagram showing Water Magnesium v/s Soil available Magnesium within Kaipad Rice Fields

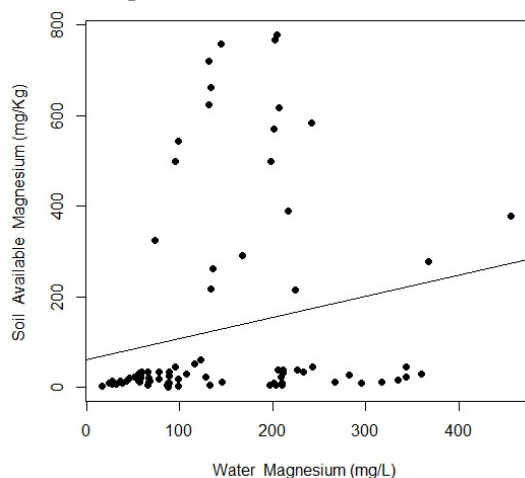


Fig.1.94: Scatter Diagram showing Water Nitrate v/s Soil available nitrogen within Kaipad Rice Fields

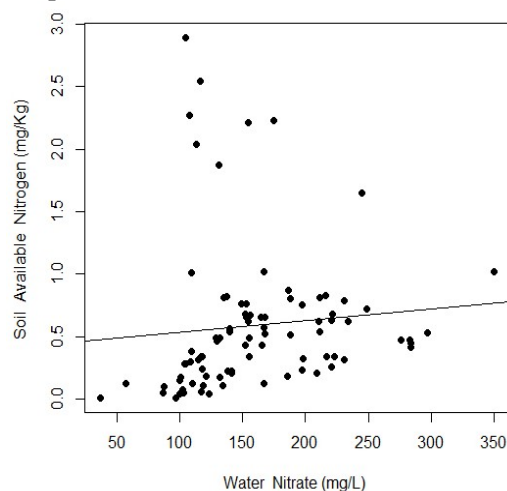


Fig.1.95: Scatter Diagram showing Water Potassium v/s Soil available Potassium within Kaipad Rice Fields

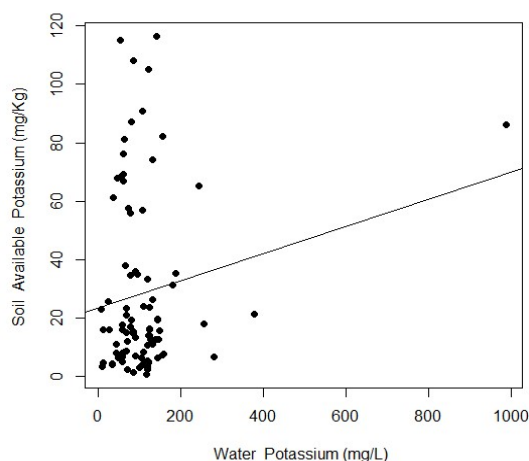
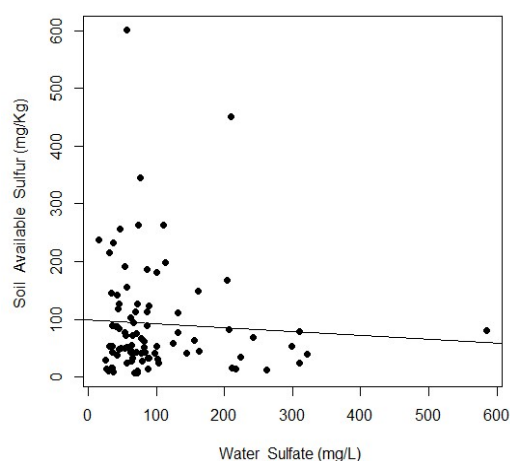


Fig.1.96: Scatter Diagram showing Water Sulfate v/s Soil available sulfur within Kaipad Rice Fields



Relationship between Soil and Leaf parameters within the Kaipad rice fields

Within the Kaipad rice fields there are negative relation between soil Nitrogen and Leaf Nitrogen ($p=1.57e-05$ ***) (Fig.1.97), soil Copper and Leaf Copper ($p=0.0199$ *) (Fig.1.98), and those relations are significant (Tab.1.3). Whereas the relation between soil Calcium and Leaf Calcium ($p=8.58e-06$ ***) (Fig.1.99), soil Manganese and Leaf Manganese ($p=<2e-16$ ***) (Fig.1.100), and soil Zinc and Leaf Zinc ($p=5.74e-07$ ***) (Fig.1.101) are positive and significant (Tab.1.3).

Fig.1.97: Scatter Diagram showing Soil available Nitrogen v/s Leaf total Nitrogen within Kaipad Rice Fields

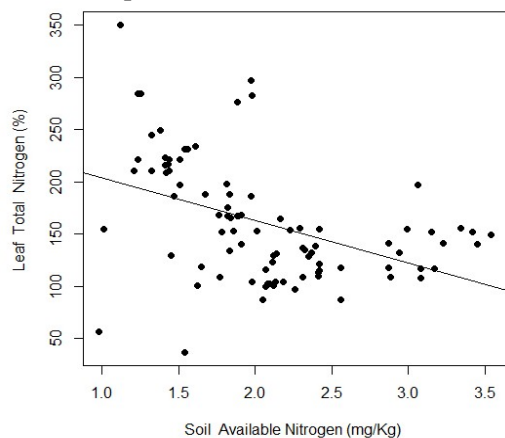


Fig.1.98: Scatter Diagram showing Soil available Copper v/s Leaf total Copper within Kaipad Rice Fields

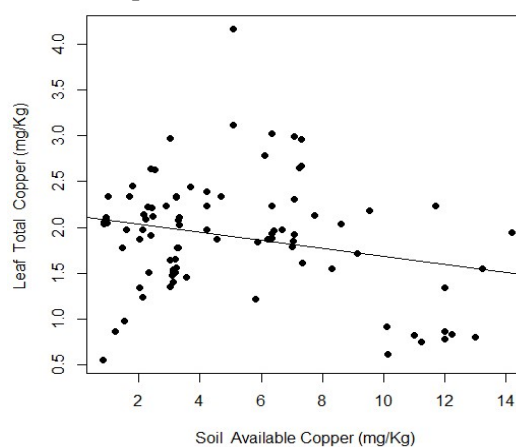


Fig.1.99: Scatter Diagram showing Soil available Calcium v/s Leaf total Calcium within Kaipad Rice Fields

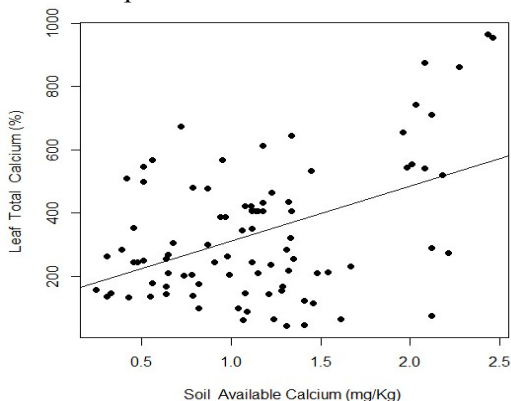


Fig.1.100: Scatter Diagram showing Soil available Manganese v/s Leaf total Manganese within Kaipad Rice Fields

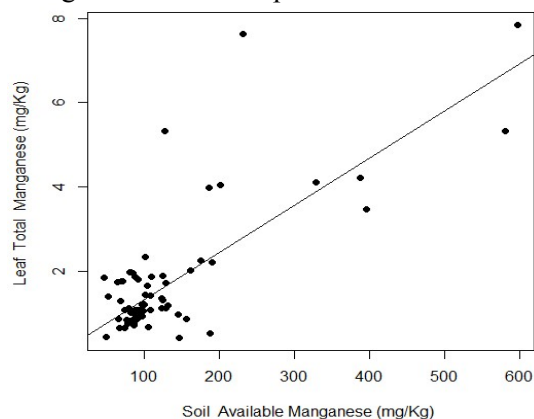


Fig.1.101: Scatter Diagram showing Soil available Zinc v/s Leaf total Zinc within Kaipad Rice Fields

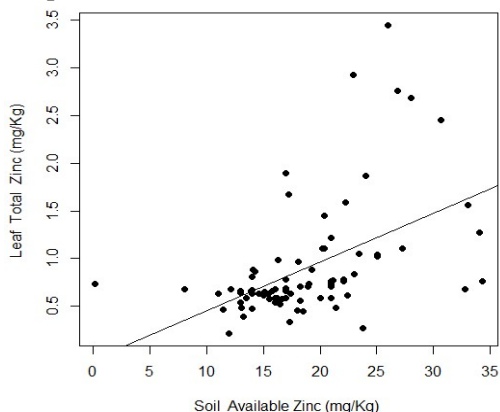
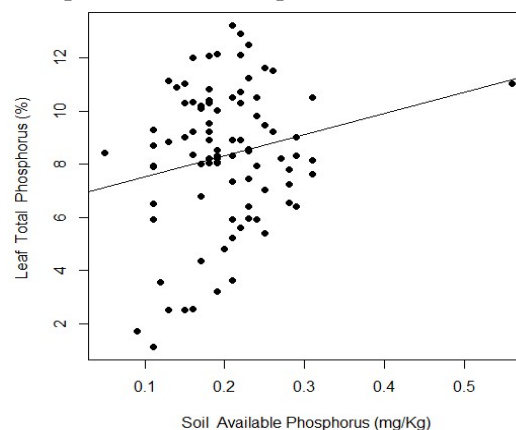


Fig.1.102: Scatter Diagram showing Soil available Phosphorus v/s Leaf total Phosphorus within Kaipad Rice Fields



The relation between soil Phosphorus and Leaf Phosphorus ($p=0.0575$)(Fig.1.102), soil Magnesium and Leaf Magnesium ($p=0.0652$)(Fig.1.103), soil Sulfur and Leaf Sulfur ($p=0.578$)(Fig.1.104), soil Iron and Leaf Iron ($p=0.111$)(Fig.1.105), soil Potassium and Leaf Potassium ($p=0.8327$)(Fig.1.106), and soil Boron and Leaf Boron ($p=0.796$)(Fig.1.107) are not significant (Tab.1.3).

Fig.1.103: Scatter Diagram showing Soil available Magnesium v/s Leaf total Magnesium within Kaipad Rice Fields

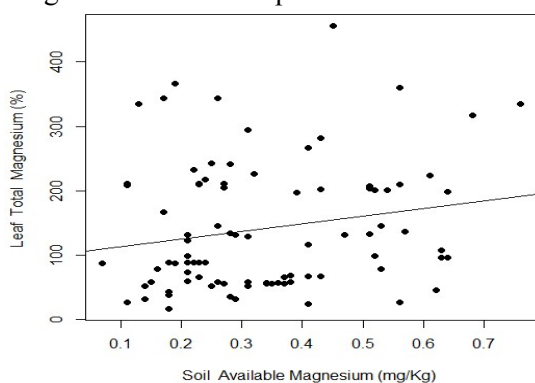


Fig.1.104: Scatter Diagram showing Soil available sulfur v/s Leaf total Sulfur within Kaipad Rice Fields

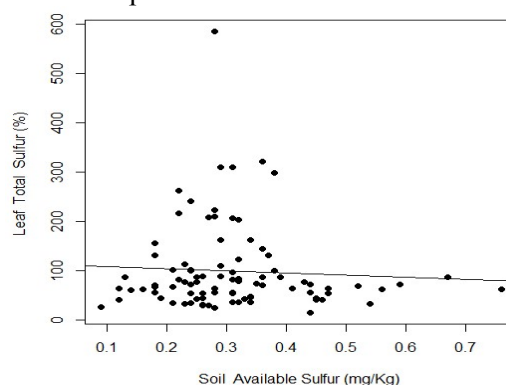


Fig.1.105: Scatter Diagram showing Soil available Iron v/s Leaf total Iron within Kaipad Rice Fields

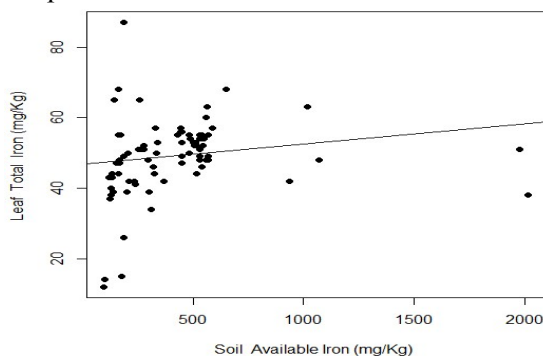


Fig.1.106: Scatter Diagram showing Soil available Potassium v/s Leaf total Potassium within Kaipad Rice Fields

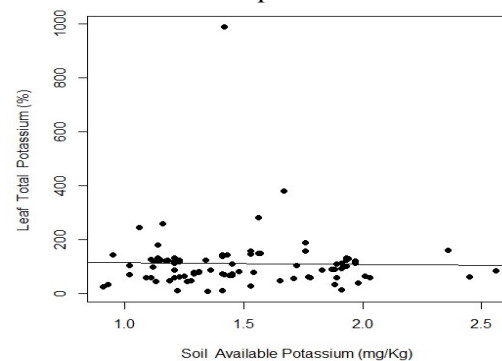


Fig.1.107: Scatter Diagram showing Soil available Boron v/s Leaf total Boron within Kaipad Rice Fields

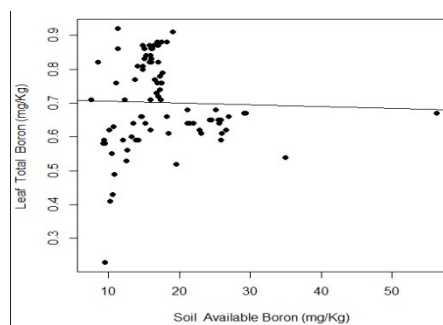


Table 1.3: The ANOVA table of relation between parameters within Kaipad rice fields

Sl.No	Parameters	Estimate	Std. Error	t value	Pr(> t)
1	Water pH vs Soil pH	-0.04940	0.05569	-0.887	0.378
2	Water EC vs Soil EC	5490	4794	1.145	0.255
3	Water Nitrate Vs Soil available Nitrogen	0.0009345	0.0010739	0.870	0.3865
4	Water Phosphate Vs Soil available Phosphorus	0.004830	0.002126	2.272	0.0255 *
5	Water Potassium Vs Soil available Potassium	0.04644	0.02865	1.621	0.109
6	Water Calcium Vs Soil available Calcium	0.05869	0.02131	2.754	0.00715 **
7	Water Magnesium Vs Soil available Magnesium	0.4688	0.2326	2.016	0.0469 *
8	Water Sulfate Vs Soil available sulfur	-0.06471	0.11693	-0.553	0.581
9	Soil available Nitrogen Vs Leaf total Nitrogen	-40.955	8.957	-4.572	1.57e-05 ***
10	Soil available Phosphorus Vs Leaf total Phosphorus	7.9798	4.1457	1.925	0.0575
11	Soil available Potassium Vs Leaf total Potassium	-6.967	32.882	-0.212	0.8327
12	Soil available Calcium Vs Leaf total Calcium	174.78	36.97	4.727	8.58e-06 ***
13	Soil available Magnesium Vs Leaf total Magnesium	119.76	64.13	1.867	0.0652
14	Soil available Sulfur Vs Leaf total Sulfur	-44.06	78.96	-0.558	0.578
15	Soil available Iron Vs Leaf total Iron	0.005740	0.003567	1.609	0.111
16	Soil available Manganese Vs Leaf total Manganese	0.011187	0.001001	11.181	<2e-16 ***
17	Soil available Zinc Vs Leaf total Zinc	0.050868	0.009431	5.394	5.74e-07 ***

18	Soil available Copper Vs Leaf available Copper	-0.04401	0.01856	-2.372	0.0199 *
19	Soil available Boron Vs Leaf total Boron	-0.0005159	0.0019862	-0.26	0.796
20	Atmospheric Minimum temperature Vs Atmospheric Humidity	0.04052	0.07498	0.540	0.590278
21	Atmospheric Maximum temperature Vs Atmospheric Humidity	0.07698	0.09934	0.775	0.44046
22	Atmospheric Minimum temperature Vs Water Surface Temperature	0.54896	0.07591	7.232	1.66e-10 ***
23	Atmospheric Maximum temperature Vs Water Surface Temperature	0.96026	0.07552	12.715	<2e-16 ***
34	Atmospheric Minimum temperature Vs Bottom Water Temperature	0.56614	0.08066	7.019	4.44e-10 ***
25	Atmospheric Maximum temperature Vs Bottom Water Temperature	0.98197	0.08318	11.806	<2e-16 ***

Relationship between atmospheric parameters within the Conventional rice fields.

There are positive relation between atmospheric minimum temperature and water surface temperature ($p < 2e-16^{***}$)(Fig.1.108), atmospheric maximum temperature and water surface temperature ($p < 2e-16^{***}$)(Fig.1.109)(Tab.1.4).

Fig.1.108: Scatter Diagram showing Atmospheric Minimum Temperature v/s Water Surface Temperature within Conventional Rice Fields

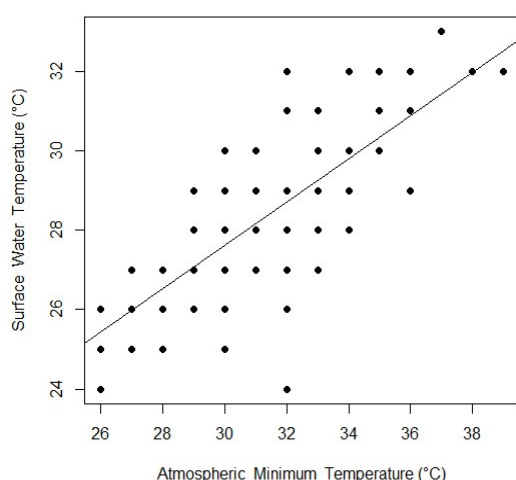
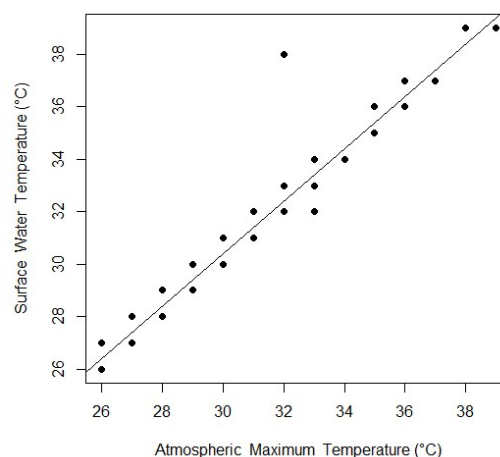


Fig.1.109: Scatter Diagram showing Atmospheric Maximum Temperature v/s Water Surface Temperature within Conventional Rice Fields



Relationship between water and soil parameters within the Conventional rice fields.

In physical parameters, the relation of water pH and soil pH ($p=0.575$)(Fig.1.110) and water electrical conductivity and soil electrical conductivity ($p=0.1857$)(Fig.1.111) are not significant (Tab.1.4).

Within Conventional rice fields, the only significant relation in water-soil parameters is between water Nitrate and soil Nitrogen ($p=0.00437^{**}$)(Fig.1.112). Water Phosphate and soil Phosphorus ($p=0.786$)(Fig.1.113), water Potassium and soil Potassium ($p=0.30003$)(Fig.1.114), water Calcium and soil Calcium ($p=0.675$)(Fig.1.115), water Magnesium and soil Magnesium ($p=0.251$)(Fig.1.116), and water Sulfate and soil Sulfur ($p=0.978841$)(Fig.1.117) are not significant (Tab.1.4).

Fig.1.110: Scatter Diagram showing Water pH v/s Soil pH within Conventional Rice Fields

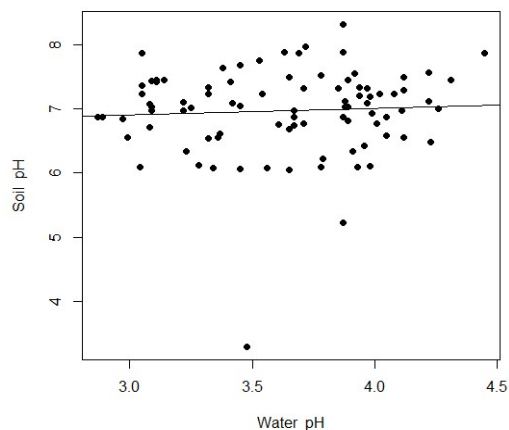


Fig.1.111: Scatter Diagram showing Water Electrical Conductivity v/s Soil Electrical Conductivity within Conventional Rice Fields

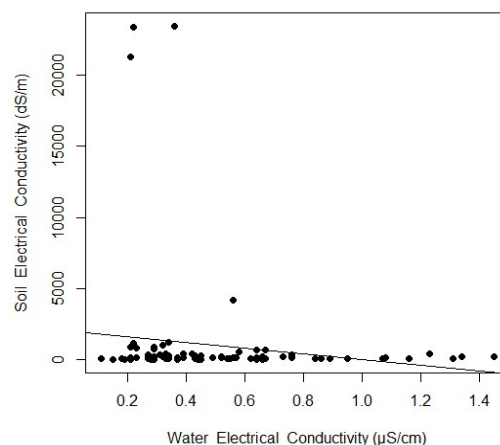


Fig.1.112: Scatter Diagram showing Water Nitrate v/s Soil available Nitrogen within Conventional Rice Fields

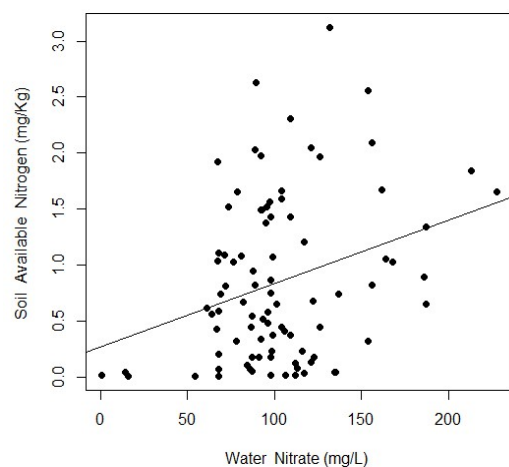


Fig.1.113: Scatter Diagram showing Water Phosphate v/s Soil available Phosphorus within Conventional Rice Fields

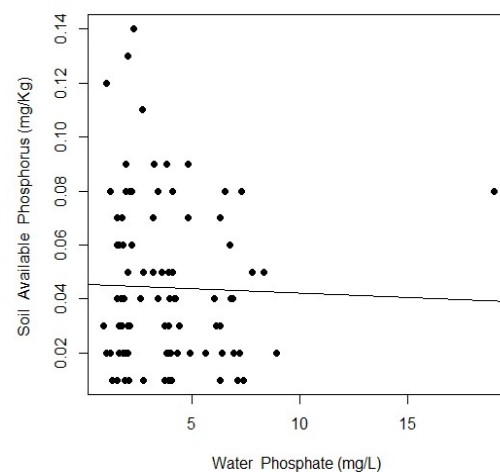


Fig.1.114: Scatter Diagram showing Water Potassium v/s Soil available Potassium within Conventional Rice Fields

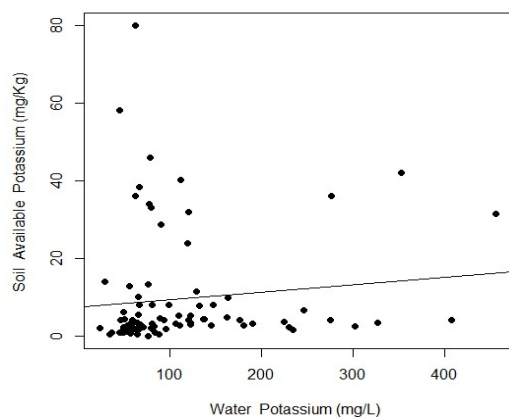


Fig.1.115: Scatter Diagram showing Water Calcium v/s Soil available Calcium within Conventional Rice Fields

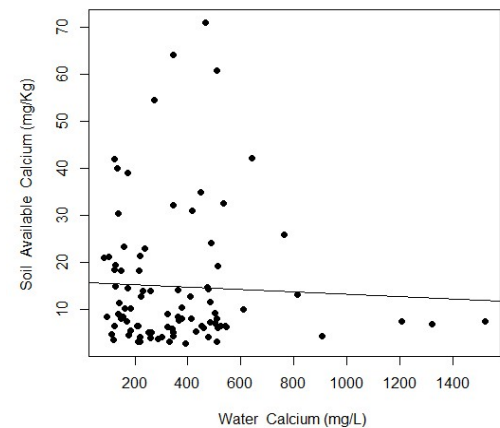


Fig.1.116: Scatter Diagram showing Water Magnesium v/s Soil available Magnesium within Conventional Rice Fields

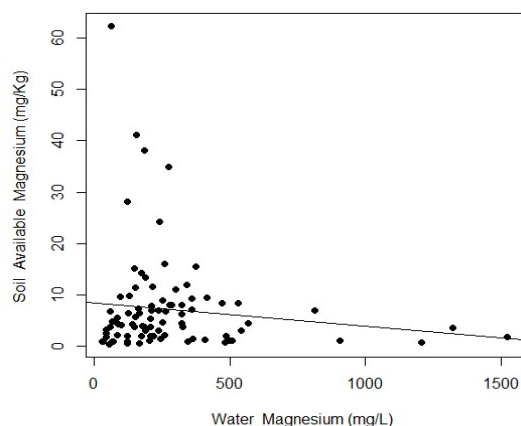
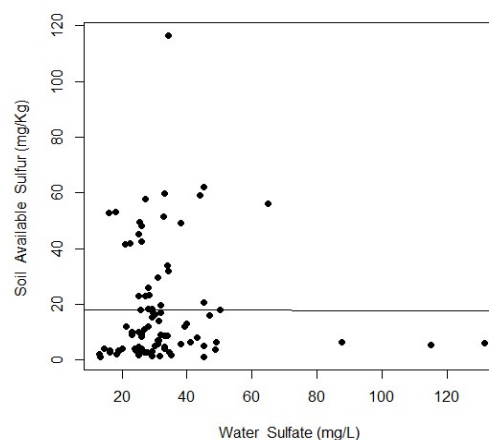


Fig.1.117: Scatter Diagram showing Water Sulfate v/s Soil available Sulfur within Conventional Rice Fields



Relationship between soil and leaf parameters within Conventional rice fields.

In Conventional rice fields, soil Nitrogen and leaf Nitrogen ($p=0.0297$ *) (Fig.1.118), soil Phosphorus and leaf Phosphorus ($p=0.045654$ *) (Fig.1.119), soil Zinc and leaf Zinc ($p=0.00206$ **) (Fig.1.120) and soil Boron and leaf Boron ($p=0.00156$ **) (Fig.1.121) are positively correlated and significant and negative significant correlation is found between soil Magnesium and leaf Magnesium ($p=0.00553$ **) (Fig.1.122) (Tab.1.4).

Fig.1.118: Scatter Diagram showing Soil available Nitrogen v/s Leaf total Nitrogen within Conventional Rice Fields

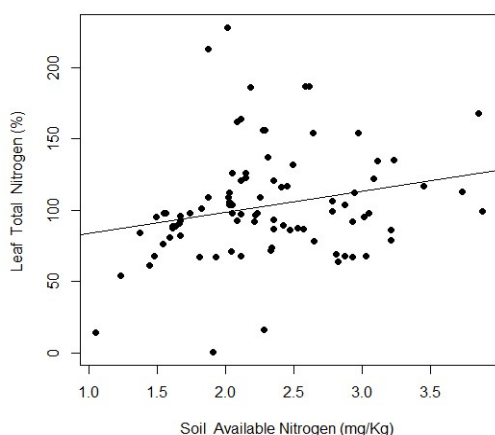


Fig.1.119: Scatter Diagram showing Soil available Phosphorus v/s Leaf total Phosphorus within Conventional Rice Fields

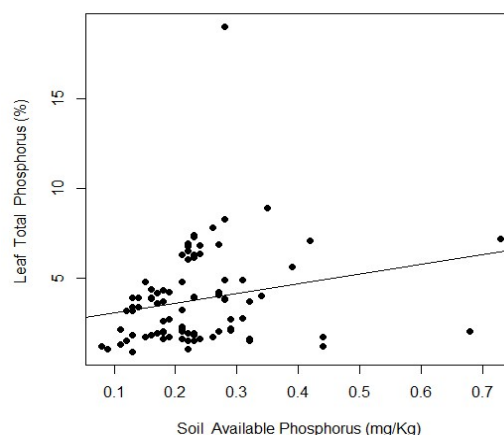


Fig.1.120: Scatter Diagram showing Soil available Zinc v/s Leaf total Zinc within Conventional Rice Fields

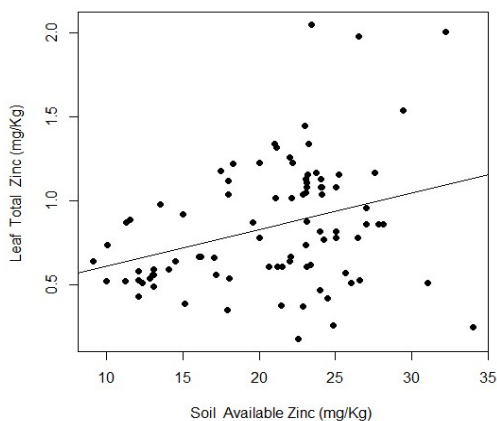


Fig.1.121: Scatter Diagram showing Soil available Boron v/s Leaf total Boron within Conventional Rice Fields

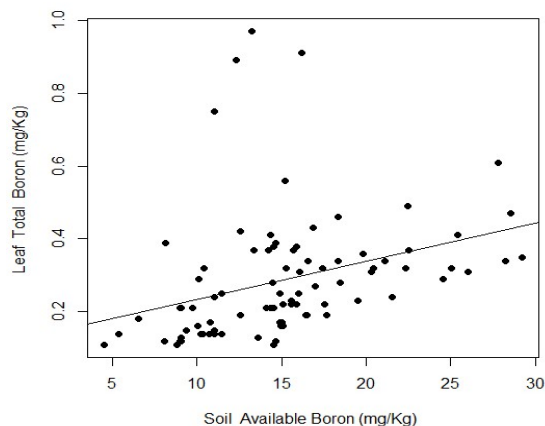


Fig.1.122: Scatter Diagram showing Soil available Magnesium v/s Leaf total Magnesium within Conventional Rice Fields

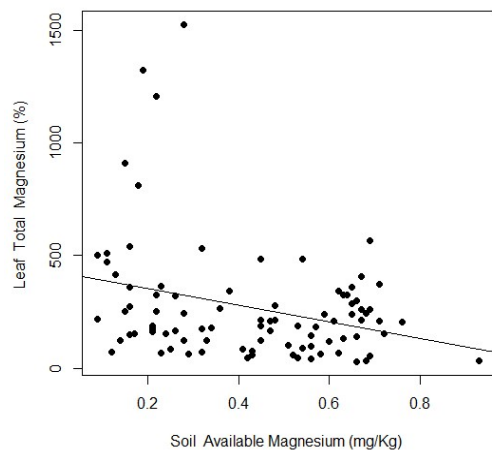
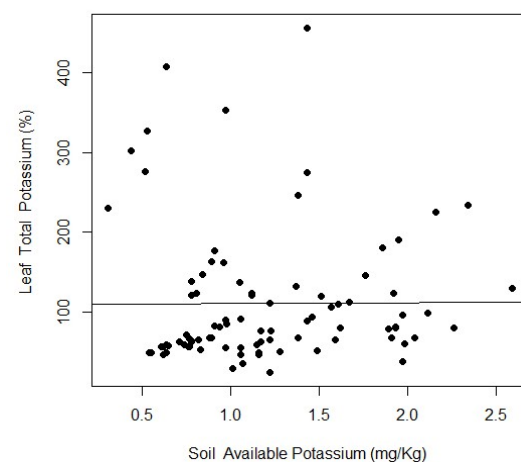


Fig.1.123: Scatter Diagram showing Soil available Potassium v/s Leaf total Potassium within Conventional Rice Fields



In Conventional rice fields, the relations between soil Potassium and leaf Potassium ($p=0.967$)(Fig.1.123), soil Calcium and leaf Calcium ($p=0.698$)(Fig.1.124), soil Sulfur and leaf Sulfur ($p=0.77$)(Fig.1.125), soil Iron and leaf Iron ($p=0.125$)(Fig.1.126), soil Manganese and leaf Manganese ($p=0.346$)(Fig.1.127) and soil Copper and leaf Copper ($p=0.0602$)(Fig.1.128) are not significant (Tab.1.4).

Fig.1.124: Scatter Diagram showing Soil available Calcium v/s Leaf total Calcium within Conventional Rice Fields

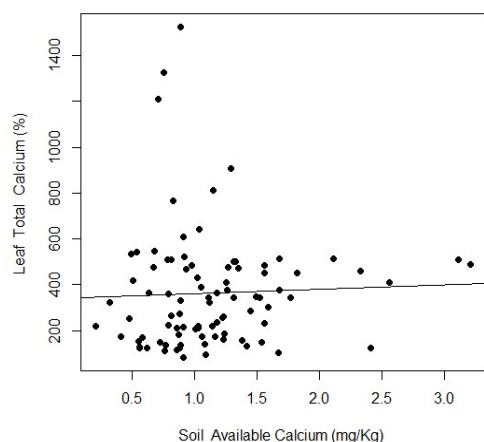


Fig.1.125: Scatter Diagram showing Soil available Sulfur v/s Leaf total Sulfur within Conventional Rice Fields

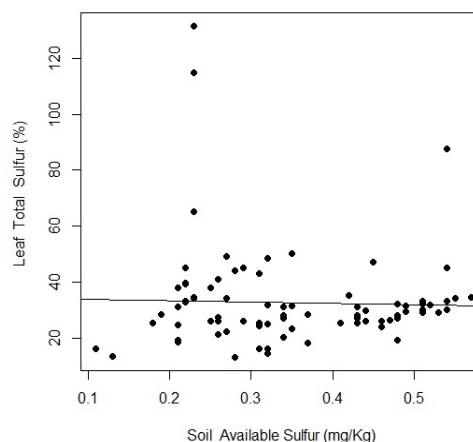


Fig.1.126: Scatter Diagram showing Soil available Iron v/s Leaf total Iron within Conventional Rice Fields

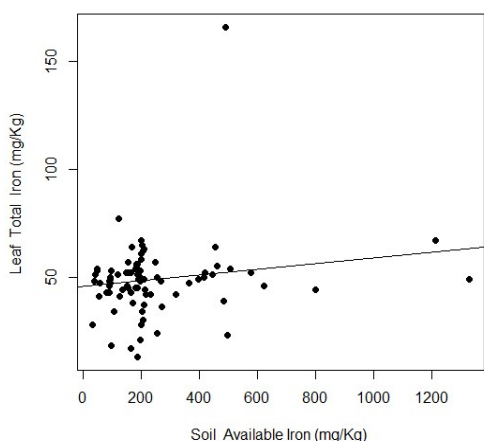


Fig.1.127: Scatter Diagram showing Soil available Manganese v/s Leaf total Manganese within Conventional Rice Fields

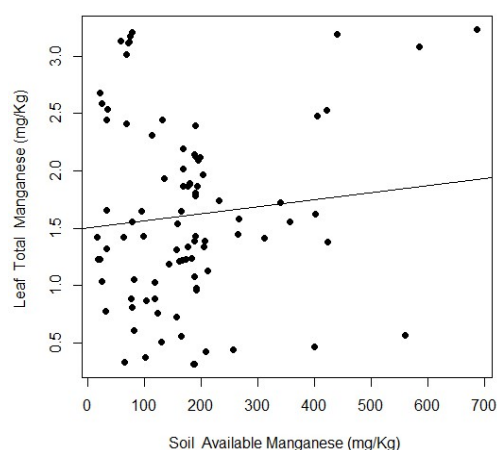


Fig.1.128: Scatter Diagram showing Soil available Copper v/s Leaf total Copper within Conventional Rice Fields

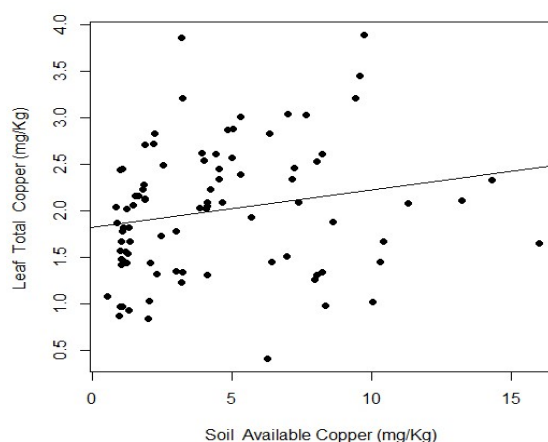


Table1.4: The ANOVA table of relation between parameters within the Conventional rice fields

Sl.No	Parameters	Estimate	Std. Error	t value	Pr(> t)
1	Water pH vs Soil pH	0.1031	0.1834	0.562	0.575
2	Water EC vs Soil EC	-1987.2	1489.6	-1.334	0.1857
3	Water Nitrate Vs Soil available Nitrogen	0.005679	0.001941	2.926	0.00437 **
4	Water Phosphate Vs Soil available Phosphorus	-0.0003365	0.0012327	-0.273	0.786
5	Water Potassium Vs Soil available Potassium	0.01916	0.01837	1.043	0.30003
6	Water Calcium Vs Soil available Calcium	-0.002533	0.006030	-0.420	0.675
7	Water Magnesium Vs Soil available Magnesium	-0.004548	0.003933	-1.156	0.251
8	Water Sulfate Vs Soil available Sulfur	-0.003284	0.123450	-0.027	0.978841
9	Soil available Nitrogen Vs Leaf total Nitrogen	14.844	6.714	2.211	0.0297 *
10	Soil available Phosphorus Vs Leaf total Phosphorus	5.3886	2.6575	2.028	0.045654 *
11	Soil available Potassium Vs Leaf total Potassium	0.7297	17.7931	0.041	0.967
12	Soil available Calcium Vs Leaf total Calcium	19.60	50.28	0.39	0.698
13	Soil available Magnesium Vs Leaf total Magnesium	-367.52	129.17	-2.845	0.00553 **
14	Soil available Sulfur Vs Leaf total Sulfur	-4.730	16.116	-0.294	0.77
15	Soil available Iron Vs Leaf total Iron	0.01318	0.00851	1.549	0.125
16	Soil available Manganese Vs Leaf total Manganese	0.0006143	0.0006480	0.948	0.346
17	Soil available Zinc Vs Leaf total Zinc	0.021753	0.006848	3.177	0.00206 **
18	Soil available Copper Vs Leaf total Copper	0.04013	0.02107	1.904	0.0602
19	Soil available Boron Vs Leaf total Boron	0.010482	0.003209	3.267	0.00156 **

20	Atmospheric Minimum temperature Vs Atmospheric Humidity	0.19064	0.06952	2.742	0.00741 **
21	Atmospheric Maximum temperature Vs Atmospheric Humidity	0.1244	0.1011	1.231	0.2217
22	Atmospheric Minimum temperature Vs Surface Water Temperature	0.54280	0.05317	10.208	< 2e-16 ***
23	Atmospheric Maximum temperature Vs Surface Water Temperature	0.99899	0.02871	34.792	<2e-16 ***
24	Atmospheric Minimum temperature Vs Bottom Water Temperature	0.56113	0.05691	9.861	7.78e-16 ***
25	Atmospheric Maximum temperature Vs Bottom Water Temperature	1.00611	0.04397	22.880	<2e-16 ***

Relation of atmospheric parameters between the Kaipad and Conventional Rice fields.

The difference in Atmospheric minimum temperature ($p=0.65$)(Fig.1.129), atmospheric maximum temperature ($p=0.306$)(Fig.1.130), surface water temperature ($p=0.676$)(Fig.1.131), bottom water temperature ($p=0.729$)(Fig.1.132) and atmospheric humidity ($p=0.795$)(Fig.1.133) between Kaipad and Conventional rice fields are not significant (Tab.1.5).

Fig.1.129: Box Plot showing Atmospheric Minimum Temperature in Conventional and Kaipad Rice Fields

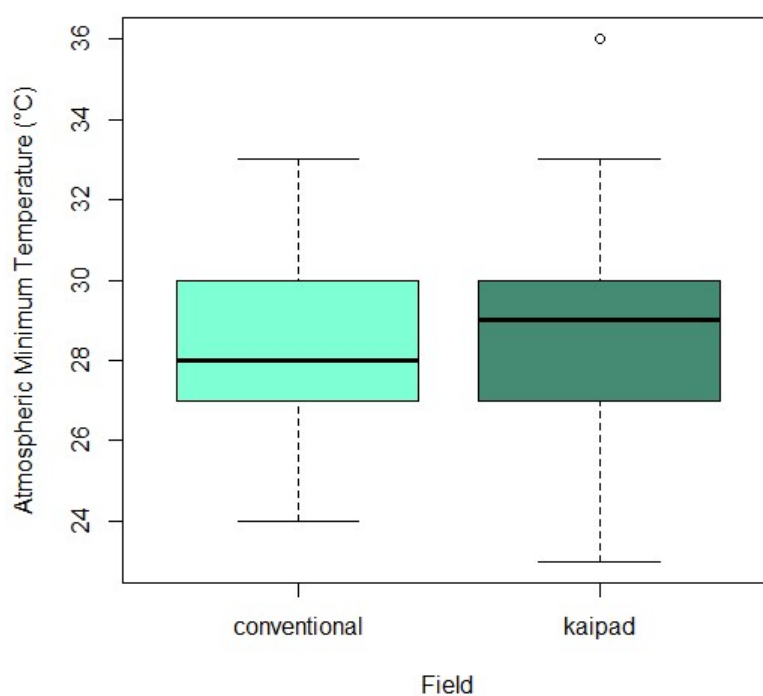
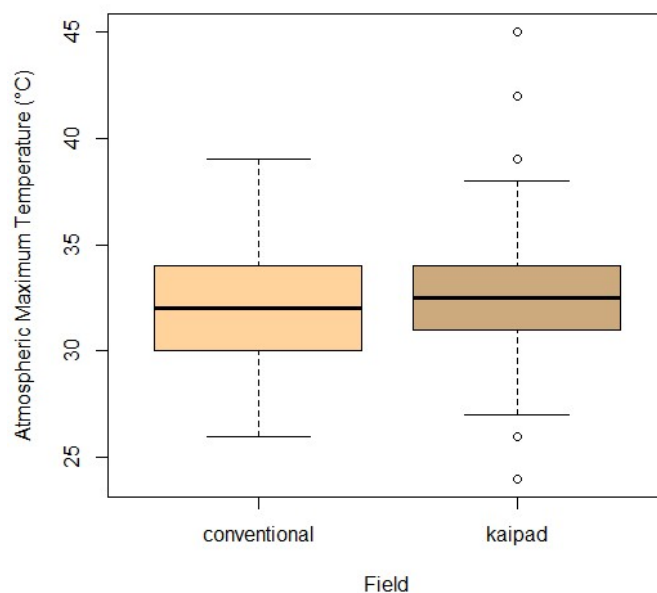
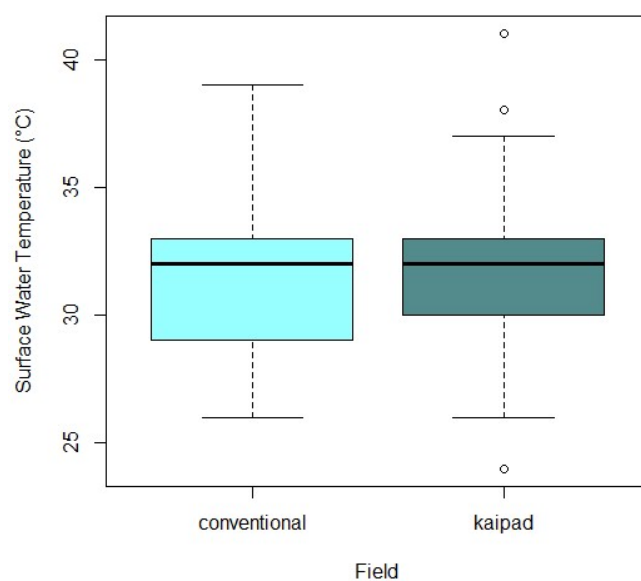


Fig.1.130: Box Plot showing Atmospheric Maximum Temperature in Conventional and Kaipad Rice Fields



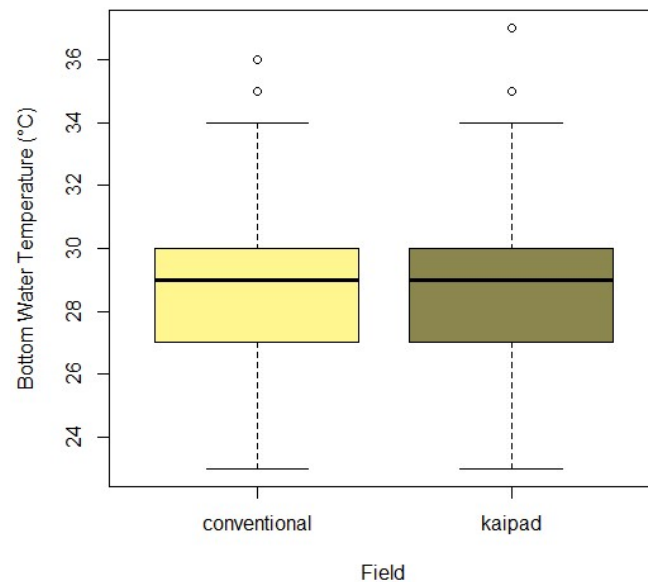
No significant difference in Water surface temperature between Kaipad and Conventional rice fields was observed. Kaipad shows the higher water surface temperature than Conventional rice fields, but its range is higher in Conventional rice fields (Fig.1.131).

Fig.1.131: Box Plot showing Surface Water Temperature in Conventional and Kaipad Rice Fields



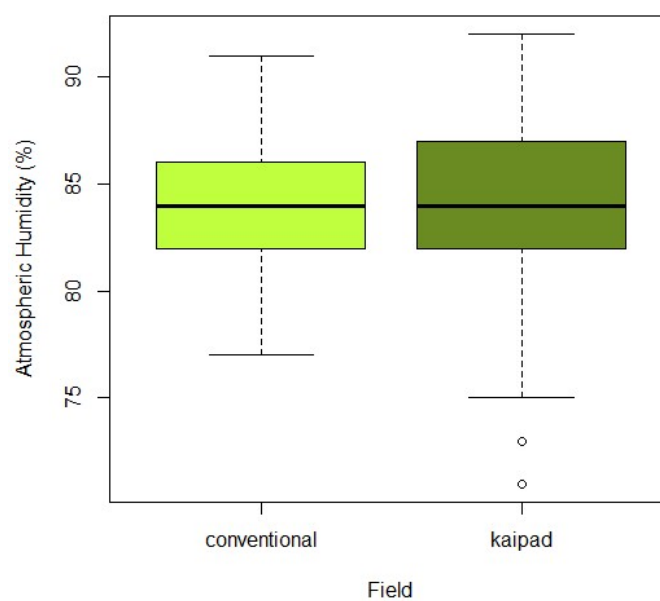
The bottom water temperature is higher in Kaipad rice fields than Conventional rice fields, but showing similar range (Fig.1.132).

Fig.1.132: Box Plot showing Bottom Water Temperature in Conventional and Kaipad Rice Fields



The atmospheric humidity, and their range are higher in the Kaipad rice fields than Conventional rice fields (Fig.1.133).

Fig.1.133: Box Plot showing Atmospheric Humidity in Conventional and Kaipad Rice Fields

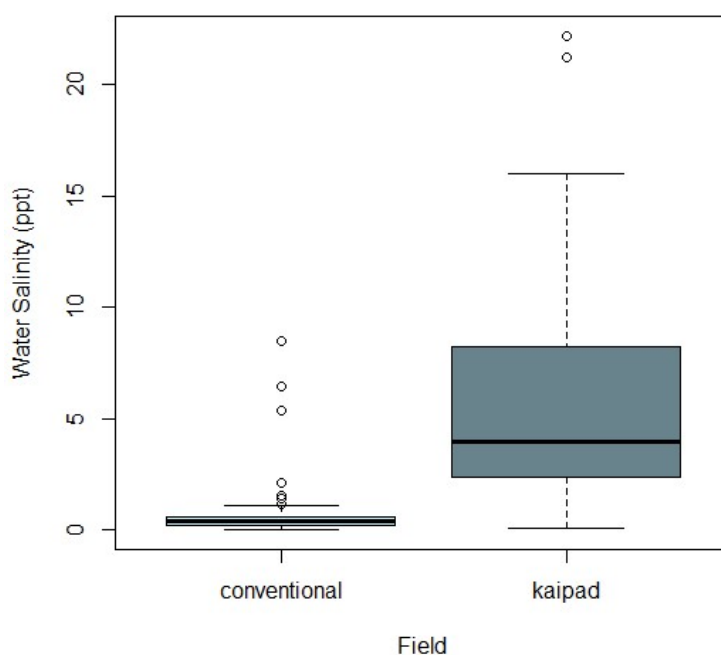


Relation of water physical parameters between the Kaipad and Conventional Rice fields.

There is a significant relation in water physical parameters viz., water salinity ($p < 2e-16$ ***) (Fig.1.134), water electrical conductivity ($p < 2e-16$ ***) (Fig.1.135), water total hardness ($p < 2e-16$ ***) (Fig.1.136), water chemical oxygen demand ($p < 2e-16$ ***) (Fig.1.137) and water turbidity ($p < 2e-16$ ***) (1.138) between Kaipad and Conventional rice field (Tab.1.5).

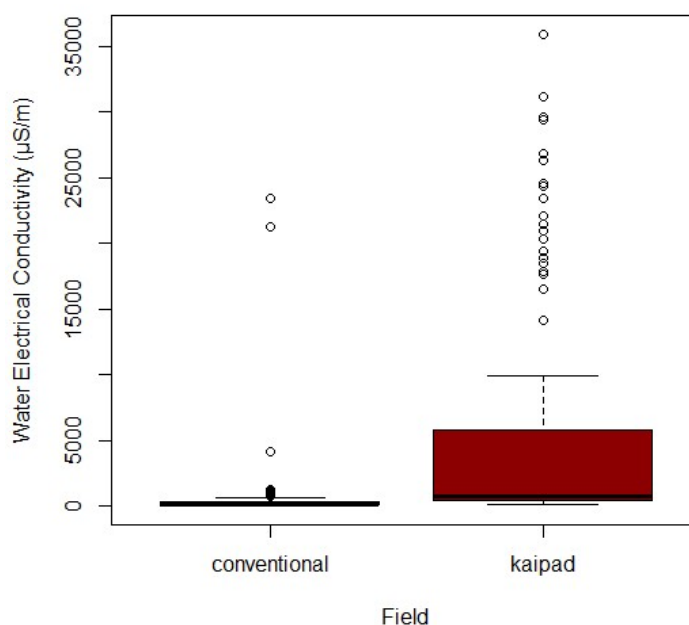
The water salinity is higher in Kaipad rice fields than in Conventional rice fields; and the range of water salinity is also higher in Kaipad rice fields (Fig.1.134).

Fig.1.134: Box Plot showing Water Salinity in Conventional and Kaipad Rice Fields



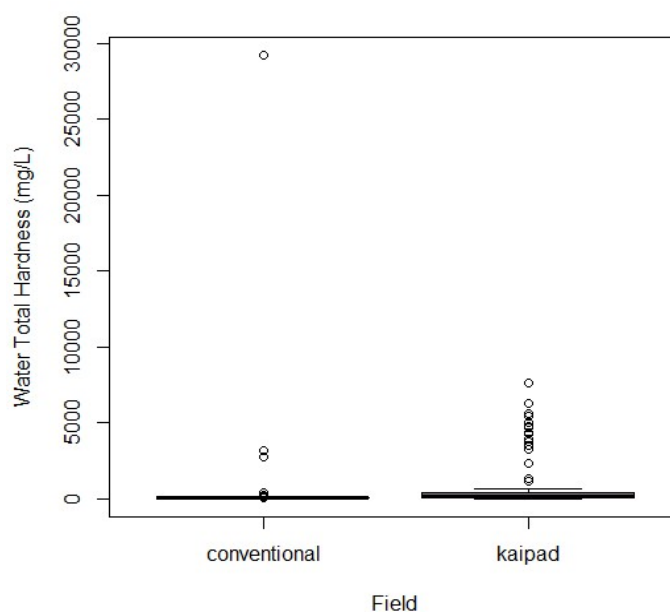
Higher water electrical conductivity is noted from Kaipad rice fields, than in Conventional rice fields, and their range is also observed higher in Kaipad rice fields (Fig.1.135).

Fig.1.135: Box Plot showing Water Electrical Conductivity in Conventional and Kaipad Rice Fields



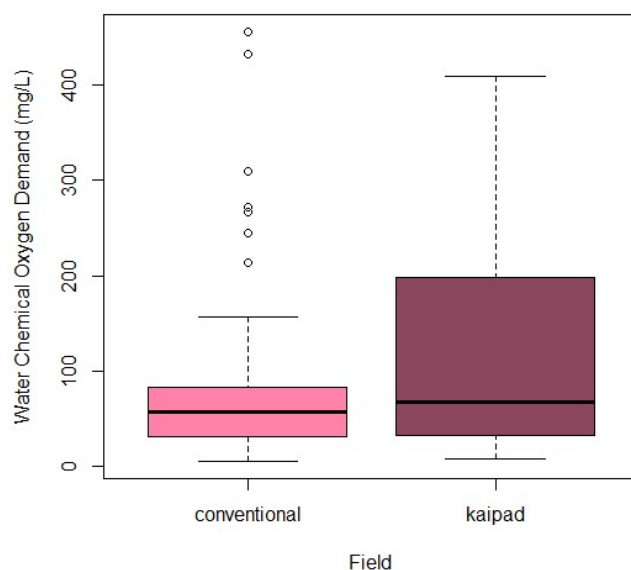
Higher water total hardness is in Kaipad rice fields, their range is also higher in Kaipad rice fields (Fig.1.136).

Fig.1.136: Box Plot showing Water Total hardness in Conventional and Kaipad Rice Fields



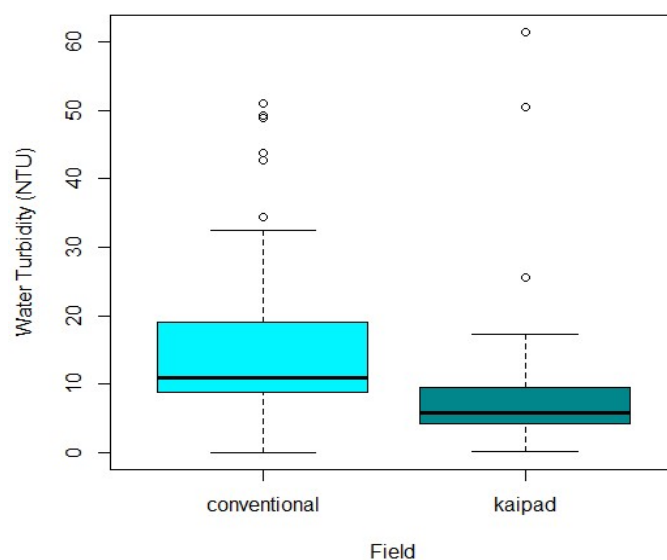
The amount and range of water chemical oxygen demand is higher in Kaipad rice fields than in Conventional rice fields (Fig.1.137).

Fig.1.137: Box Plot showing Water Chemical Oxygen Demand in Conventional and Kaipad Rice Fields



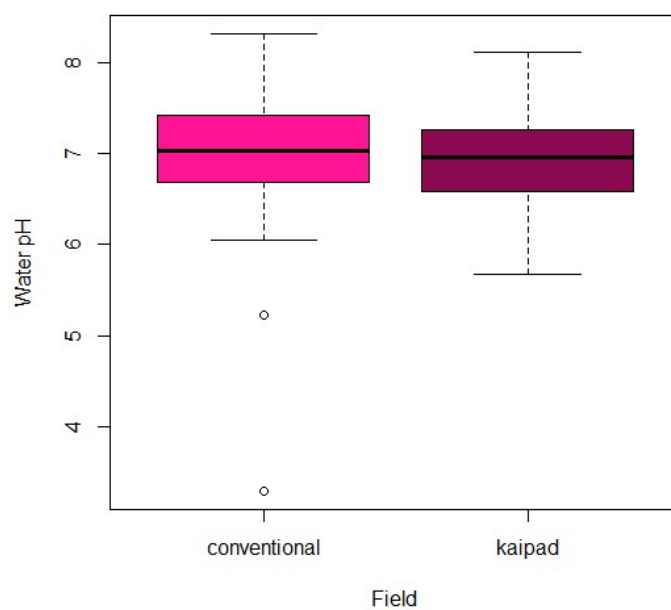
Water turbidity observations range is higher in Conventional rice fields than in Kaipad rice fields, and higher water turbidity is also noted from Conventional rice fields (Fig.1.138).

Fig.1.138: Box Plot showing Water Turbidity in Conventional and Kaipad Rice Fields



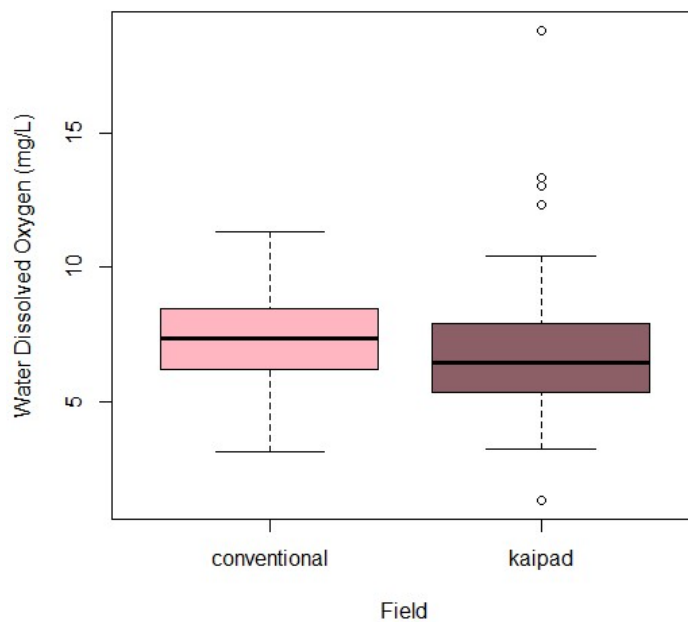
Conventional rice fields showed the higher water pH than the Kaipad rice fields (Fig.1.139).

Fig.1.139: Box Plot showing Water pH in Conventional and Kaipad Rice Fields



Higher water dissolved oxygen and range are in Conventional rice fields than in Kaipad rice fields (Fig.1.140).

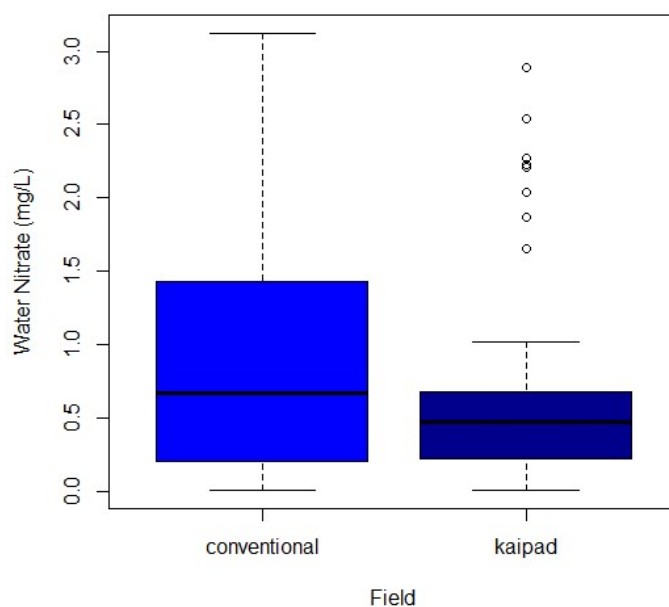
Fig.1.140: Box Plot showing Water Dissolved Oxygen in Conventional and Kaipad Rice Fields



Relation of water chemical parameters between the Kaipad and Conventional Rice fields.

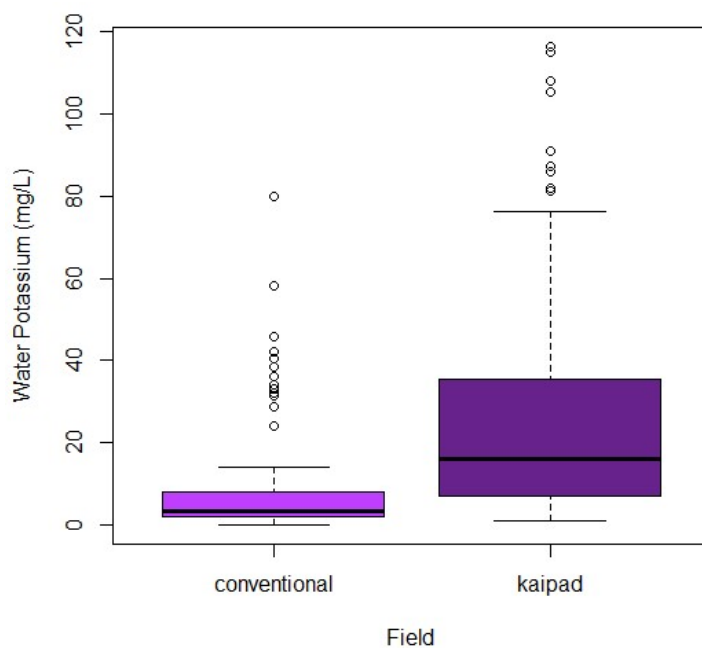
There is a significant relation in water Nitrate ($p=0.0413$ *), water Potassium ($p=<2e-16$ ***), water Calcium ($p=<2e-16$ ***), water Magnesium ($p=<2e-16$ ***) and water Sulfate ($p=<2e-16$ ***) between the Kaipad and Conventional rice fields (Tab.5). The amount and range of water nitrate is more in Conventional rice fields than in Kaipad rice fields (Fig.1.141).

Fig.1.141: Box Plot showing Water Nitrate in Conventional and Kaipad Rice Fields



The water Potassium is higher in Kaipad rice fields than Conventional rice fields, and their range is also higher in Kaipad rice fields (Fig.1.142).

Fig.1.142: Box Plot showing Water Potassium in Conventional and Kaipad Rice Fields



Higher Water Calcium (Fig.1.143), Water Magnesium (Fig.1.144) and Water Sulfate (Fig.1.145) are noted from Kaipad rice fields. They also show higher range in Kaipad rice fields than in Conventional rice fields.

Fig.1.143: Box Plot showing Water Calcium in Conventional and Kaipad Rice Fields

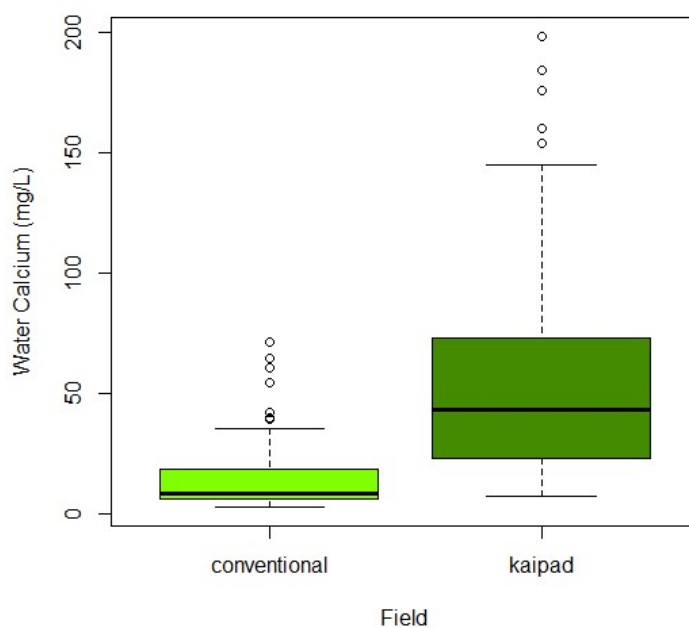


Fig.1.144: Box Plot showing Water Magnesium in Conventional and Kaipad Rice Fields

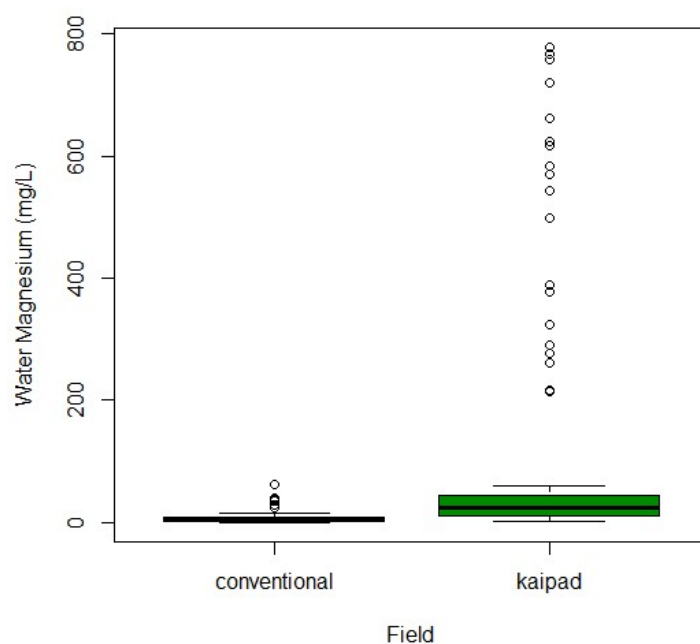
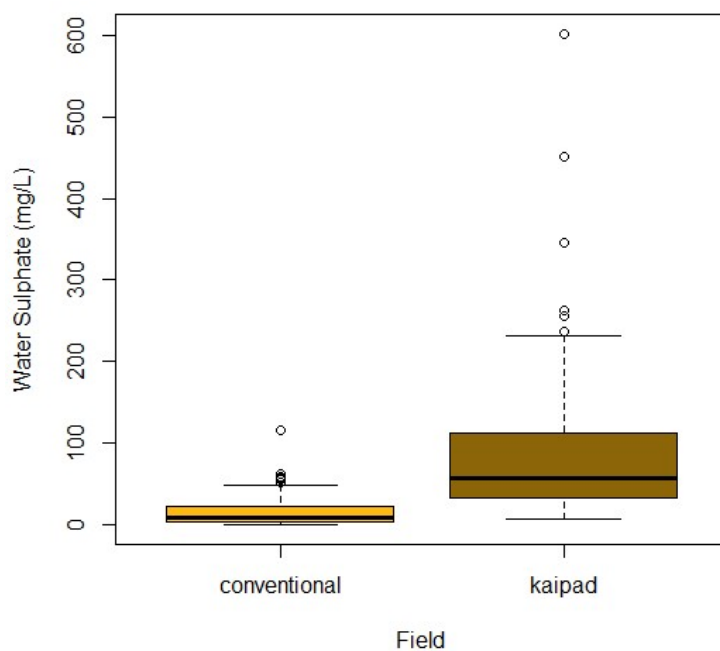
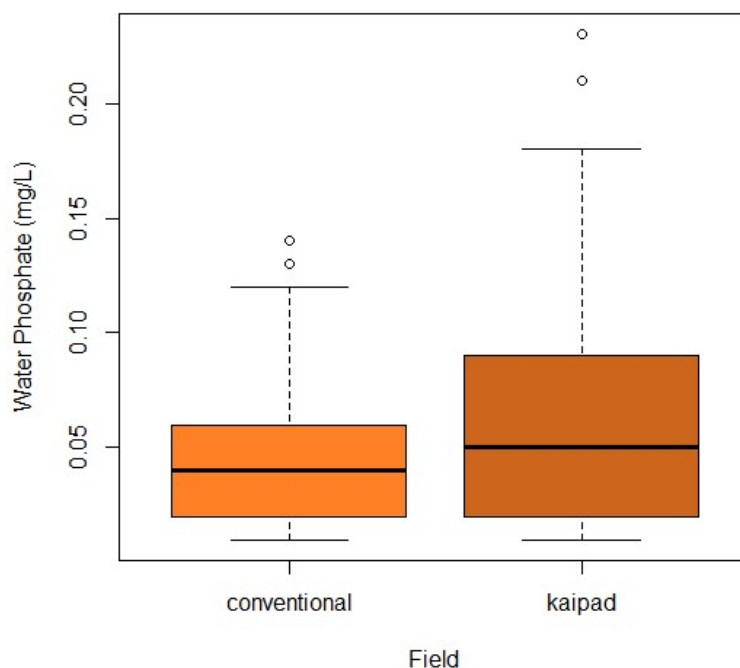


Fig.1.145: Box Plot showing Water Sulfate in Conventional and Kaipad Rice Fields



Water Phosphate is higher in Kaipad rice fields than in Conventional rice fields, and their range is also higher in Kaipad rice fields (Fig.1.146).

Fig.1.146: Box Plot showing Water Phosphate in Conventional and Kaipad Rice Fields



1.1. Relation of soil physical parameters between Kaipad and Conventional Rice fields.

In the case of soil physical parameters, soil electrical conductivity ($p=1.93 \times 10^{-5}$ ***) (Fig.1.147) between the fields is showing significant relation, but the relation of soil pH ($p=0.282$) (Fig.1.148) between Kaipad and Conventional rice fields is not significant (Tab.1.5). Higher Soil electrical conductivity is observed in Kaipad rice fields, but their range is also higher in Conventional rice fields (Fig.1.147). Even though the range of soil pH is higher in Kaipad rice fields, higher soil pH is noted in Conventional rice fields (Fig.1.148).

Fig.1.147: Box Plot showing Soil Electrical Conductivity in Conventional and Kaipad Rice Fields

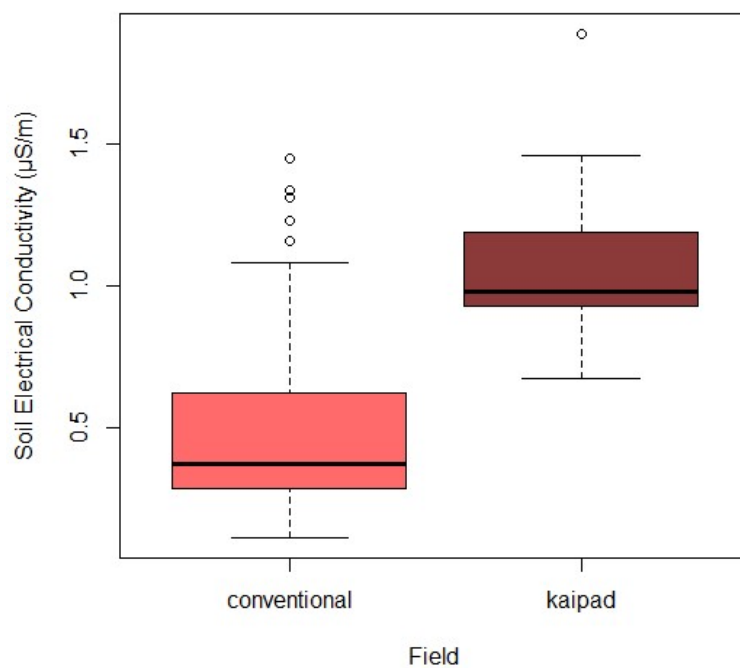
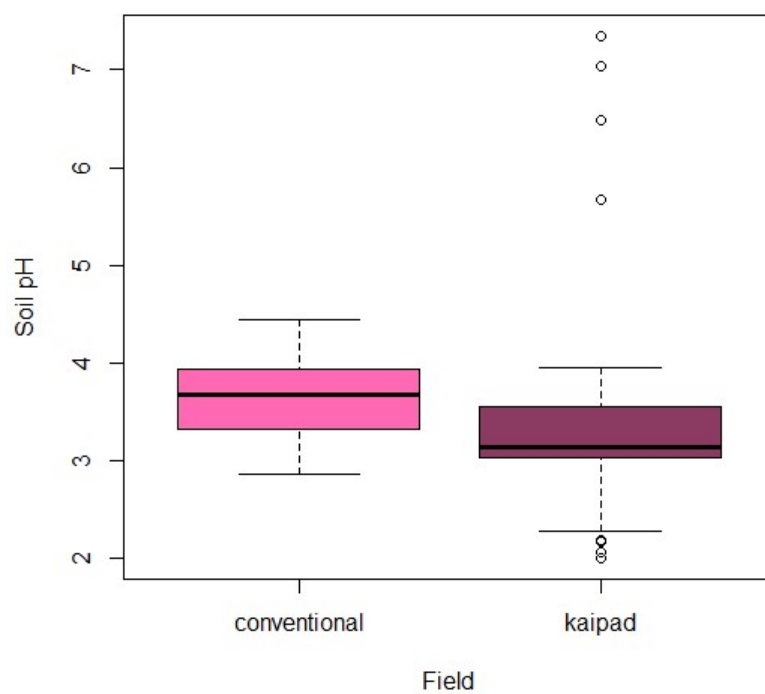


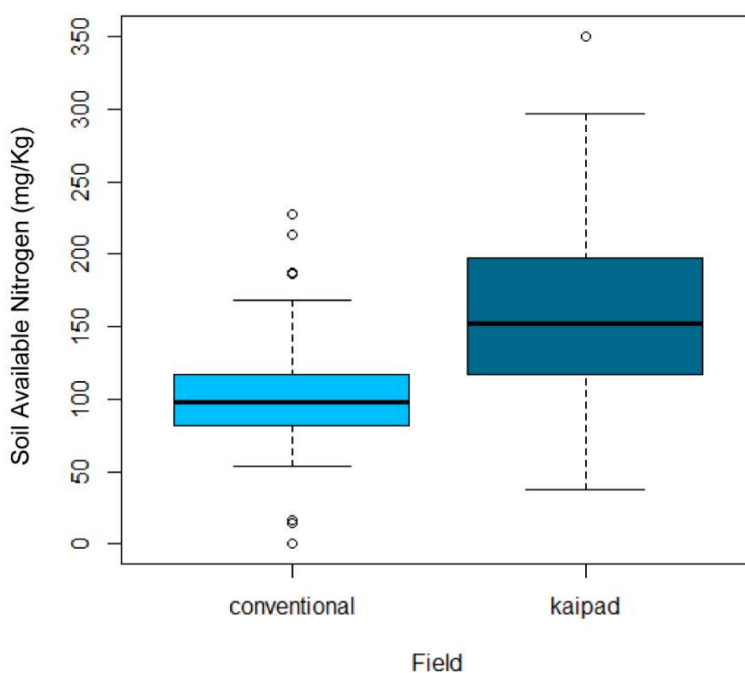
Fig.1.148: Box Plot showing Soil pH in Conventional and Kaipad Rice Fields



1.2. Relation of soil chemical parameters between Conventional and Kaipad rice fields.

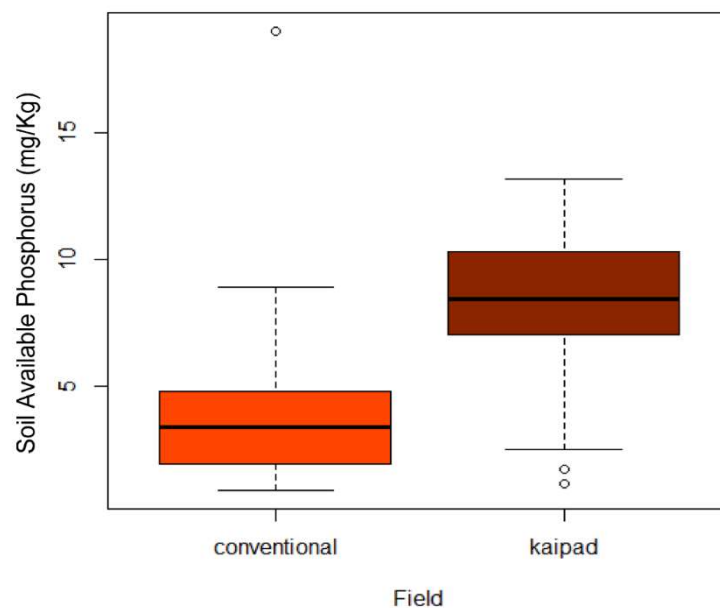
Soil Nitrogen ($p < 2e-16$ ***), soil Phosphorus ($p < 2e-16$ ***), soil Calcium ($p < 2e-16$ ***), soil Magnesium ($p < 2e-16$ ***), soil Sulfur ($p < 2e-16$ ***), and soil Boron ($p = 0.000143$ ***) are showing significant relation between Kaipad and conventional rice fields (Tab.5). But the relations of soil Potassium ($p = 0.503$), soil Iron ($p = 0.882$), soil Manganese ($p = 0.842$), soil Zinc ($p = 0.831$) and soil Copper ($p = 0.661$) between the two categories of rice fields are not significant (Tab.5).

Fig.1.149: Box Plot showing Soil available Nitrogen in Conventional and Kaipad Rice Fields



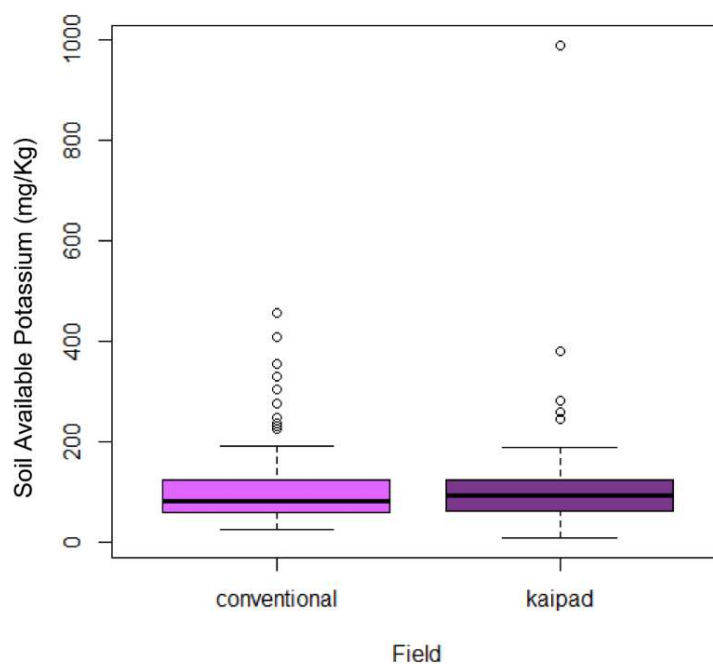
Soil Nitrogen (Fig.1.149) and soil Phosphorus (Fig.1.150) also shows variation in range and inter-quartile range. The soil available Nitrogen of Kaipad shows higher range than Conventional rice fields, and in the case of soil available Phosphorus also the range is higher in Kaipad rice fields than Conventional rice fields.

Fig.1.150: Box Plot showing Soil available Phosphorus in Conventional and Kaipad Rice Fields



Higher Soil available Potassium is noted from Kaipad rice fields than in Conventional one. Their range is also higher in Kaipad rice fields (Fig.1.151).

Fig.1.151: Box Plot showing Soil available Potassium in Conventional and Kaipad Rice Fields



The soil Calcium showed similar range in both categories of rice fields (Fig.1.152), but the range of soil Magnesium (Fig.1.153) in Conventional fields are higher when compared with rice fields of Kaipad.

Fig.1.152: Box Plot showing Soil available Calcium in Conventional and Kaipad Rice Fields

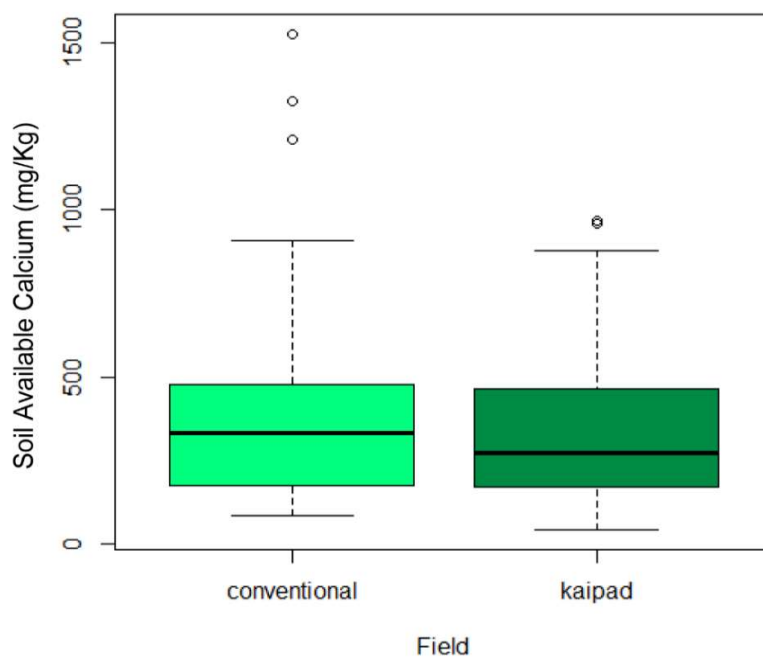
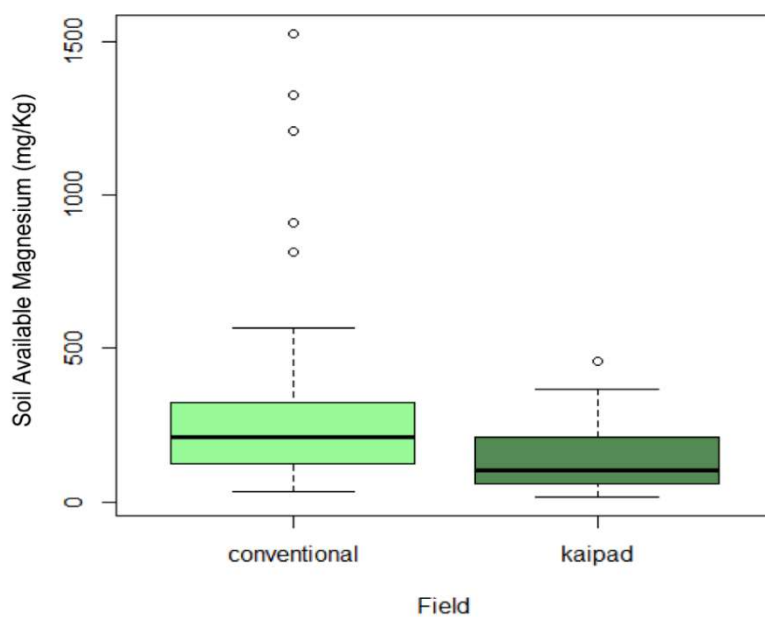
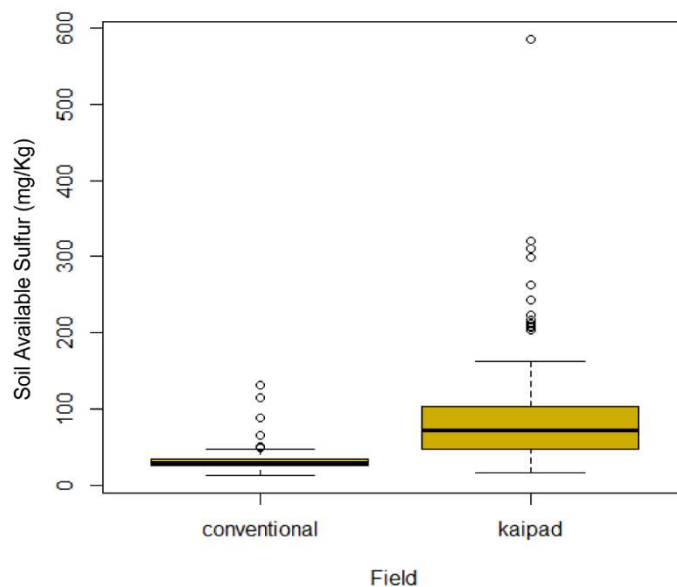


Fig.1.153: Box Plot showing Soil available Magnesium in Conventional and Kaipad Rice Fields



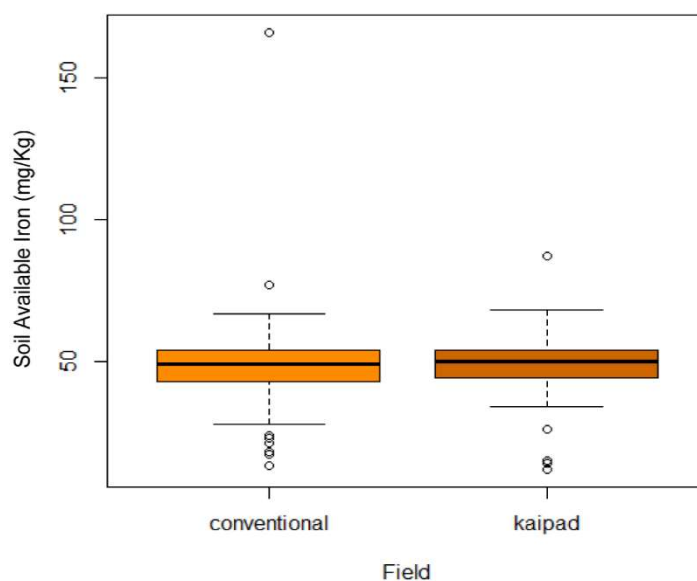
Higher soil Sulfur is seen in Kaipad rice fields than that of Conventional rice fields. The ranges are also higher in rice fields of Kaipad than Conventional rice fields (Fig.1.154).

Fig.1.154: Box Plot showing Soil available Sulfur in Conventional and Kaipad Rice Fields



The range of soil Iron content in Conventional rice fields is higher than in Kaipad rice fields, but higher soil Iron is observed in Kaipad rice fields (Fig.1.155).

Fig.1.155: Box Plot showing Soil available Iron in Conventional and Kaipad Rice Fields



The amount and range of values of soil Manganese (Fig.1.156) and soil Zinc (Fig.1.157) is higher in Conventional rice fields than the Kaipad type of rice fields.

Fig.1.156: Box Plot showing Soil available Manganese in Conventional and Kaipad Rice Fields

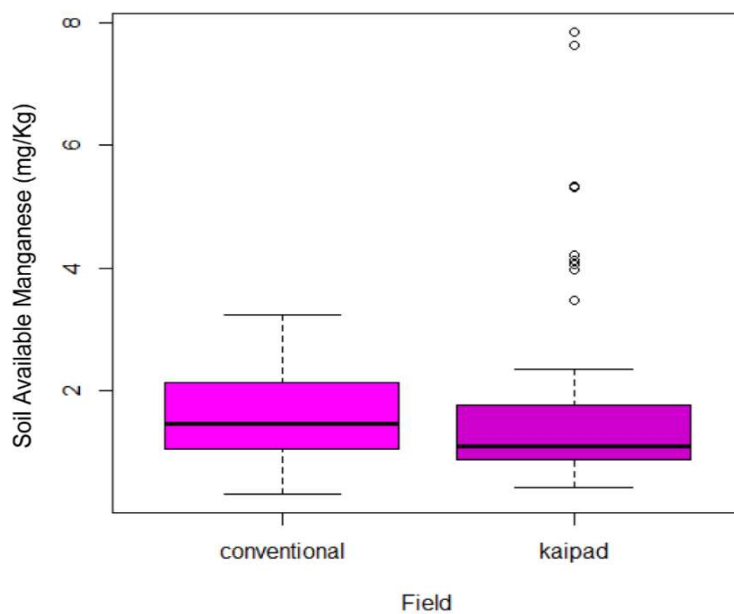
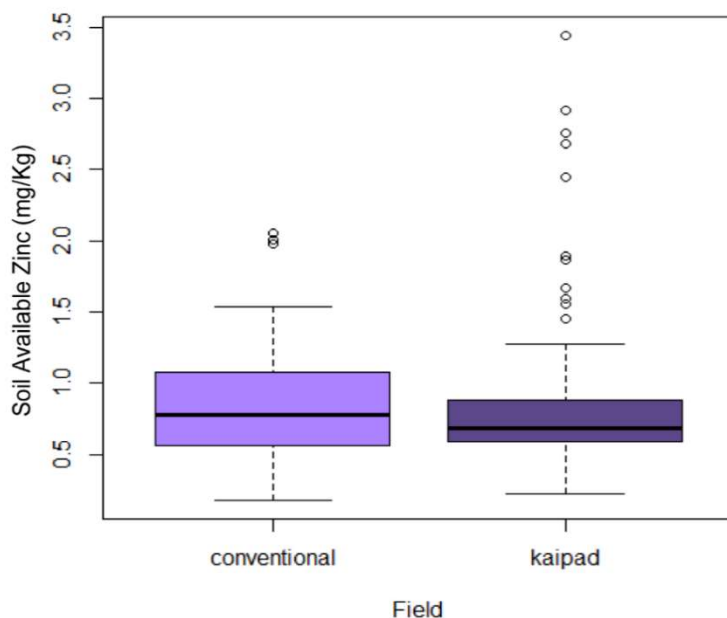
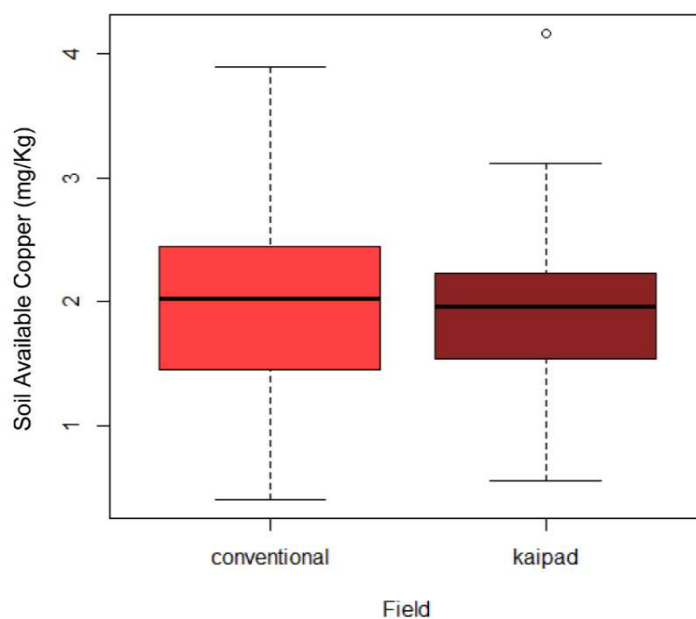


Fig.1.157: Box Plot showing Soil available Zinc in Conventional and Kaipad Rice Fields



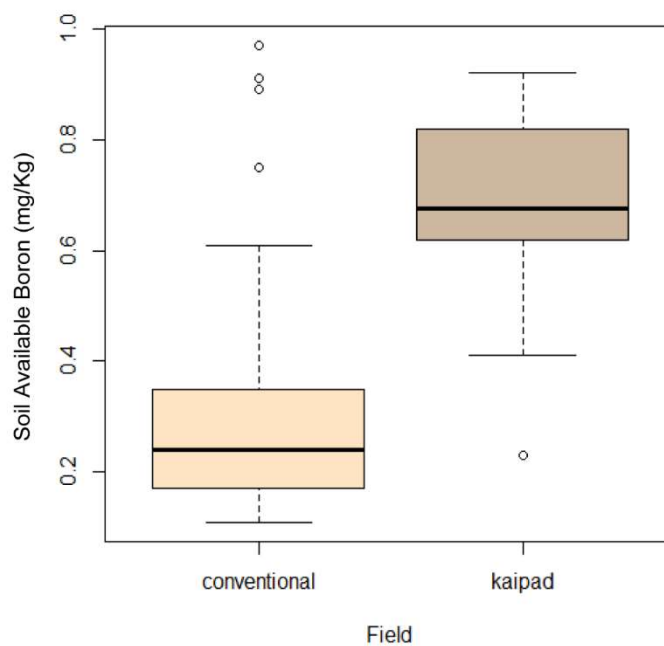
Higher soil Copper is noted from Conventional rice fields, and their range is also higher in Conventional rice fields than in Kaipadrice fields (Fig.1.158).

Fig.1.158: Box Plot showing Soil available Copper in Conventional and Kaipad Rice Fields



Soil Boron is higher in Kaipad rice fields, and their range is also high in Kaipad rice fields than in Conventional rice fields (Fig.1.159).

Fig.1.159: Box Plot showing Comparison of Soil available Boron in Conventional and Kaipad Rice Fields

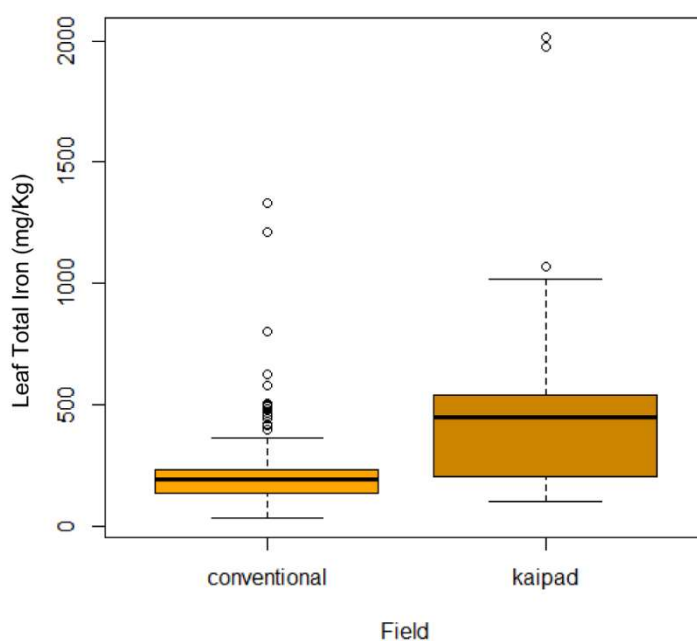


Relation of leaf parameters between Conventional and Kaipad Rice fields.

The Leaf Iron ($p < 2e-16$ ***), Leaf Manganese ($p < 2e-16$ ***), Leaf Zinc ($p = 0.000197$ ***), Leaf Copper ($p = 0.0304$ *) and Leaf Boron ($p = 0.000116$ ***) between Conventional and Kaipadrice fields are significant (Tab.5); but Leaf Nitrogen ($p = 0.304$), Leaf Phosphorus ($p = 0.63$), Leaf Potassium ($p = 0.0956$), Leaf Calcium ($p = 0.954$), Leaf Magnesium ($p = 0.342$) and Leaf Sulfur ($p = 0.643$) between Conventional and Kaipadrice fields are not significantly different (Tab.1.5).

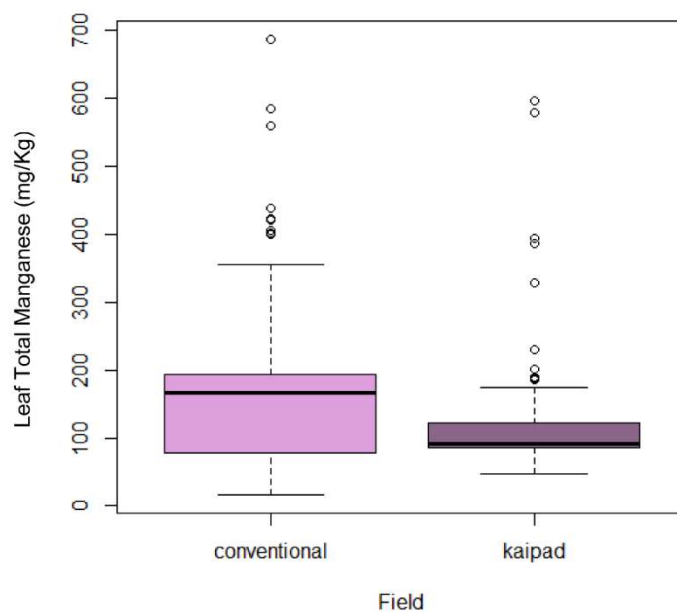
The leaf Iron content is higher in Kaipad rice fields, than compared to Conventional rice fields. And their range is also higher in Kaipad (Fig.1.160).

Fig.1.160: Box Plot showing Comparison of Leaf total Iron in Conventional and Kaipad Rice Fields



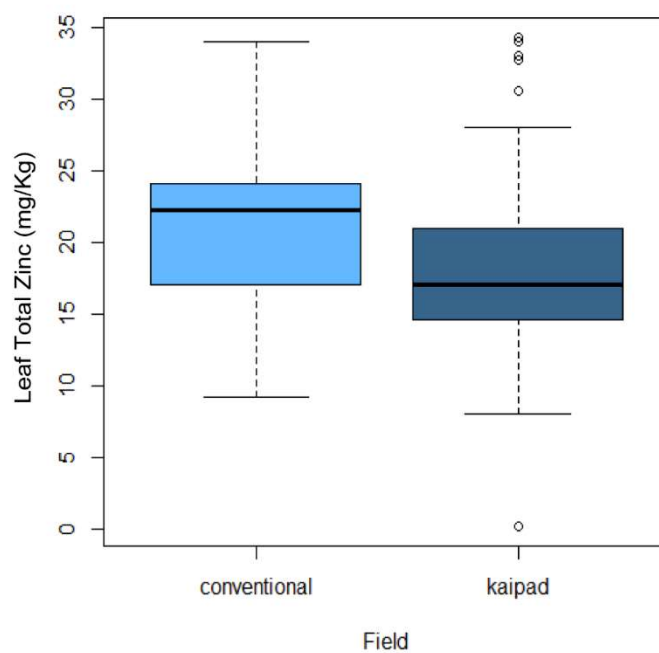
The range of Leaf Manganese is higher in Conventional rice fields than in Kaipad rice fields, and higher content of leaf Mn is also reported from Conventional rice fields (Fig.1.161).

Fig.1.161: Box Plot showing Comparison of Leaf total Manganese in Conventional and Kaipad Rice Fields



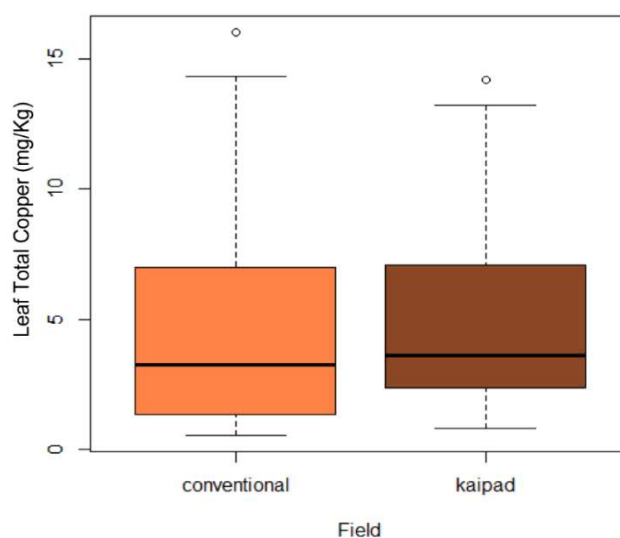
The observed range of Leaf Zinc is high in Conventional rice fields than Kaipad rice fields. And higher Zn is also recorded in the leaves collected from Conventional rice fields (Fig.1.162).

Fig.1.162: Box Plot showing Comparison of Leaf total Zinc in Conventional and Kaipad Rice Fields



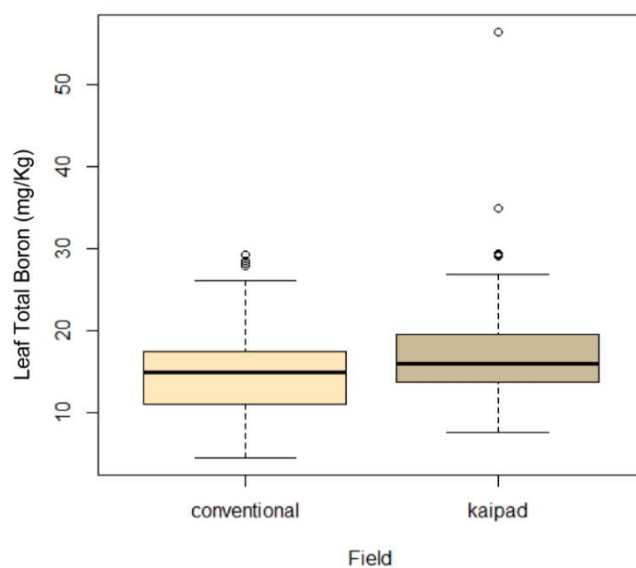
The higher leaf Copper is observed from Kaipad rice fields than that of Conventional rice fields. The range of Leaf Copper between the Conventional and Kaipad rice fields are also different, higher range is recorded from Conventional rice fields (Fig.1.163).

Fig.1.163: Box Plot showing Comparison of Leaf total Copper in Conventional and Kaipad Rice Fields



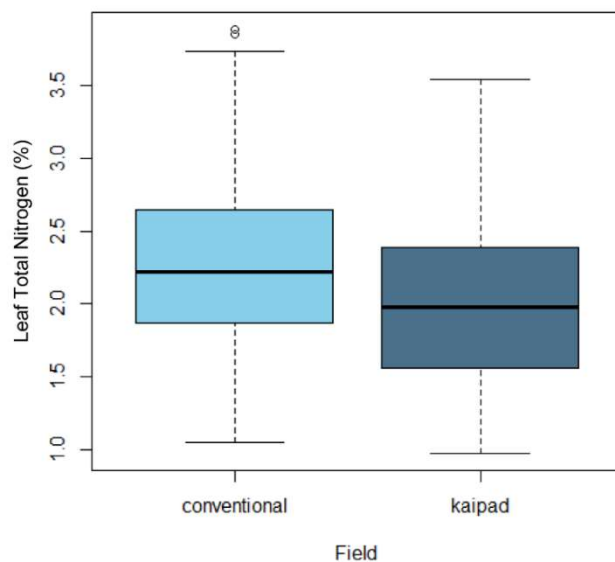
The higher Leaf Boron content is noted from Kaipad rice fields, but its range is higher in Conventional rice fields than in Kaipad rice fields (Fig.1.164).

Fig.1.164: Box Plot showing Leaf total Boron in Conventional and Kaipad Rice Fields



The leaf Nitrogen is higher from Conventional rice fields than that of Kaipad rice fields and their range is also high in conventional rice fields (Fig.1.165).

Fig.1.165: Box Plot showing Leaf total Nitrogen in Conventional and Kaipad Rice Fields



The leaf Phosphorus is higher from Conventional rice fields (Fig.1.166), but higher leaf Potassium is recorded from leaves collected from Kaipad rice fields (Fig.1.167). Both of them showed higher range in Conventional rice fields.

Fig.1.166: Box Plot showing Leaf total Phosphorus in Conventional and Kaipad Rice Fields

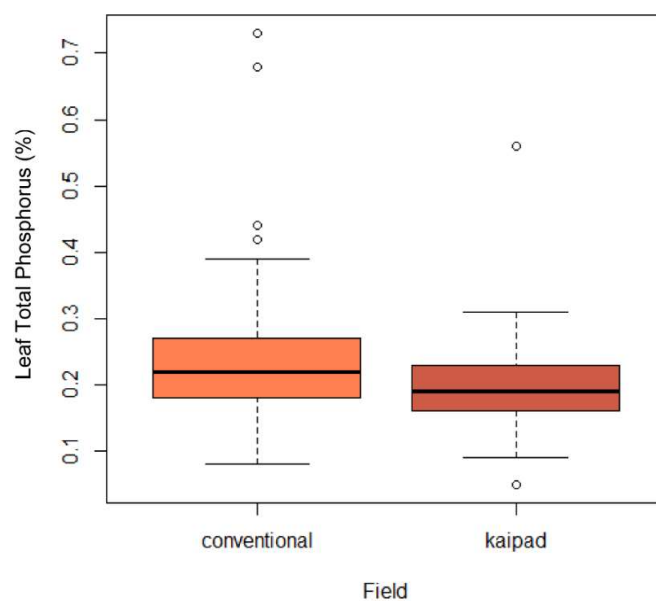
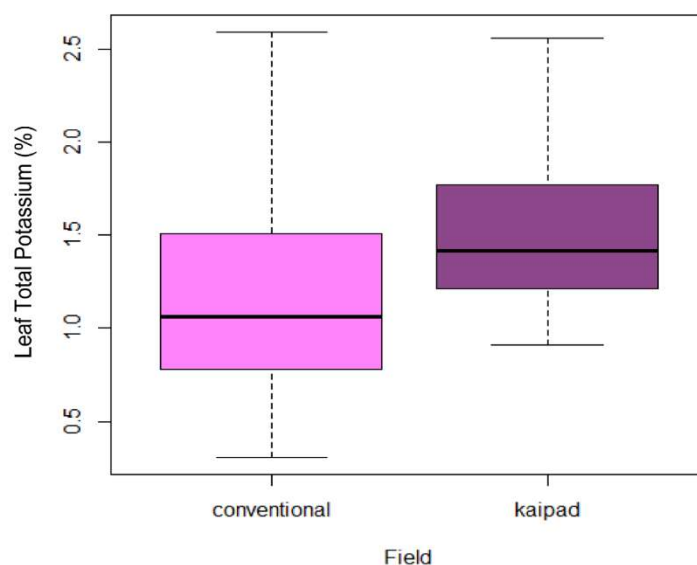
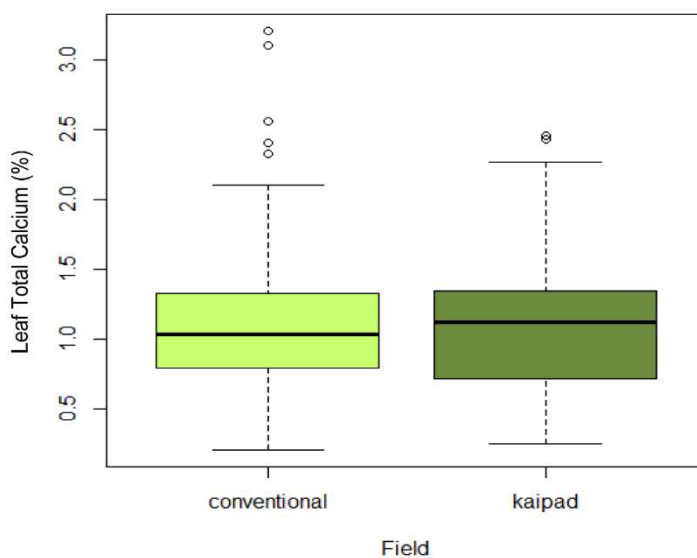


Fig.1.167: Box Plot showing Leaf total Potassium in Conventional and Kaipad Rice Fields



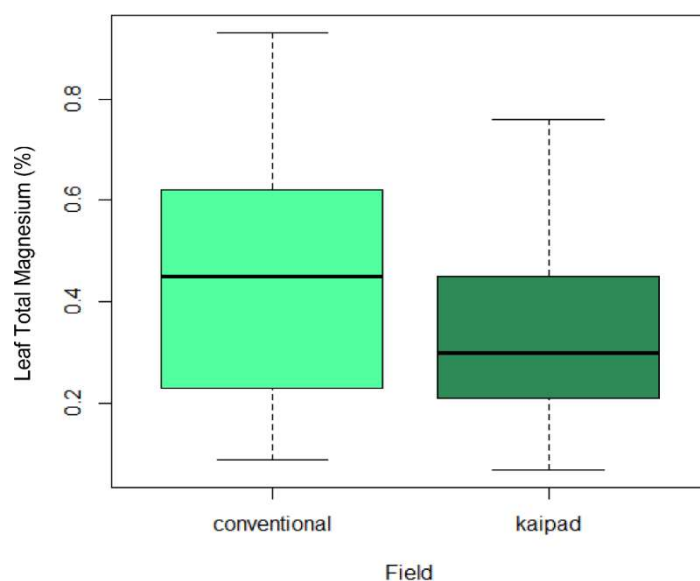
The amount and range of Leaf Calcium is seen in Kaipad rice fields than in Conventional rice fields (Fig.1.168).

Fig.1.168: Box Plot showing Leaf total Calcium in Conventional and Kaipad Rice Fields



The higher leaf Mg is estimated from Conventional rice fields than that of Kaipadrice fields, and range of Magnesium content of rice leaves in Conventional rice fields is also higher than in the rice leaves of Kaipad rice fields (Fig.1.169).

Fig.1.169: Box Plot showing Leaf total Magnesium in Conventional and Kaipad Rice Fields



Both the amount and range of leaf Sulfur are higher in the case of rice leaves of Conventional rice fields than in the leaves of Kaipad rice fields (Fig.1.170).

Fig.1.170: Box Plot showing Comparison of Leaf total Sulfur in Conventional and Kaipad Rice Fields

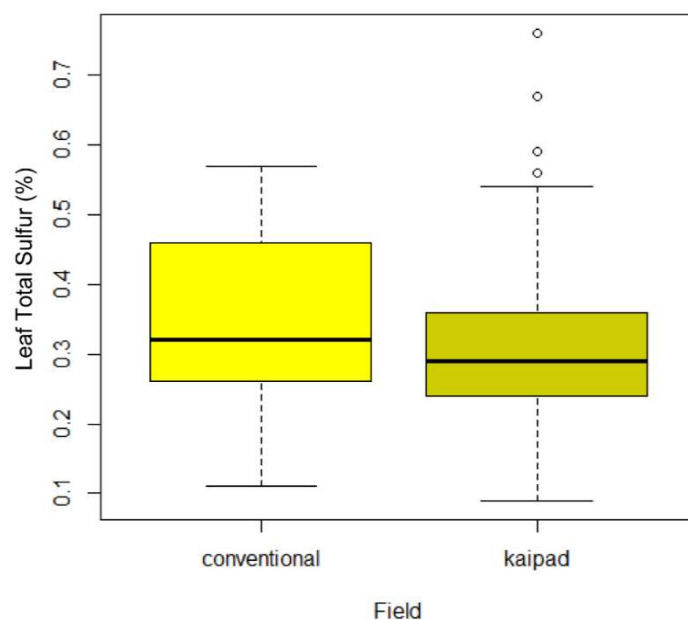


Table1.5. The ANOVA table of Atmospheric, water, soil and leaf parameters between Kaipad and Conventional rice field

SI.No	Parameters	Estimate	Standard error	Z value	P Value
1	Atmospheric Minimum Temperature	0.01270	0.02798	0.454	0.65
2	Atmospheric Maximum Temperature	0.02697	0.02634	1.024	0.306
3	Surface Water Temperature	0.01113	0.02661	0.418	0.676
4	Bottom Water Temperature	0.009637	0.027763	0.347	0.729
5	Atmospheric Humidity	0.004246	0.016305	0.26	0.795
6	Water Salinity	2.1752	0.1403	15.499	< 2e-16 ***
7	Water pH	-0.005821	0.056699	-0.103	0.918
8	Water EC	1.789175	0.003543	505	<2e-16 ***
9	Water Dissolved Oxygen	-0.07488	0.05649	-1.326	0.185
10	Chemical Oxygen Demand	0.40983	0.01579	25.95	<2e-16 ***
11	Water Total Hardness	0.748580	0.006102	122.7	<2e-16 ***
12	Water Turbidity	-0.58407	0.04587	-12.73	<2e-16 ***
13	Water Nitrate	-0.3652	0.1790	-2.041	0.0413 *
14	Water Phosphate	0.3824	0.6519	0.587	0.558
15	Water Potassium	1.09254	0.03955	27.63	<2e-16 ***
16	Water Calcium	1.34263	0.03086	43.51	<2e-16 ***
17	Water magnesium	2.84952	0.04026	70.78	<2e-16 ***
18	Water Sulfate	1.63803	0.02737	59.86	<2e-16 ***
19	Soil pH	-0.08628	0.08024	-1.075	0.282
20	Soil Electrical Conductivity	0.7908	0.1851	4.273	1.93e-05 ***
21	Soil available Nitrogen	0.44414	0.01336	33.26	<2e-16 ***

22	Soil available Phosphorus	0.78251	0.06543	11.96	<2e-16 ***
23	Soil available Potassium	-0.009535	0.014242	-0.67	0.503
24	Soil available Calcium	-0.081616	0.007996	-10.21	<2e-16 ***
25	Soil available Magnesium	-0.644652	0.010964	-58.8	<2e-16 ***
26	Soil available Sulfur	1.11695	0.02132	52.39	<2e-16 ***
27	Soil available Iron	0.003179	0.021346	0.149	0.882
28	Soil available Manganese	-0.02366	0.11846	-0.200	0.842
29	Soil available Zinc	0.0343	0.1610	0.213	0.831
30	Soil available Copper	-0.04690	0.10711	-0.438	0.661
31	Soil available Boron	0.8913	0.2343	3.804	0.000143 ***
32	Leaf total Nitrogen	-0.10435	0.10146	-1.029	0.304
33	Leaf total Phosphorus	-0.1545	0.3211	-0.481	0.63
34	Leaf total Potassium	0.21666	0.13002	1.666	0.0956
35	Leaf total Calcium	0.008131	0.139996	0.058	0.954
36	Leaf total Magnesium	-0.2310	0.2429	-0.951	0.342
37	Leaf total Sulfur	-0.1212	0.2612	-0.464	0.643
38	Leaf total Iron	0.581523	0.008531	68.16	<2e-16 ***
39	Leaf total Manganese	-0.377569	0.012484	-30.25	<2e-16 ***
40	Leaf total Zinc	-0.12612	0.03387	-3.723	0.000197 ***
41	Leaf total Copper	0.14866	0.06867	2.165	0.0304 *
42	Leaf total Boron	0.14312	0.03712	3.855	0.000116 ***

DISCUSSION

The focus of this study was to analyze the water, soil, and leaf parameters between and within the Kaipad and Conventional Rice Fields of North Kerala.

The minimum temperature, maximum temperature and optimum temperature limits for optimum growth of rice are 10-12°C, 36-38°C and 30-32°C respectively ([https:// agritech.tnau. ac.in/](https://agritech.tnau.ac.in/)). The average temperatures noted from both categories of rice fields during the present study are within the limits of the recommended temperature for rice growth. According to Anonymous (2014), the average temperature required throughout the life period of the crop species ranges from 21 to 37°C, and a crop can tolerate up to a maximum temperature of 40 to 42°C. As per the studies of Jagadish et al., (2007) and Satake and Yoshida, (1978), the rice spikelet sterility is induced by heat stress and according to Mohammed and Tarpley (2009) and Peng et al., (2004) there is a decline in grain quality and yield with high temperature (above 38°C). Our results from both categories of rice fields indicate that the temperature was within the accepted limits for rice plant growth and no adverse effect on plant growth was noted. According to Davis et al., (1998), and Kiritani (2006) global warming will favor insect parasitoids rather than their host insects, so high atmospheric temperature (above 38°C) in Kaipad and other Conventional rice fields may be good for the better performance of the parasitoids.

The average humidity recorded from both categories of rice fields during the present study are higher than the optimum limit, but still not in the range of humidity which affects the yield of rice growth. A relative humidity of 60-80 % is said to be optimum for rice growth, and humidity directly influences the water relations of rice and indirectly affects leaf growth, photosynthesis, pollination, occurrence of diseases and finally economic yield (<http://www.agritech.tnau.ac.in>). Yan et al., (2010) noted that higher relative humidity at the flowering stage under increased temperature negatively affects spikelet fertility. In another study (Abey Siriwardena et al., 2002) also documented that relative humidity of 85- 90% at the heading stage induces almost complete grain sterility in rice.

During the present study, rice plants were observed to be healthy within the noted range of water surface temperature in both categories of rice fields. Chen et al., (2012) reported that fluctuation in water surface temperature is due to the surrounding water/air temperature. In our results also, atmospheric temperature showed significant positive correlation with water surface temperature in Kaipad and Conventional rice fields. According to several authors, water temperature affects growth rate and yield of rice plants through various biological processes, e.g., leaf photosynthesis, phenological development, root water uptake, and fertilization of the spikelet (Roel et al., 2005, Shimono et al., 2004; Fukui et al., 2015; van Oort et al., 2011, Murai et al., 2008, Julia and Dingkuhn, 2013; Shimono et al., 2005).

The impact of salinity on crops leads to reduction of growth due to high osmotic potential and ion toxicity, photosynthesis inhibition by decreased CO₂ availability and pigment content, diminished nutrient and water uptake, and root damage; eventually resulting in yield reduction (Velmurugan et al., 2016; Machado and Serralheiro, 2017). The salinity status is marginal (Between 0.5-1ppt) in Conventional rice fields, and saline (between 2-10 ppt) in the case of Kaipad rice fields. In rice, earlier studies documented that salinity acts mainly on delaying seed germination than reducing germination percentage; moreover, salt tolerance in rice increases with time, being lowest during the early seedling stage with a certain variability amongst different rice varieties (Mondal and Borromeo, 2016). According to Akbarimoghaddam et al., (2011) and Singh and Chatrath (2001) also the salinity effects are the results of complex interactions among morphological, physiological, and biochemical processes including seed germination, plant growth, and water and nutrient uptake. Although the salinity level is high in Kaipad rice fields, the use of saline tolerant Ezhome varieties and the adoption of cultural methods like preparation of “Koonaa” (heaped up mud) in Kaipad rice fields reduces the effect of salinity on seed germination and growth of rice.

Acidic water leads to reduction in calcium, magnesium and potassium level. If water is too alkaline, calcium builds up, effectively cutting off the flow of nutrients to plants roots, and those extreme cases affects plant growth. During the

present study, water pH range noted from Kaipad rice field was 5.5 to 8.0 (Ideal range- 5.0-8.0). Earlier, Chandramohan and Mohanan (2012) reported water pH between 6.71 and 7.45 in April and in July it ranged from 6.15 to 6.71 from Kaipad rice fields. During a study in Pokkali areas, Deepa (2014) reported maximum water pH during December (7.4). The range of pH observed in the present study is within the tolerable limits for rice plant growth and is reflected in the normal growth of the rice plants.

Nutrients are most available to plants in the optimum 5.5 to 7.0 pH range. Jiang et al., (2017) documented that many plant characteristics such as height, lateral spread, biomass, flower size and number, and pollen production are influenced by soil pH. According to Yu, (1991), rice can grow effectively at soil pH 5.5. The present study recorded optimum range of pH in Kaipad rice fields which indicates the suitability of this traditional method of cultivation for rice growth. As per Loncaric et al., (2008), in Kaipad and Conventional rice fields ($\text{pH} \leq 5$), most micronutrients are more easily available to plants than in neutral-alkaline soils, generally favoring plant growth. As per the studies of Li et al., (2008), during the whole rice growth periods, soil pH increased from the transplanting stage to the heading stage. However, it decreased again at the ripening stage. In the present study, the increase in soil pH from June (transplanting stage) to September (heading stage) was similar to the observation of Li et al. (2008).

In the case of Kaipad rice fields, the range of water electrical conductivity is between 2500-10000 $\mu\text{S}/\text{cm}$, and it is higher than in Conventional rice fields. Umali (1993) has observed that E_c as low as 3500 $\mu\text{S}/\text{cm}$ results in about 10% yield loss, and at E_c 7200 $\mu\text{S}/\text{cm}$, 50% yield loss is recorded. But in the present study, no such yield loss was reported by farmers, possibly indicating that the rice varieties cultivated in Kaipad rice fields may be tolerant to high E_c.

Optimal EC levels in the soil range from 1.10-5.70 dS/m, and average values noted from both categories of rice fields in the present study are lower than this optimal range. According to Abegunrin et al., (2013) soil EC does not directly affect plant growth but utilized as an indirect indicator of nutrients available for plant

uptake and high soil EC serve as an indication of salinity ($EC > 4$ dS/m) problems, which slow down the crop growth. According to Rengasamy (2006) also, soil is considered saline when EC is above 4 dSm⁻¹, even at EC_e as low as 3.5 dSm⁻¹, rice loses about 10% of its yield, and 50% yield loss was recorded for rice at EC_e 7.2 dSm⁻¹ (Umali, 1993). But no such soil salinity problems and reduction in crop growth was reported during the present study, due to EC lower than 4 dS/m, which may indicate the adaptability of the rice varieties.

As per Becker (2016), the average dissolved oxygen content in Kaipad and Conventional rice fields observed in the present study are ideal for better root growth and hence, the health of the plants. The range of dissolved oxygen content recorded by Uddin (1998) in his experiment conducted on rice-fish culture were 3.7 to 6.0 mg/L. Their range of DO is lower than the range of the present study.

Higher COD levels mean a greater amount of oxidizable organic material in the sample, which will reduce dissolved oxygen levels. As per Becker (2016) lower Dissolved Oxygen level will reduce root growth followed by health of the plant and yield loss. But in the present study, no such yield loss was reported by farmers and further studies need to be conducted on the same. The results of Krishnani et al., (2011) showed maximum COD value of 75 mg/L during rice cultivation in shrimp fields, but in present study, the maximum COD value is higher in both categories of rice fields than the above results, but no adverse effect on plant growth is noted indicating that the mode of cultivation and the variety of the rice plants used, do play a role in minimizing the effect of abnormal levels of COD.

Total hardness is usually classified (Environmental Protection Agencies, 2012) as soft (0–60 mg/l), moderately hard (60–120 mg/l), hard (120–180 mg/l) and very hard (> 180 mg/l) (Rawat et al., 2018). The results of the present study reveals that the observation range of water total hardness is high in Kaipad rice fields than that of Conventional rice fields. Water total hardness does not directly impact growth of rice plants, and no impact on plant health and yield loss was reported during the present study.

The ideal amount of nitrate in water is typically low (less than 1 mg/l). Ali (1992) noted 0.23 mg/l water nitrate in rice fields which is lower than the average values noted during the present study. The range reported by Chowdhury et al., (2000)(1.30 to 3.20 mg/l), Ghosh (1992) (0.02 to 2.60 mg/l) and Bhuiyan (1970) (0.06 to 0.1 mg/l) are in the range of the present study. Overuse of chemical fertilizers, or improper disposal of human and animal waste are the reason for increased nitrate level in water. If the water contains too much nitrate, there will come a point where the plant is not able to absorb any water against the concentration gradient and the plant will start to dry up. Even before this point is reached, the plant will grow slower (Hewitson, J ,<https://www.saps.org.uk/>) which will affect plant health and yield. Without nitrates, the chlorophyll in the leaves reduces, and followed by lowered ability for photosynthesis and crop growth, which reduces farmer's crop yield. No such impact on rice plants has been reported during the present study.

The recorded average soil Nitrogen from both categories of rice fields is higher than the adequate amount (40 mg/Kg). The present study recorded higher average and range of soil nitrogen from Kaipad rice fields than in Conventional one. As per, Santhi et al., (2016), soil nitrogen is higher in Kaipad rice fields than in Conventional rice fields. The presence of effluents as part of the cultivation of fish/prawn in Kaipad rice fields may be the reason behind the higher amount of nitrogen in Kaipad soils. According to Zhao et al., (2011), Hayashi et al., (2017) and Drescher et al., (2020), nitrogen has positive effects on root growth, nitrogen accumulation of rice plants, stimulate above ground growth and produces the rich green color which is the characteristic of healthy plants.

Healthy plants often contain 3 to 4 percent nitrogen in their above-ground tissues, and when the N level in leaves drops below 2.75 percent, N deficiency symptoms appear and yield and quality decline. The average and range of leaf Nitrogen noted in the present study is higher in Conventional than Kaipad rice fields. According to Ahmed et al., (2018), the optimum total N concentration in plants is 1.0-5.0 %, which means the concentration of leaf Nitrogen in both

categories of rice fields lies in optimum range. But, according to Munson (1998), the average leaf nitrogen values recorded from Conventional and Kaipad rice fields during the present study lies in deficient range ($<2.50\%$). However, no plant health and yield loss related issues are reported by the farmers due to the deficiency of Nitrogen during the present study, which may be due to the adaptability of rice varieties.

Phosphorus is an essential element with role in seed germination, seedling establishment, root, shoot, flower and seed development, photosynthesis, respiration and nitrogen fixation (Malhotra et al., 2018). Phosphate occurs in very low concentrations in natural waters, and its average values are around 0.01 mg/l in fresh water. Ghosh (1992) reported that the concentration of phosphate ranged from 0.03 to 0.09 mg/l in his experiment on rice fish culture, which lies within the range of phosphate observed during the present study. Results of Krishnani et al., (2011) shows there is no significant difference between the concentrations of water phosphate in two types of fields in Pokkali rice cultivation area. Similar kind of results is reported in the present study, i.e. there is no significant difference in the observations of water phosphate values between Conventional and Kaipad rice fields. No effect of phosphate toxicity was reported by farmers even though the values observed in the present study is higher than ideal values in both categories of rice fields.

According to Ahmed et al., (2018), range of soil Phosphorus in Kaipad rice fields lies in very low to optimum range (3.75 or lower to 15.0), and in the case of Conventional rice fields, it is in very low to very high range (lower than 3.75 to higher than 18.76). Lower availability of phosphorus in soils leads to reduced biomass and grain yield of rice grown in highly weathered soils (Dogbe et al., 2015). Fageria et al., (2011) also mentioned that production of rice is majorly affected by soil phosphorus (P) deficiencies in many areas of the world. According to Rathnayake et al., (2015), also rice production is affected by available soil. Presence of phosphorus is highly variable in nature mainly due to the variability in water availability. But during the present study, no such problems related to lower or

higher amount of soil P are raised from farmer's side, indicating the adaptability of rice varieties cultivated in both categories of rice fields. The farmers should be made aware of the same and it need to be studied whether keeping phosphorous levels within the optimum range in these fields results in increased yield of rice.

Grasses have higher P requirements with critical values ranging from 0.20 to 0.25 percent. The range of leaf Phosphorus is higher in Conventional rice fields than Kaipad rice fields. The average leaf Phosphorus noted from Conventional and Kaipad rice fields in the present study lies in normal or sufficient level (0.20-0.75%) as per Munson (1998). Ahmed et al., (2018) also noted 0.1-0.4 % as the optimum range of leaf total P in plants. The phosphorus deficiency usually happens when it is lower than 0.15 %, and become toxic to plant when it exceeds 1.0 % (Munson, 1998). Although the range of phosphorous in the soil is higher in both types of fields, the range of P stabilizes in the rice plants and is well within the optimum range.

The amount of water potassium is higher in Kaipad rice fields than Conventional rice fields. As per the studies by Dobermann and Fairhurst (2000), Maryam and Amiri, (2014), Zain et al., (2014) and Zaman et al., (2015), water potassium is required for many significant functions. The minimal amount of potassium concentration leads to deficiency and the higher concentration leads to toxicity effects in rice. Under K deficiency, dark-green plants with yellowish-brown leaf margins or dark brown necrotic spots first appear on the tips of older leaves (Armstrong, 2002). As no deficiency symptoms are noted in rice plants in the present study, more detailed studies are needed to determine how the rice varieties in Kaipad fields tolerates the higher water potassium levels without any adverse effects.

100 to 150 mg/Kg of Potassium is the optimum level for light-colored, coarse-textured soils, and dark-colored, heavy textured soils may require potassium levels from 150 to 250 mg/Kg. Higher average and range of soil available K is recorded from Kaipad rice fields than Conventional rice fields. Potassium plays an important role in plant development and the optimum range for soil K in rice is

130-175 mg/Kg, and the values less than 61 mg/Kg, between 61-90 mg/Kg, between 91-130 mg/Kg and more than 175 mg/Kg are under very low, low, medium and above optimum (High) categories (Solanki and Chavda, 2012) which indicates that the average values recorded in the present study are in medium range and ideal for rice growth.

The Potassium requirement of plants varies widely depending on plant species. For grasses, the K requirement is higher with the critical value in leaves ranging from 1.20 to 2.00 percent. As per Munson (1998), average values of leaf K recorded from both rice fields in the present study are in normal or sufficient range (1.0-5.50 %). Ahmed et al., (2018) noted the optimum range of leaf total K is 1.0 % - 2.5 %, and it is also clear that our average values are within the optimum range. Potassium (K) is required in great quantities for rice growth and yield formation (Oosterhuis et al., 2014).

Calcium in the range of 40 - 100 mg/l is considered desirable for irrigation water. During the present study, the average Ca noted from Conventional rice field is lower than the desirable range, while average Ca in Kaipad is in the desirable range. As per McGowan, (2000), the average values of Water Ca in both type of fields are within the soft water category, but moderately hard values (high value 71 mg/l) are also noted in Conventional rice fields, and even hard and very hard Ca values (higher value 198 mg/l) are observed in Kaipad rice fields during few months. These higher values of Ca may impact plant health and thereby yield. But such impacts have not been reported by the farmers in the present study indicating that the rice varieties cultivated in Kaipad rice fields are tolerant to the effect of high concentration of calcium in water.

Soil Calcium average and range is higher in Conventional rice fields than in Kaipad rice fields. As per Ahmed et al., (2018), the optimum range for soil available Ca is 451-600 mg/Kg. So, the average values of available Ca in the present study are lower than the optimum range in both categories of rice fields. But no negative impact of lower amount of soil available Ca is reported during the present study.

According to Schimansky, (1981), higher amount of calcium in plants cause reduction in total yield due to due to antagonism of Ca with NH_4 , K, and Mg, and number of micro-nutrients such as Fe, B, Cu, Mo, Mn, and Zn. Plants growing with adequate Ca in their natural habitats have shoot Ca concentrations between 0.1 and 5 % (Marschner, 1995). The average values noted from both fields are normal (1.0-4.0%) but not toxic (>5.00%) and agrees with the findings of Munson (1998). When Calcium is deficient, new tissue such as root tips, young leaves, and shoot tips often exhibit distorted growth (Buechel, 2020).

The ideal amount of water Magnesium required for plant growth is between 30-50 mg/l. The average values noted from Kaipad rice field is within this range, but average Mg recorded from Conventional rice field is lower than the ideal range. As Conventional rice fields are mostly rainfed ecosystems, deficiency of Mg can occur (IRRI, 2000) while Kaipad rice fields being a unique form of rice cultivation where debris from prawn farming prior to rice cultivation may have played a role in better Mg levels. The average and range of water Magnesium in Kaipad rice fields (31.45 mg/l) are higher than that of Conventional rice fields (12.34 mg/l).

Ahmed et al., (2021) observed that deficiency of Mg in alkaline soils reduces physiological efficiency of rice plants and that fertilization of rice plants with the Mg source (MgSO_4) showed marked difference in growth and yield. According to Biswas et al., (2019), Magnesium (Mg) also plays an important role in maintenance of good quality soil and in sustainable crop production. The average soil Mg recorded from Conventional and Kaipad rice fields lies in the very low concentration level (375 mg/Kg or below) as per Ahmed et al., (2018). But this low concentration of Mg is not causing any notable reduction in plant vigor or yield in the rice fields.

Mg is required for growth and metabolism, and their deficiency can result in reduced spikelet number, reduced grain weight and reduced grain quality (Marschner, 2012). And as per Kaiser, (2016), if Mg is deficient, the shortage of chlorophyll results in poor and stunted plant growth. Christina et al., (2014) also noted that, deficiency of Mg causes chlorosis in the interveinal parts of leaf and induce reduction in photosynthetic pigments in plants leaves. Mg deficiency occurs

in many plants when the leaf level is less than 0.10 to 0.15 percent. The optimum range of leaf Mg during tillering to panicle initiation, flowering and maturation are 0.15-0.30 (%), 0.15-0.30 (%), and 0.20-0.30 (%) respectively (<http://www.ks-minerals-and-agriculture.com>), which indicates that the average amount of leaf Mg in Conventional and Kaipad rice fields are above the optimum range. But, according to Munson (1998) also, the average values of leaf Mg noted from both categories of rice fields are in the normal range (0.25-1.00 %).

Sulfur is an essential element for plant growth that is not normally included in fertilizers. If the concentration is less than about 50 mg/l in irrigation water, supplemental Sulfate may need to be applied for good plant growth (<https://ag.umass.edu/>). The average water Sulfate value noted from Conventional rice fields is lower than 50 mg/l, so Sulfate supplemental may be needed. But the average water Sulfate value in Kaipad is above 50 mg/l which may indicate the better suitability of the Kaipad fields for rice cultivation. The unique form of rotation of prawn-rice cultivation practiced in Kaipad rice fields may be contributing to better nutrient levels.

During the present study, both fields recorded optimum level of soil Sulfur. As per Ahmed et al., (2018), the optimum range of soil Sulfur is between 27.1 to 36.0 mg/Kg, and it is deficient when the values are ≤ 9.0 mg/Kg and become very high when it exceeds 45.0 mg/Kg. According to Tandon and Messick (2007) soil S is important throughout the growth cycle of the crops and plant tissues must contain sufficient concentrations of Sulfur, only then the plants can produce carbohydrates, proteins, oils and vitamins to their full potential. As per Lefroy et al., (1992), Sulfur levels in rice paddy fields vary widely (83–1,176 mg kg⁻¹ soil), the present study also observed variations in the amount of Sulfur in different growth stages of rice. The farmers did not report any observable effect on the plant growth and yield due to the fluctuations in the amount of soil Sulfur observed in the present study.

Sulfur has a significant role in rice growth, and it is involved in chlorophyll production and hence, needed for protein synthesis, plant function and

structure; and it also increases Nitrogen use efficiency and has a positive effect on yield. As per findings of Yoshida and Chaudhry (1979), the Sulfur deficiency leads to stunted growth of the plant. Sulfur tissue concentration in a healthy crop range from 0.1 to 0.5%. The recorded average leaf Sulfur from Conventional and Kaipad rice fields during the present study lies in the normal range (0.25-1.00%) as per Munson (1998) and Ahmed et al., (2018).

Iron plays significant role in the regulation of critical functions in plants, such as mitochondrial respiration, biosynthesis of nucleotides, photosynthesis, nitrogen assimilation, hormonal regulation, and transport of nutrients (Bashir et al., 2010), and Fe toxicity leads to the leaf bronzing and reduced root oxidation power. Singh (2009) noted that available Fe to the plant is extremely variable, from 0.36 to 174 mg/Kg, and depends on the soil, plant, and environmental factors. Ahmed et al., (2018) recorded the optimum range of soil available Iron in rice as 9.12 - 12.10 mg/Kg, and beyond 15.0 mg/Kg means soil contains very huge soil available Fe. During the present study, both categories of rice fields showed very higher values of soil available Fe. Both deficiency and an excess of Fe in the soil inhibit several physiological functions in the rhizosphere (Bashir et al., 2014). In the opinion of Bhindhu et al., (2018), higher iron content in the rhizosphere has antagonistic effect on uptake of essential nutrients leading to reduction of rice yield. But in the present study no such yield reduction was reported, it may be due to cultivation of rice varieties tolerant to higher Fe.

The optimum range of Iron in leaf tissue of most crops is from 20 to 100 mg/Kg. The rice plants in Kaipad carries high average leaf Iron in their leaves, and its range is also higher in Kaipad rice field than in Conventional rice fields. As per Vose (1982), rice plants usually have 60–300 mg/Kg of iron. The average Fe recorded from Conventional rice fields in the present study is normal, but in Kaipad rice fields the iron concentration in the soil as well as in the leaves are in the toxicity range (400-1000 mg/Kg). According to Ahmed et al., (2018), the generalized nutrient concentration of leaf Fe is between 70-150 mg/Kg, which means the average leaf total Fe values recorded from Kaipad and Conventional fields during

the present study are above the normal level. According to Silva et al., (2003) and Hansen et al., (2006), the Iron toxicity is a widespread nutritional disorder of rice resulting in up to 88% production losses. Even though the Fe values recorded in the present study are high, no adverse effect on rice yield has been reported by the farmers, which may due to the adaptability of the rice varieties used.

The optimum range of soil available Mn is 2.25-3.0mg/Kg, and according to Ahamed et al., (2018), the average soil Mn values recorded from Conventional and Kaipad rice fields lies in the medium range (1.51-2.25mg/Kg). Even the average values are in medium range, optimum values are also noted from both categories of rice fields. In the report of Karim and Mohsin, (1964), the combined role of Iron and Manganese in plant nutrition is much more important than their individual roles and several previous studies are there regarding the response to both Fe and Mn in the growth and nutrition of the rice plant (Chiu, 1967; Patel et al., 1977; Alam, 1982). No impact on plant growth and yield loss due to Mn deficiency is reported by farmers during the study.

Timotiwu and Dewi (2014) noted that the application of Mn increased the growth and rice yield, except angle of tillers and the number of empty grains. According to Mousavi et al., (2011) and Agustina (2011), leaf Manganese is an essential micronutrient and its existence could stimulate the growth of plants substantially. Critical concentrations of Mn in leaves ranges from 20 to 100 mg/Kg for most plants. As per Munson (1998), the average concentration of Mn obtained from both categories of rice fields in the present study lies in the optimum level (20-300 mg/Kg). The range 15-25 mg/Kg indicates deficiency and 300-500 mg/Kg indicates toxic levels of Mn in plant tissue (Munson, 1998).

Zinc is an important trace element, essential for the healthy crop growth and metabolism (Alloway, 2008), and its deficiency cause an adverse effect on healthy crop growth and yield may be reduced up to 30 percent. The average soil Zn in Conventional and Kaipad rice fields during the present study lies below the optimum range in both categories of rice fields as per Ahmed et al., (2018). According to Cakmak, (2002), Karak et al., (2006) and Gao et al., (2006), Zinc deficiency is found

to be a major constraint for annual crops as well as in rice in developing as well as in developed countries like India, China, USA and Australia, and continues to be one of the key factors in determining rice production in several parts of those countries (Chaudhary et al., 2007), and it has been reported in lowland rice also (Mandal et al., 2000). The low level of soil Zn does not have any notable effect on rice plant growth in the both types of rice fields.

As per Tisdale et al., (1993) the average leaf Zn from Conventional and Kaipad rice fields in the present study are in the normal range (25 to 150 mg/Kg), and Zn deficiencies are usually associated with concentrations of less than 20 mg/Kg, and toxicities will occur when the Zn leaf concentration exceeds 400 mg/Kg. But, according to Munson (1998), the average Zn value noted from Conventional and Kaipad rice fields are in the normal (20-100 mg/Kg) and deficient categories (10-20 mg/Kg) respectively. Malik et al., (2011) observed that, the length of roots, shoots and spikelets of rice increased with increasing zinc levels and the highest was observed at 200 mg/Kg Zn. No adverse effect on growth of rice plants due to zinc deficiency has been reported from Kaipad rice fields. Whether the rice production in the areas under study can be increased by keeping the Zn values within the optimum range needs to be investigated.

The range of values of soil Copper (0.45-0.60 mg/Kg) reported from both categories of rice fields in the present study are within the optimum range needed for rice growth (Ahmed et al., 2018). According to the findings of DalCorso et al., (2013), Khush and Peng (1966), Dobermann and Fairhurst (2000) and Liew et al., (2012), soil Cu is an essential micronutrient for crops and plays an important role in the crop growth by increasing the tillering and pollen viability of the crop (Das, 2014). But excessive amount of the same in soil shows highly toxic effect in plant (Adrees et al., 2015, Marschner 1995; Kopsell and Kopsell (2007) and other organisms (Elguindi et al., 2011). Although the values of soil copper are high during certain months this does not have an adverse impact on the growth of rice plants in the present study.

Leaf Copper function is related to respiration and photosynthesis (Marschner, 1995) and Yruela et al., (2000). As per Bloodnick (2020), in most tissues the normal range of total Cu is between 3-10 mg/Kg. Although copper deficiencies or toxicities very rarely occur, and it is better to avoid either extreme as both can cause negative effect on crop growth and quality. Rice leaves in both categories of the rice fields have Cu level in normal range in the present study and agree with the findings of Bloodnick (2020) and Ahmed et al., (2018).

The range between boron deficiency and toxicity is extremely narrow (Eaton, 1944). Generally, soils with less than 0.5 mg/Kg are considered deficient, while only a few cases may result in toxicity (Yau et al., 1994). As per Allison et al., (1954), 0.7 mg/Kg is optimal while concentrations higher than 1.5 mg/Kg represent toxicity for sensitive plant species, so the present average values are below the optimum values, but the range is not exceeding toxicity limit. While, according to Ahmed et al., (2018), the optimum range for available B is 0.45-0.60 mg/Kg for clay soils of wetland rice fields, which means average soil B in Kaipad soils exceeds optimum range, and it lies in high range (0.61 to 0.75 mg/Kg); and Conventional field showed lower concentration of soil available B (0.15-0.3 mg/Kg). Boron enhances the stability of rice plants because of its important role for cell wall synthesis as well as for carbohydrate metabolism, and it activates the sucrose production and speeds up the transport from the leaf to grains (<http://www.ks-minerals-and-agriculture.com>). According to Ahamad et al., (2009), the function of boron will improve the spikelet number and fertility that influenced the yield and productivity.

The average value and range of leaf Boron recorded from Kaipad rice fields are higher than that of Conventional rice fields, and lies in optimum Boron content of the leaves for crop (30-100 mg/Kg). As per Lordkaew et al., (2013), relatively higher amount of B is required for reproductive and vegetative growth of rice; and at below 20 mg kg^{-1} concentration, significant reductions in reproductive and vegetative growth occur. But, according to Munson (1998) and Ahmed et al., (2018), the average leaf total Boron recorded from Conventional and Kaipad rice fields is sufficient or normal. During the present study, no reduction in plant growth is

recorded during these growth stages in both types of fields even when leaf B values are below 20 mg/Kg.

The present study provides a data base of the various physico-chemicals parameters recorded from Conventional and Kaipad rice of North Kerala. The studies on this aspect is lacking in Kaipad rice fields and the findings will help farmers in improving the yield by input and reduction of various nutrients which are recorded to be below or above the acceptable limits needed for normal rice growth. As no adverse effect on growth of the rice varieties in Kaipad rice fields due to the deficiency/excess concentration of nutrients are noted, further studies need to be taken up to understand the adaptability of these rice varieties and the mode of cultivations in helping the rice plants to maintain healthy plant growth and yield.

CHAPTER 2

TO STUDY AND COMPARE THE ABUNDANCE AND DIVERSITY OF INSECT PESTS OF SELECTED KAIPAD AND CONVENTIONAL RICE FIELDS

INTRODUCTION

In this chapter we are dealing with the abundance and diversity of insect pests of selected Kaipad and Conventional rice fields of north Kerala.

Biodiversity is the basis for human survival and composition and richness of species assemblages is strongly associated with functioning of ecosystem and its stability (Naeem et al., 1994; Tilman and Downing, 1994; McCann, 2000). However, following the industrial revolution, the rapid increase in human population and economic activities has caused a considerable loss in global biodiversity, resulting in significant disturbance to environment and our living conditions. Rapid urbanization has also become a phenomenon of great concern because of dramatic changes in land use patterns and the global decline of biodiversity (Shochat et al., 2006; Anton et al., 2010). Hence, biodiversity conservation has become one of the most important challenges we face.

Rice cultivation occupies a wide area of land under tropical humid condition and provides a dynamic ecosystem for many species to adopt it as their niches (Edirisinghe and Bambaradeniya, 2006). Rice fields are inhabited by different kinds of invertebrates and vertebrates that occupy soil, water, and vegetation. Terrestrial arthropods include rice insect pests, their natural enemies and non-rice pest insects that visit rice ecosystems for other concerns (Thongphak et al., 2012). Almost 800 insect species are reported from rice agro ecosystems worldwide. Out of which, 100 species attack rice, while rest are considered as friendly insects (Pathak, 1970). Herbivores in the rice field tend to be more dominant than the non- herbivores (Settle et al., 1996). However, herbivorous insects live together with other insects (predators, parasitoids, decomposers and pollinators), which can control the

population of herbivorous insects (Untung, 2006; Foottit and Adler, 2009). Almost 20 insects are considered as rice pests of economic importance that include stem borers, gall midge, defoliators and vectors like leafhoppers and plant hoppers that cause direct damages and transmit various diseases (Pathak and Khan, 1994). Insects damages rice plant by chewing plant tissues, boring into stems or sucking fluid saps from stem and grains and attack all stages of its growth period. The damages caused by insects disturb the physiology of plants and result in lower crop yield (Nasiruddin and Roy, 2012).

The insect pest species belong to the orders Diptera, Lepidoptera, Coleoptera and Hemiptera and Orthoptera. The major pests of rice belong to the families Cecidomyiidae and Ephydriidae in order Diptera; Pyralidae, Nymphalidae, Crambidae, Erebididae, Noctuidae and Hesperidae in Lepidoptera; Chrysomelidae in order Coleoptera; Acrididae in order Orthoptera and families Alydidae, Cicadelidae, Delphacidae in Hemiptera.

The major insect pests of rice are categorized as stem borers, leaf defoliators, leaf hoppers and plant hoppers, grain sap suckers and leaf gall makers. Rice yellow stem borer, *Scirpophaga incertulas* (Walker, 1863) and rice white stem borer, *Scirpophaga innotata* (Walker, 1863) are the major stem borer pest species of rice. Common evening brown, *Melanitis leda* (Linnaeus, 1758), small branded swift, *Pelopidas mathias* (Fabricius, 1798), rice leaf folder, *Marasmia patnalis* (Bradley, 1981), rice hispa, *Dicladyspa armigera* (Olivier, 1808), rice grasshopper, *Hieroglyphus banian* (Fabricius, 1798), rice whorl maggot, *Hydrellia philippina*, *Oxya chinensis* (Thunberg, 1815), rice army worm *Spodoptera mauritia* (Boisduval, 1833) *Spodoptera litura* (Fabricius, 1775), rice caseworm, *Paraponyx stagnalis* (Zeller, 1852) and yellow hairy caterpillar, *Psalis pennatula* (Fabricius, 1793) are the insect pests in leaf defoliators category. Whitebacked plant hopper, *Sogatella frucifera*, brown plant hopper, *Nilaparvata lugens* (Stal, 1854), *Cofana spectra* (Distant, 1908), Zigzag leafhopper, *Recilia dorsalis* (Motchulsky 1859), rice green leafhopper, *Nephotettix nigropictus*, green paddy leaf hopper, *Nephotettix virescens* (Distant, 1908), rice black bug, *Scotinophora coarctata* (Fabricius) and rice thrips,

Stenocheatothrips biformis (Bagnall), are the leaf sap sucking pests of rice. Rice gundhy bug, *Leptocorisa acuta* is the grain sap sucking pest and *Orseolia oryza* is the leaf gall making ones.

The diversity and composition of the arthropod guilds in the rice fields are apparently influenced by some specific characteristics of each area, by phases of the cultivation or by local cultural practices (Wilby et al., 2006; Bambaradeniya and Edirisinghe, 2008). These factors may include agronomic practices such as (1) growth duration of the rice variety, (2) date of planting, (3) soil fertility levels, (4) level of varietal pest resistance or tolerances, (5) rice plant height, (6) canopy density (Fritz et al., 2011).

Species diversity regarding abundance and species richness is a quantitative parameter of community structure (May, 1975 and Magurran, 1988). In modern pest control, an estimation of species diversity and identifying the presence of an insect species in field is essential to decide whether to apply pesticides (van Emden and Williams, 1974). Poolprasert and Jongjitvimol (2014) concluded that, generally, species diversity and complexity of association among species are important to the stability of the ecosystem community, and it is necessary to provide the essential data about species richness and abundance of rice pests and their natural enemies as a partially taxonomic aspect in rice protection.

As the insect pests cause damage to rice and are one of the major reasons of total annual yield loss, it is important to survey those rice insect pests, especially their seasonal abundance and incidence, to evaluate the control measures (Oo et al., (2020).

The present study aims to compare the abundance and diversity of insect pests of rice in Kaipad and nearby Conventional rice fields of North Kerala.

REVIEW OF LITERATURE

India, China, Bangladesh, Thailand, Myanmar, Philippines, Japan, Pakistan, USA, Indonesia, Korea, and Vietnam are the major rice growing countries in the World of which India and China produce 50% of rice in the World (Wasim, 2002).

According to Poolprasert and Jongjitvimol (2014) the rice cultivation has grown up to 158 ha out of which 90% production is being carried out in developing countries.

Rice fields are well managed ecosystems in which a large diversity of floral, faunal, and microbial species provides a wide range of services for human well-being (Millenium Ecosystem Assesment, 2005). Majority of these species do not reduce production; indeed, many are beneficial, such as predators, parasitoids, and soil bacteria. But a few species become pests and they are responsible for crop losses exceeding acceptable thresholds, mostly when they occur in high densities (Norton et al., 2010). The arthropod community is considered as a significant part in rice fields, showing differences in composition, diversity and species richness between communities of different habitats and development stages (You, 1997).

Over 800 species of insects in rice ecosystems were reported worldwide, of which 100 species infest rice, while rest are considered as beneficial ones (Pathak, 1970). According to Dhaliwal and Arora, (1998), a total of 221 species were reported feeding on rice plants from India and more than fifty species were recorded as pests from the rice tracts of Kerala. According to Dhaliwal et al. (2010), the Indian agricultural field has suffered an annual loss of about Rs. 8, 63, 884 million due to insect pests.

Despite many species prevailing in the rice ecosystem, significant damage to the crop is caused only by 5-8 major pests, the intensity of damage inflicted being influenced by the agro-ecological conditions, variety, and stage of the crop. According to Pathak and Khan, (1994), almost 20 insects are considered as rice pests of economic importance that include stem borers, gall midge, defoliators and vectors like leafhoppers and plant hoppers that cause direct damage and transmit various diseases. Sardesai et al. (2001) reported that the stem borer, gall midge, brown plant hopper and leaf hopper were the among significant pests in Southeast Asia and China, while major rice yield losses in South Asia are due to the incidence of gall midge, brown plant hopper and yellow stem borer. According to Oerke (2005), 15% of global rice production is lost to animal pests (Arthropods, nematodes, rodents, birds, slugs and snails).

Ane and Hussain (2016) reported the greatest diversity of rice pests from the order Lepidoptera, Hemiptera, Coleoptera, Diptera, Orthoptera and Thysanoptera from India and China because of their huge land area for rice cultivation, and the Plant hoppers and leafhoppers were found to be widely distributed in paddy fields in the two countries and are responsible for huge economic losses to rice yields.

Ali et al., (2019) observed that rice yield losses has increased due to widespread outbreaks of the *N. lugens*, *C. medinalis* (=M. patnalis), small brown planthopper (*Laodelphax striatellus* Fallen), *D. armigera*, *S. incertulas* and *S. furcifera*, and these insect pests cause loss of hundreds of millions of dollars every year and threaten food security in regions where rice is the staple food.

Several studies have been conducted in Asia by several authors (Matsumura (1996), Kuno and Dyck (1985), Marheni (2004), Dyck and Thomas (1979) and Amogh et al., (2016). Matsumura (1996) reported that plant hoppers are important pests of rice and caused 7- 10% yield loss but in severe infestation the pest destroyed the crop completely causing hopper burns. *N.lugens* is widely distributed in Asia, now being one of the most important insect pest of rice not only in Japan, a temperate country, but also in tropical and sub-tropical countries such as Indonesia, Philippines, and Taiwan (Kuno and Dyck, 1985). Marheni (2004) reported that *N. lugens* was a migratory pest with high virulence, and it is very difficult to control them through one method because their power to multiply is high and their adaptabilities to environmental changes are rapid.

Amogh et al., (2016) also reported that the leaf hoppers and plant hoppers were an important threat to rice in Asian countries and their heavy infestation was not only due to their abundance, but also due to their ability to transmit viral diseases in rice plants. From Tropical Asia, sixty-five species of planthoppers associated with rice agro-ecosystems were reported (Hare, 1994; Dupo and Barrion, 2009). The most notable are the leafhoppers such as *C. spectra*, *Pyrilla perpusilla* (sugarcane leafhopper), *N. lugens*, and *S. furcifera*, *N. nigropictus* and *N.virescens* (Chen and Chiu, 1981). Among rice insect pests, *N.lugens* and *S. frucifera* are the most devastating (Krishnaiah et al., 2008). Bentur et al. (1992, 2003) reported *O.*

oryzae as a major insect pest of rice in several Asian countries and in India. In India, crop losses due to these pests ranged from 10-100% and average annual yield loss due to the pest was estimated at 80 million US\$ (Ramaswamy and Jatileksono, 1996).

Ovawanda et al. (2016) examined the index of insect biodiversity by measuring species richness, species evenness and heterogeneity in organic and non-organic rice farming ecosystem, and high number of species richness was found in the non-organic rice field during April –May, 2015. But high number of species richness was found in the organic rice fields during October-November 2015. The species evenness and heterogeneity in the organic farming were also higher than those in the non-organic rice in both planting season.

Siregar and Matondang (2017) carried out a random sampling of insects using yellow trap, sweeping net, and core sampler in rice-fish farming areas in Purwosari village, Indonesia. They recorded rice pests, *C. medinalis* (= *M. patnalis*), *Melanitis* sp, *Scirpophaga* sp, *N. depunctalis* (= *Paraponyx stagnalis*), *S. coarcatata*, *R. dorsalis*, *Nephotettix* sp, *Nilaparavata* sp and *Sogatella* sp.

Kulagod (2009) recorded that the rice leaf folder has wide distribution in various parts of the world, and it enjoys wide prevalence in almost all rice growing areas. This pest was earlier noted as a minor pest but has now assumed the status of a major one with the appearance of high yielding rice varieties with broad leaves and indiscriminate use of insecticides leading to wiping out of its natural enemies (Chatterjee and Prakasa Rao, 1997; Rao et al., 2010; Behera et al., 2013).

Pasalu et al., (2005) reported that leaf folders were active year-round in tropical rice areas, but in temperate countries they were active only from May to October. They also added that the expanded rice areas with irrigation systems, multiple rice cropping and insecticide induced resurgences were important factors affecting its abundance and indiscriminate applications of Carbofuran and Phorate leading to resurgence of leaf folder populations has further compounded the problem.

Five species of rice stem borers have been identified in South East-Asia namely; *C. polychrysus*, *S. incertulas*, *S. inferens*, *C. suppressalis*, *S. innotata*, and *S. incertulas* was the most destructive insect pest of rice crop (Mahar et al., 1985) and responsible for an annual yield loss of 10-15% with local catastrophic outbreaks causing up to 60% damage (Catling and Islam, 1981 and Daryaei, 2005).

Leafhoppers are abundant and widespread phytophagous insects mainly occupying paddy and other grasses (Krishnankutty and Viraktamath, 2008), and they are abundant in rice-growing areas across the Oriental, Afrotropical and Australian regions (Kamitani et al., 2004). *Cofana* spp. are abundant in West Bengal, Northeast and southern states regions of India (CAB International, 2007).

Singh and Sharma (2014) recorded 19 hemipteran and lepidopteran insect pests from rice fields of Talwandi Sabo, Punjab, causing damage to both kharif and rabi crops. In Karnataka, Parasappa et al. (2017) reported *S. incertulas*, *N. lugens*, *Nephotettix* sp, *L. oratorius*, *C. medinalis* (= *M. patnalis*) and *N. depunctalis* (= *P. stagnalis*) as predominant pests in different rice ecosystem of Cauvery command areas of Karnataka. Whereas, paddy horned caterpillar, Skipper, Stem borer, thrips, green leafhopper, hispa, grasshopper and caseworm were recorded as minor pests. Among the sucking pests the population of green leafhoppers was found throughout the crop growth. Among the defoliators, rice skipper, Paddy horned caterpillar was active at the tillering stage of the crop and declined with the advancement in the crop stage.

Vijaykumar and Patil (2003) conducted a rice pest survey in five rice growing districts in Karnataka to compare the incidence of some major pests in pesticide free and pesticide applied farmer's field and observed that only a few insect pests were attacked on unsprayed rice fields.

Investigation by Dinesh et al. (2018) revealed the presence of insects, *Sympetrum flaveolum*, *S. incertulas*, *N. lugens*, *N. virescens*, *D. armigera*, *C. medinalis* (= *M. patnalis*), *N. depunctalis* (= *P. stagnalis*), *S. mauritia*, *S. litura*, *Atractomorph alata*, *Agriocnemis pygmaea*, *Solenopsis geminate*, *Leptocorisa oratoria* and *Nezara viridula* in the wetlands farm of Tamil Nadu Agricultural

University, Coimbatore during Thaladi season. Higher diversity of insects and birds were noted in inorganic rice fields.

Among the various rice pests, lepidopterans like stem borers and leaf folders assume greater economic importance and cause considerable damage to rice crop (Saini et al., 2017). Among the various insect pests of paddy, *S. incertulas*, *N. lugens*, *S. frugifera*, *N. nigropictus*, *C. medinalis* (*M. patnalis*), *O. oryzae*, *S. mauritia* were reported regularly during entire crop season in Zonal Agricultural Research Station, Chandrapur district of Maharashtra (Sawai and Kothikar, 2019).

Sogatella furcifera is one of the most important sucking pest in many rice growing tracts in India. In 2008, Krishnaiah et al., documented that during 70s and 80s *S. frugifera* used to be confined to North-Western belt of Punjab, Haryana, and Western Uttar Pradesh. Later, the pest spread to almost all areas where rice is grown and started occurring together with Brown Plant Hopper in many deltas of the Southern States.

The rice hispa is regarded as one of the major pests in paddy growing areas of India (Hazarika et al., 2005; Chakraborty and Deb, 2012). They were earlier known to be a sporadic pest of paddy and has presumed the status of major pest in many rice growing regions of the country (Polaszek et al., 2002; Islam et al., 2004; Hazarika et al., 2005; Bhattacharjee and Ray, 2010; Chakraborty and Deb, 2012).

Prakash (2013) recorded the presence of Rice hispa in irrigated as well as lowland rice cultivation in West Bengal, Assam and North-East Indian states. He also added that the white grubs were a problem in specific upland hill rice, whereas in deep water, only the stem borers and in semi-deepwater stem borers, caseworms and hispa were the key pests.

Prasad (2011) recorded that gall midges were destructive to rice in some parts of Kerala, Orissa, Andhra Pradesh, Madhya Pradesh, Jharkhand and Bihar and it also breeds on a number of grasses such as *Paspaladium geminatum*, *Paspalum scrobiculatum*, *Panicum* spp., *Ischaeum ciliare*, *Cynodondactylon* and *Eleusine indica*.

Akhtar et al.,(2012) listed out the grasshopper fauna from rice fields of Uttar Pradesh, India in Rabi and Kharif seasons, and 26 species of grasshoppers identified belonged to 2 families, 8 sub-families and 12 tribes. Majority of diversity was shown by Acrididae i.e.85%, and followed by Pyrgomorphidae (up to 15%) (Ane and Hussain, 2016). They collected all the species of genera *Oxya*, *Hieroglyphus* and *Acrida* from field which were feeding on the rice foliage. Akhtar et al., (2012) informed that grasshoppers may be regarded as serious pests of rice as they can cause severe damages to rice crop at advance stages of growth.

In 2012, Usmani et al., recorded 34 species of grasshoppers belonging to 25 genera, 2 families, 10 subfamilies and 19 tribes, from paddy and pulses crops of Bihar and Jharkhand 26% diversity of grasshoppers shown by subfamily Oedipodinae followed by Acridinae (12%), Oxyinae (11%), Gomphocerinae (9%), Catantopinae (9%), Cyrtacanthacridinae (6%), Pyrgomorphinae (6%), Tropidopolinae (6%), Hemiacridinae (6%) with least diversity (3%) in case of Spathosterninae. Maximum number of grasshopper species (Twenty eight) was recorded from paddy.

Kharbangar et al., (2014) collected five species of thrips from rice crops in Meghalaya which belongs to 2 families; Thripidae and Phlaeothripidae. *S. biformis* was dominant species comprising 68% abundance followed by *Anaphothrips sudanensis* (17%), *Haplothrips ceylonicus* (10%), *Haplothrips tenuipennis* (3%) and *Bolacothrips indicus* (2%).

Yellow stem borer, *S. incertulas* and rice leaf folder, *C. medinalis* (= *M. patnalis*) are the dominant and the most destructive insect-pests occurring throughout the country causing yield loss of about 10-60 per cent (Chatterjee and Mondal, 2014).

More than twenty species of insects were recorded as pests from the rice tracts of Kerala, but significant damage to the crop is caused only by 8-12 major pests and is influenced by the agro-ecological conditions, variety and stage of the crop. Nair (1978) reported, *S. incertulas*, *L. acuta*, *N.lugens*, *O.oryzae*, *C. medinalis* (= *M. patnalis*), *N.depunctalis* (= *P. stagnalis*), and *Baliothrips biformis* as the major

pests in various rice ecosystems of Kerala. Survey of insect pests in Thiruvananthapuram district was conducted by several authors from time to time. Ajayakumar (2000) recorded *C. medinalis* (= *M. patnalis*), *S. incertulas*, *N. lugens*, *L. acuta*, *N. depunctalis* (= *P. stagnalis*). Premila, in 2003 noted *N. lugens* and *S. furcifera* (Horvath) and Smithagopan (2004) reported *C. medinalis* (= *M. patnalis*) and *L. acuta* as severe pests in Thiruvananthapuram district. Nandakumar et al., (2002) carried out the pest survey in the rice fields of Kollam district, and the pests, *L. acuta*, *O. oryzae*, *S. incertulas*, *N. depunctalis* (= *P. stagnalis*) and *L. acuta* dominated. In 1996, Nalinakumari et al., reported *C. medinalis* (= *M. patnalis*), *S. incertulas*, *O. oryzae* and *L. acuta* as important pests from Kuttanad. *S. furcifera* and *N. lugens* were observed to be the important pests in Kuttanad by Ambikadevi, (1998) and Premila (2003) respectively.

Seasonal variation in the incidence of *O. oryzae*, *S. incertulas* and *C. medinalis* (= *M. patnalis*) were reported from Palakkad district (Abraham and Nair, 1975; Nadarajan, 1996). Karthikeyan and Sosamma (2012) reported Rice blue beetle, *Leptispa pygmaea* Baly, a minor pest, which has attained the status of a major pest in several rice growing tracts of Palakkad, Kannur and Kasaragod districts in Kerala, India.

Samui et al., (2002) recorded that under favorable weather conditions kharif rice crop is infested heavily by *C. medinalis* (= *M. patnalis*) year after year. On average 15 to 20% damage was reported due to the *C. medinalis* (= *M. patnalis*) in rice fields of Pattambi (Karthikeyan, 2002). According to Ramasamy and Jatileksono (1996), the damage caused by *C. medinalis* (= *M. patnalis*) ranges between 18.3 and 58.4% depending on crop age at the time of infestation, and the damage was positively related to the percentage of infested leaves (Bautista et al., 1984).

Growth stages of the crop too influence the pest status and intensity of the damage. Some researchers observed that the pest population to be low during early stages of the crop and gradually increased and reached higher level during maximum tillering and flower initiation stages and then showed a declining trend (Nair, 1978;

Nalinakumari et al., 1996; Ajayakumar, 2000; Smithagopan, 2004; Rahman et al., 2004).

The major factors that influence pest attack was extensive cultivation of high yielding varieties, growing of varieties with low resistance to major pests attacks, intensified rice cultivation throughout the year providing constant niches for pest multiplication, imbalanced use of fertilizers, particularly application of high levels of nitrogen, non-judicious use of insecticides resulting in pest resistance to insecticides, and resurgence of pests and out breaks of minor pests(Prakash et al., 2014).

Khan and Alam (2007) reported that diversity indices of insect pests and natural enemies were affected by the combined effect of management practices and growth stages of rice plant. According to Adalla and Alzona (2007), *S. coarctata* was the dominant species found in the paddy area, probably due to the high adaptive capacity and during its 200-day lifespan, *S. coarctata* infested paddy at the various stages of its development, but it was most predominant at the active tillering stage of the paddy plants.

Dale (1994) reported that the Rice caseworm is a sporadic insect pest of rice and is commonly found in lowlands with poorly drained and flooded fields of both wetland and irrigated environments. Their build up was severe in early vegetative stage during floods, and the transplanted young seedlings suffer heavy damage. He also noted that the severe infestations were observed occasionally on dwarf, compact, heavy tillering, and high yielding varieties of rice during the rainy season.

Pasalu et al., (2005) noted that the Asian rice gall midge (*O. oryzae*) was a major insect pest of rice causing significant economic loss to the crop over space and time and is found in irrigated and rain fed wetland environments during the crop tillering stage. It is also common in upland and deep-water rice. Devi and Devi (1997) recorded that the Gall midge causes yield losses of 30-40% in some parts of India and is more severe in late planted conditions. The optimum temperature for their development is 22 to 26⁰ C. For proper egg hatching of gall midge, 90 to 100% humidity is essential (Krishnaiah et al., 2008).

Kakde and Patel (2018) observed that the population and infestation of green leaf hopper and brown plant hopper commenced during heading stage and reached highest in flowering and milk grain stage and their presence was noticed till the maturity of the crop.

Khaire and Dumbre (1984) found that the *N. lugens* adults reached peak numbers in November coinciding with flowering, dough and grain formation stages, while Desai (2008) showed that the severity of the pest was seen at the reproductive stage of the crop.

The rice leaf folder, *C. medinalis* (= *M. patnalis*) was one of the major pests of rice and causes serious economic loss when its severe infestation coincides with susceptible crop growth stages (maximum tillering to booting). They occur in all rice environments and were more in numbers during the rainy seasons and were commonly found in shady areas and areas where rice was heavily fertilized. Massive feeding by *C. medinalis* (= *M. patnalis*) reduces the vigor and photosynthetic ability of rice plant (Farooq et al., 2014). Earlier, Ram (1986) and Kushwaha (1988) reported that leaf folder attack peaked during booting to panicle emergence stage and their infestation at grain filling stage was more injurious (Saikia and Parameswaran, 1999).

Kakde and Patel (2018) observed leaf damage due to leaf folder after stem elongation and booting stage, which reached highest during flowering stage and was recorded till dough grain stage. Yield loss of 18.30 to 58.40 % was estimated due to the infestation of leaf folder which depends upon the stage of the crop at the time of infestation (Ramasamy and Jatileksono, 1996). During a survey, Samui, et al., (2007) noted that the *C. medinalis* (= *M. patnalis*) was found most active in Kharif season and the maximum infestation was observed between the 39th (24-30th September) to 47th (19- 25th November) standard week (std. week) in Kharif season. Egg laying, hatching and rapid multiplication of the pest started at and around 37th standard week under favorable weather conditions.

Heong (1993) informed that a single *C. medinalis* (= *M. patnalis*) larvae can consume approximately 25 cm² of leaf tissue, constituting less than 40 % of a

normal leaf and computer simulations showed that *C. medinalis* (= *M. patnalis*) densities reached 15 per hill before any detectable yield loss results (Fabellar et al., 1994). The normal larval densities are usually well below three per hill (Guo, 1990), mainly because of natural biological control.

S. incertulas is a monophagous insect pest of rice causing infestation during both vegetative and reproductive stage. Prasad et al., (2007) reported that there are five species of stem borers distributed in India and *S. incertulas* was the most widespread, dominant, destructive pest, and causing yield losses to the tune of 27-34 % every year. They attack the rice crop from nursery till maturity and leaving nurseries after transplantation and stubbles after harvest serve as an inoculum source for infestation in the coming season. Datta (2000) reported that the *S. incertulas* damage can lead to about 20 % yield loss in early planted and 80 % in late-planted rice and the recovery or prevention of 5% of the losses to stem borers could feed approximately 140 million people for one year. Prakash et al., (2014) recorded that *S. incertulas* occurred majorly at maximum tillering phase and dominant during flowering stage at Ludhiana (Punjab).

Bisen et al., (2019) recorded *S. incertulas* in the mid to last of September and the number also increases as the crop is moving towards vegetative phase and infestation was highest after 45 days of transplantation at Balaghat district of Madhya Pradesh. But the population of *C. medinalis* (= *M. patnalis*) increases at the time of reproductive phase mid September.

Shweta and Singh (2017) also reported that dead heart caused by *S. incertulas* on different varieties of paddy started from the 2nd week of August and white earhead from 1st week of September. Similar observations were also reported by Mishra et al., (2012) as *S. incertulas* exhibiting their peak activity in the month of September and Varma et al., (2000) reported three peak periods viz., July, August and September during Kharif season.

Tripathy et al., (1999) reported two peaks of yellow stem borer, of which first was during the last week of September and another during second week of November which coincided with the dough stage of rice. Similarly, Sankpal (2011)

observed peak level of *S. incertulas* at vegetative and reproductive stage, while Gole (2012) noted the incidence of *S. incertulas* from early stage to the harvest of the crop.

Kakde and Patel (2018) observed the incidence of yellow stem borer from tillering to reproductive stage and their intensity fluctuated and showed two peak activities during heading and flowering stages. Species belonging to family Crambidae showed high abundance, followed by Pentatomidae, Delphacidae and Coreidae from the active tillering stage until the flowering stage of paddy in Indonesia (Siregar et al., 2017).

Mainali et al., (2014) recorded that the *S. incertulas* was observed during mid to last of September and the number also increases as the crop is moving towards vegetative phase. They also noted that the attack of *S. incertulas* is more after 45 days of transplantation. But the population of leaf folder increases at the time of reproductive phase mid September.

Observation made by Singh and Triveni (2019) on the relative abundance of different species of Stem Borer revealed that *S. incertulas* (Walker) was the major species of Stem Borer infesting all the growth stages of rice crop, while the other species of stem borers viz., *Chilo polychrysus* (Meyrick), *Sesamia inferens* (Walker), *Chilo suppressalis* (Meyrick) and *Scirpophaga innotata* (Walker) were observed in traces at rice tillering stage. According to Murali Basakaran et al., (2017), among the stem borer species, *S. incertulas* dominated (92.3%; 159 female adults) followed by *C. suppressalis* (7.7%; 15 adults) and *S. innotata* (>1%) and *S. incertulas* was noticed during tillering and reproductive stage while *C. suppressalis* and *S. innotata* were noticed during late tillering and reproductive stage.

No studies have been carried out in Kaipad rice fields of Kerala on the rice pests and their parasitoids and their impact on this unique system of rice cultivation of North Kerala. Hence, in the present study we have conducted a detailed observation of rice pests of Kaipad and Conventional type of rice cultivation in North Kerala.

MATERIALS AND METHODS

Area of the study

Areas used for the insect pest survey is given in general introduction

Time of the study

Pilot studies were conducted from April 2014 to April 2015, i.e., a complete fish – rice cultivation season. We collected secondary data regarding Pre – Cultivation, Cultivation and Post cultivation in Kaipad rice fields from different sources like Village office, Krishi Bhavan, Malabar Kaipad farmer's society, scientific experts and Farmers before commencing the field studies.

The insect pest surveys were conducted from June to October for three rice cultivation years (2015, 2016 and 2017). The field visits were conducted during every month of the cropping season (June to October) to the selected Kaipad and Conventional rice fields.

Materials of the study

The materials used for the insect pest survey were Hand lens, Lock covers, Specimen jars, Collection vials, Eppendorf tubes, Scissors, Cotton, Alcohol 70 % and Ethyl acetate.

Methods of the study

Quadrates sampling was done to estimate the insect incidence in Kaipad and Conventional rice fields. In Kaipad fields, the quadrates were laid at four corners of a field containing 10 “Koonas” or “Pottas” during early stages of the rice cultivation. The Potta or Koonas is a semi globe shaped mound of mud prepared by the Kaipad farmers. The soil mounds were with a spacing of 50 cm and prepared by the end of April. Two kinds of mounds are common, hemispherical mound with 30-45 height and 50-65 cm diameter and lengthy stripe with 35 cm width. Those mounds help to leach away the high salinity by the heavy rains during early June. From July to October months, after spreading the seedlings, 25 paddy hills from each corner were selected for sampling. In Conventional rice fields, each quadrates contained 25 paddy hills from each corner in all rice cultivation months. Absolute sampling of the

egg/egg masses, larval stages, pupal stages, and adult of the pest was carried out from these quadrates and recorded.

The growth stage of rice is divided into, June- Early tillering stage, July- Late tillering stage, August- Panicle initiation and flowering stage, September- Flowering and milky stage, and October- Maturation and harvesting stage.

In each field, each paddy hill was observed by naked eye or by using Hand lens depending upon the size of the insect species life stages. Hand lenses was used in the case of tiny eggs/egg mass, early instar larva, pupa for counting the number of the same in each quadrate. Collected insect stages were brought to laboratory in labeled (Name of the Collector, Date of the Collection, Place of Collection, Rice field type) Lock cover or Specimen jar or Collection vial or Eppendorf tubes and were identified with the help of appropriate taxonomic keys or experts. The field documentation of insect pest stages were done using Canon 700D DSLR Camera 15-55mm and 55-250 lenses.

The parasitized insect pest stages like egg/egg mass, larva, pupa along with the plant part were also collected, and brought to the lab in Labeled Lock cover, Collection vial or Eppendorf tubes. The parasitized stages were kept in a beaker covered with cotton cloth or test tube covered with cotton balls until the emergence of parasitoids.

Data analysis

We used generalized linear model to study the effect of rice field type on the pest abundance. We did that for Insect pest guilds (Leaf case maker, Leaf defoliator, Leaf folders, Leaf gall midges, Leaf sap feeders, Grain sap feeders and Stem borers) and individual insect pest species. Rice field type was the independent variable and insect pest abundance of the respective group (Insect pest guild and each insect pest) was the dependent variable. We used Poisson distribution as the error factor, and log as a link function. The significance of the model was checked using one One-Way ANOVA using the R package *car*.

The dominance and diversity indices of insect pest species in Conventional and Kaipad rice fields were calculated using the statistical software PAST 3.22

version (Paleontological Statistics software package for education and data analysis) (Hammer et al., 2001); and the Simpson's Dominance index, Simpson's diversity index and Shannon's diversity index, are checked.

Results

The results of the three years survey show that insect pest species richness was higher in Conventional rice fields (22 species of insect pests) than in Kaipad rice fields (16 species of insect pests) (Tab. 2.1).

Tab. 2.1: The Insect pest species observed in Kaipad and Conventional rice fields

Sl.No	Insect pest species	Occurrence
1	<i>Cofana spectra</i> (Distant, 1908)	Conventional only
2	<i>Dicladispa armigera</i> Olivier, 1808	Both
3	<i>Hieroglyphus banian</i> (Fabricius)	Both
4	<i>Hydrellia philippina</i> Ferino	Both
5	<i>Leptocorisa acuta</i> (Thunberg)	Both
6	<i>Marasmia patnalis</i> (Bradley, 1981)	Both
7	<i>Melanitis leda</i> (Linnaeus, 1758)	Both
8	<i>Nephotettix nigropictus</i> (Stal)	Both
9	<i>Nephotettix virescens</i> (Distant)	Both
10	<i>Nilaparvata lugens</i> (Stal, 1854)	Conventional only
11	<i>Orseolia oryzae</i> Wood-mason, 1889	Both
12	<i>Oxya chinensis</i> (Thunberg, 1815)	Both
13	<i>Paraponyx stagnalis</i> (Zeller, 1852)	Both
14	<i>Pelopidas mathias</i> (Fabricius, 1798)	Both
15	<i>Psalis pennatula</i> (Fabricius, 1793)	Conventional only
16	<i>Recilia dorsalis</i> Motschulsky, 1859	Conventional only
17	<i>Scirpophaga incertulas</i> (Walker, 1863)	Both
18	<i>Scirpophaga innotata</i> (Walker,1863)	Both
19	<i>Scotinophara coarctata</i> (Fabricius)	Both
20	<i>Sogatella frucifera</i> Horvath, 1899	Conventional only
21	<i>Spodoptera mauritia</i> Boisduval	Both
22	<i>Stenchaetothrips biformis</i> (Bagnall)	Conventional only

PLATE XIV



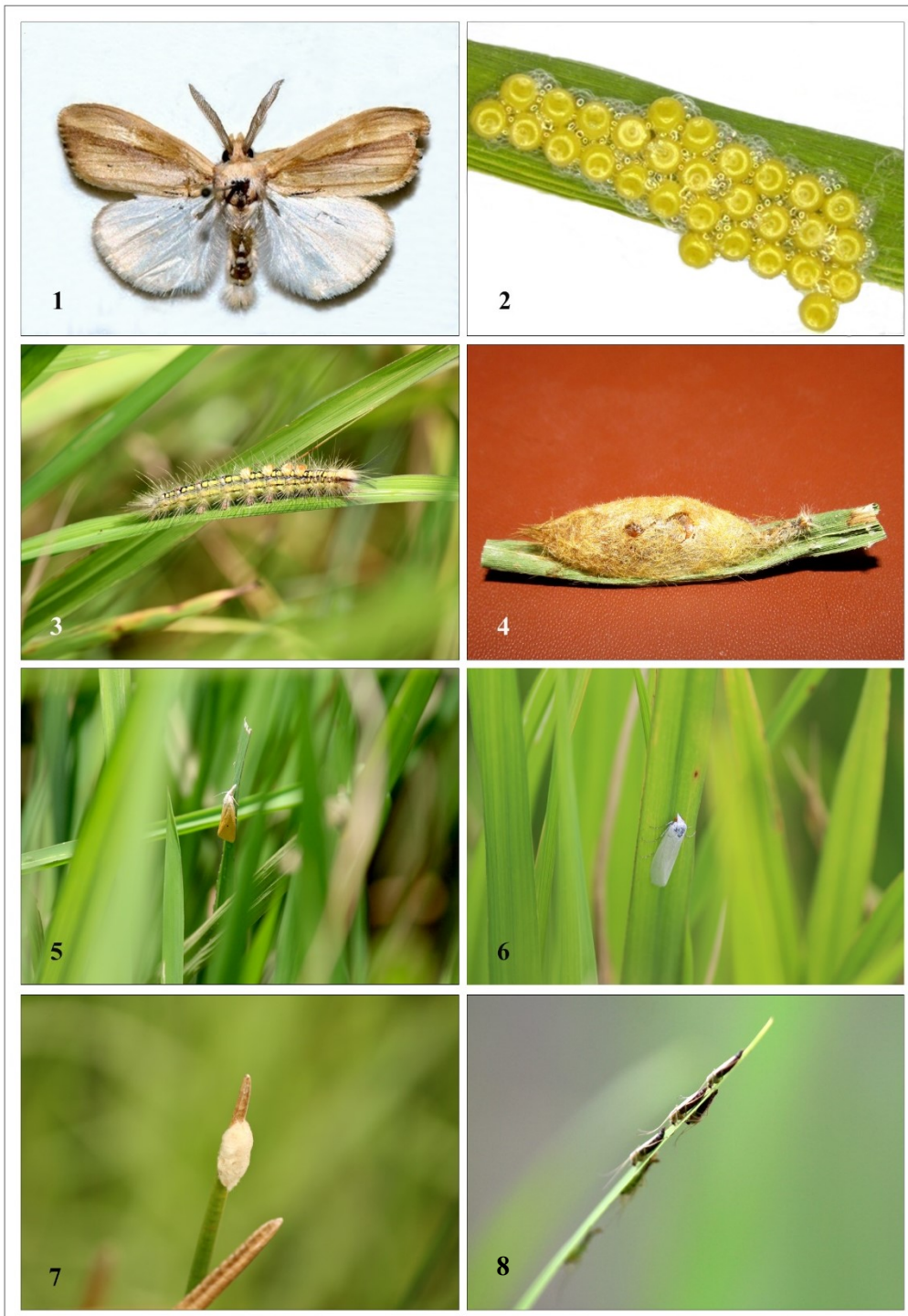
1. *Cofana spectra* (Distant) adult; 2. *Dycladispa armigera* Olivier adult; 3. *Hieroglyphus banian* (Fabricius) adult; 4. *Hieroglyphus banian* (Fabricius) nymph; 5. *Leptocorisa acuta* (Thunberg) adult; 6. *Marasmia patnalis* Bradley adult; 7. *Marasmia patnalis* Bradley larva; 8. *Melanitis leda* (Linnaeus) adult

PLATE XV



1. *Melanitis leda* (Linnaeus) larva; 2. *Melanitis leda* (Linnaeus) pupa; 3. *Nephrotettix nigropictus* (Stal) adult; 4. *Oxya chinensis* (Thunberg) adult; 5. *Paraponyx stagnalis* (Zeller) adult; 6. *Pelopidas mathias* (Fabricius) adult; 7. *Pelopidas mathias* (Fabricius) larva; 8. *Pelopidas mathias* (Fabricius) pupa.

PLATE XVI



1. *Psalis pennatula* (Fabricius) adult; 2. *Psalis pennatula* (Fabricius) eggs; 3. *Psalis pennatula* (Fabricius) larva; 4. *Psalis pennatula* (Fabricius) pupa; 5. *Scirpophaga incertulas* (Walker) adult; 6. *Scirpophaga innotata* (Walker) adult; 7. *Scirpophaga innotata* (Walker) eggmass; 8. *Orseolia oryzae* Wood-Mason

Abundance of Insect pest stages in Conventional and Kaipad rice cultivation

The three-year study revealed that in Conventional rice fields, adults of insect pests were the most abundant followed by larva, pupa, egg (Fig.2.1), and in the case of Kaipad rice fields also, adults were the most dominant insect pest stage, followed by egg, larval, and pupal stages (Fig.2.2).

Fig. 2.1: Abundance of different pest stages in Conventional Rice Fields.

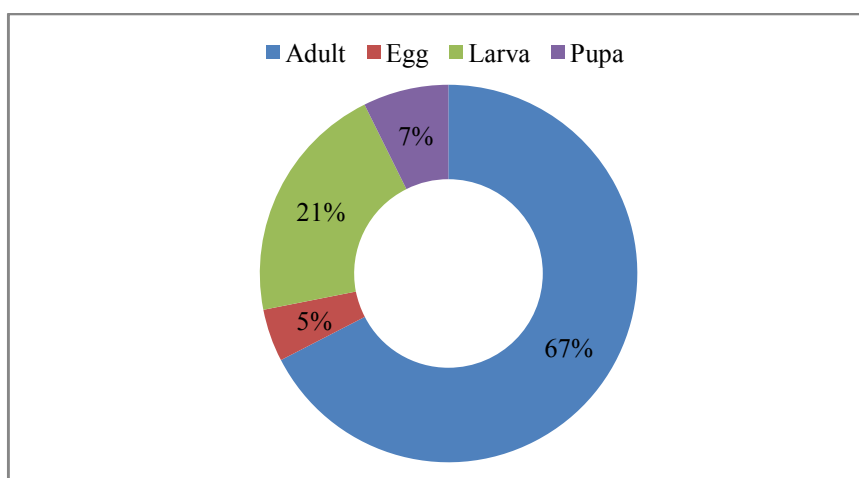
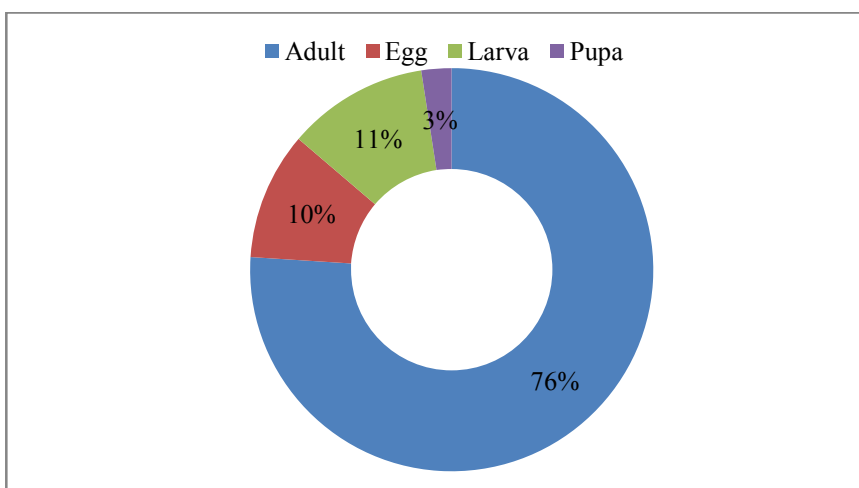


Fig. 2.2: Abundance of different pest stages in Kaipad rice fields.



Abundance of Insect pest stages in Conventional and Kaipad rice fields in different months.

In Conventional rice fields, adults of insect pests were more dominant in all months followed by larva, pupa, and egg (Fig.2.3-2.7).

Fig. 2.3: Abundance of pest stages in Conventional rice fields during June.

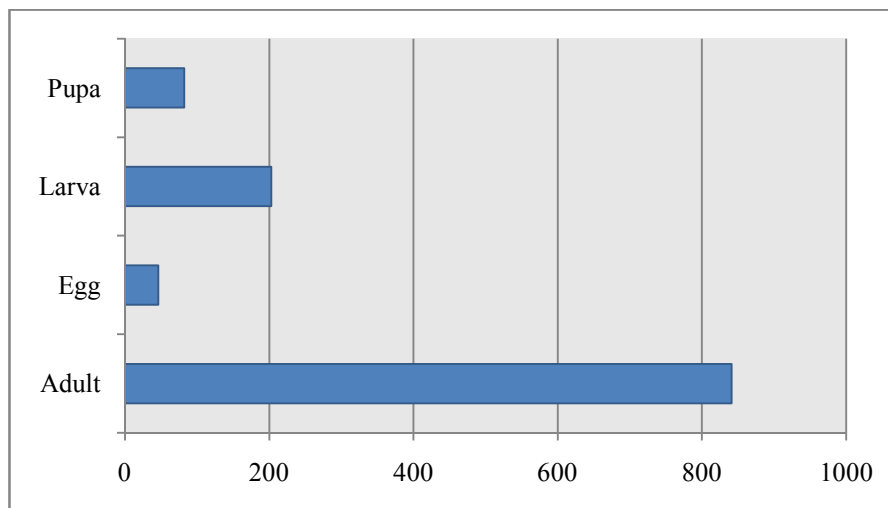


Fig. 2.4: Abundance of pest stages in Conventional rice fields during July.

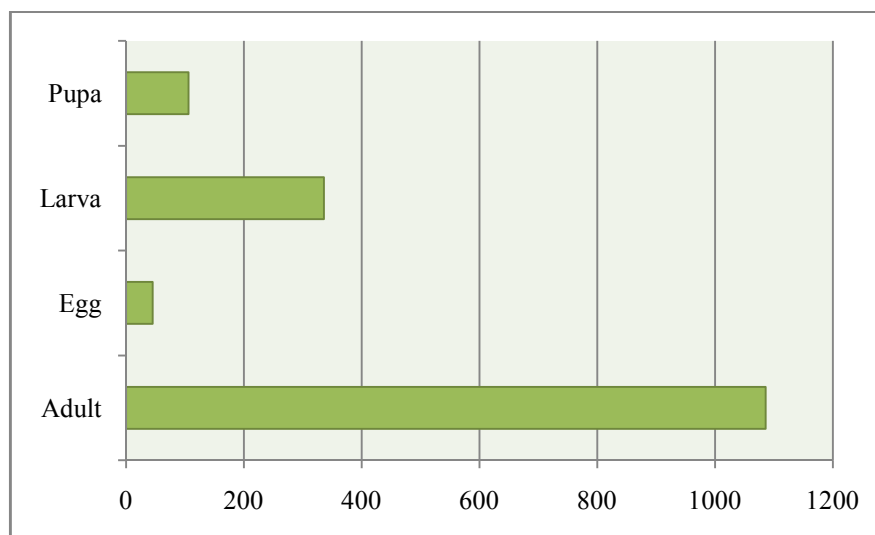


Fig. 2.5: Abundance of pest stages in Conventional rice fields during August.

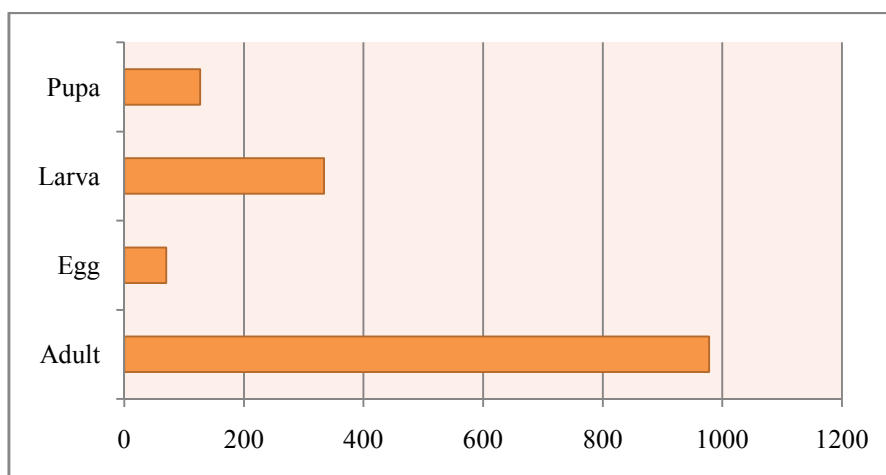


Fig. 2.6: Abundance of pest stages in Conventional rice fields during September.

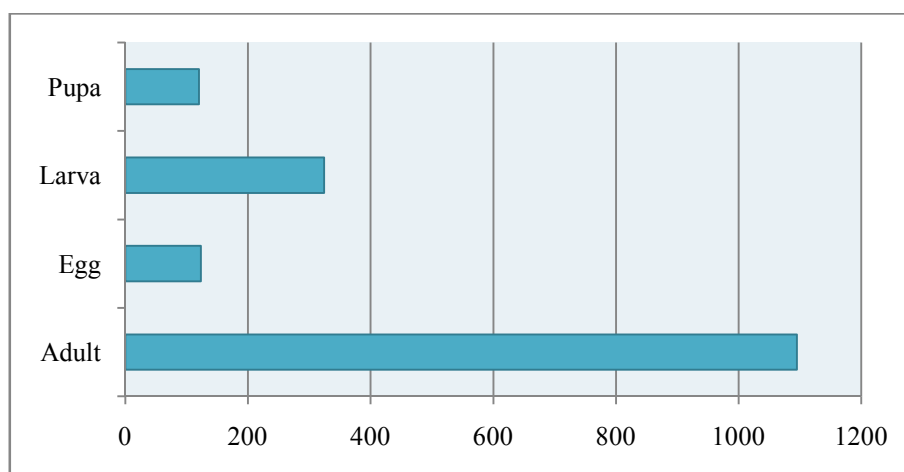
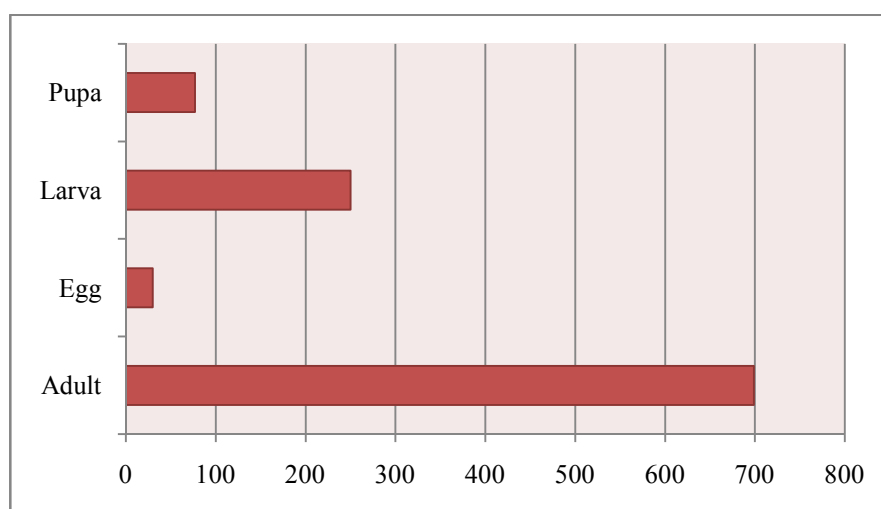
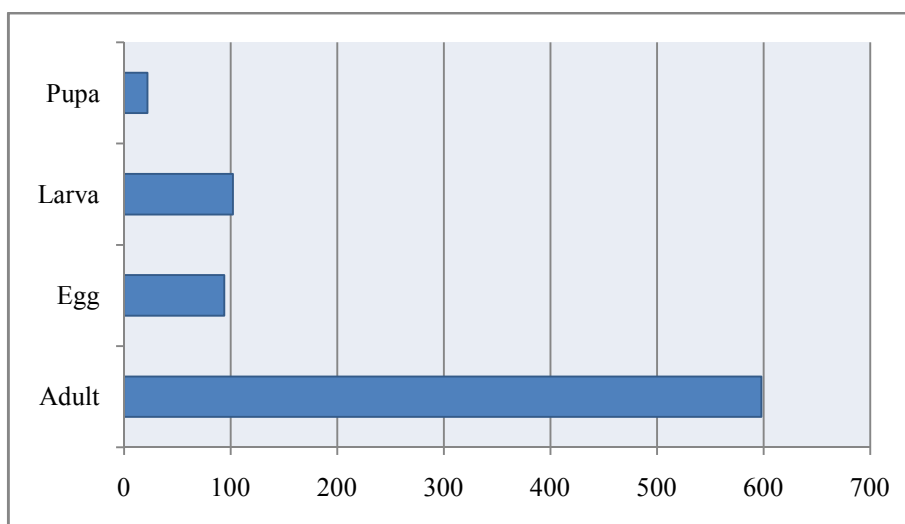


Fig. 2.7: Abundance of pest stages in Conventional rice fields during October.



In Kaipad rice fields, adults of all pest stages dominated the cropping season, while abundance of other pest stages varied across the season (Fig.2.8).

Fig. 2.8: Abundance of pest stages in Kaipad rice fields during June.



During July and August, the adult stage of the pest dominated followed by larval, egg, and pupal stage (Fig.2.9 and 2.10).

Fig. 2.9: Abundance of pest stages in Kaipad rice fields during July.

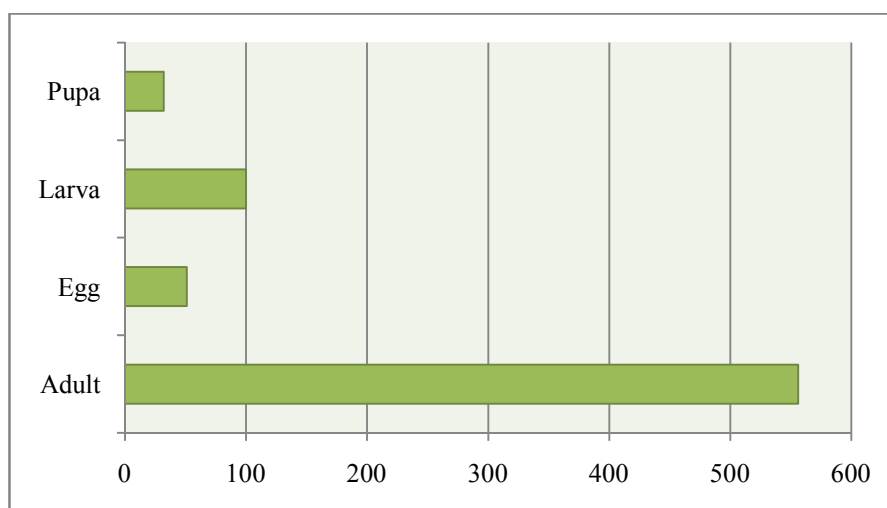
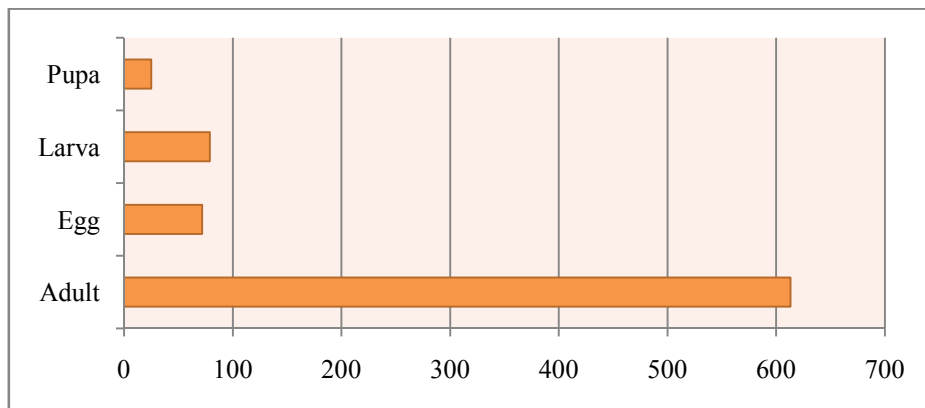


Fig. 2.10: Abundance of pest stages in Kaipad rice fields during August.



A similar trend was recorded in Kaipad rice fields during September and October, with adults dominating followed by eggs, larvae and pupae (Fig.2.11& 2.12).

Fig. 2.11: Abundance of pest stages in Kaipad rice fields during September.

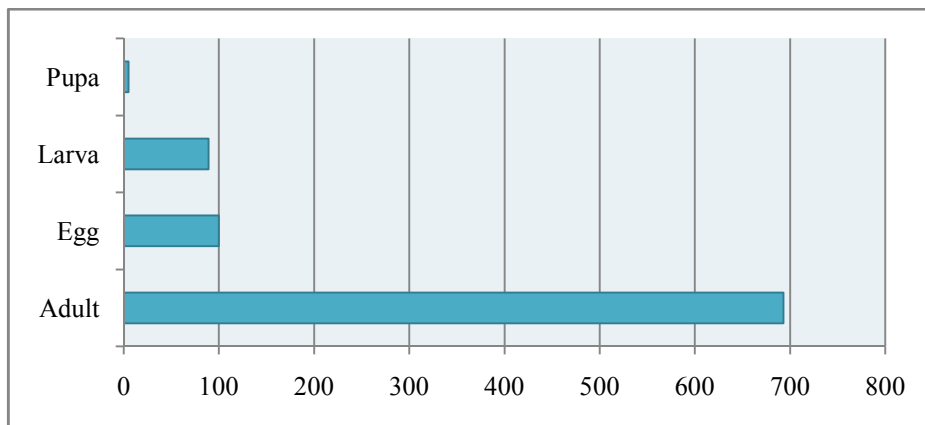
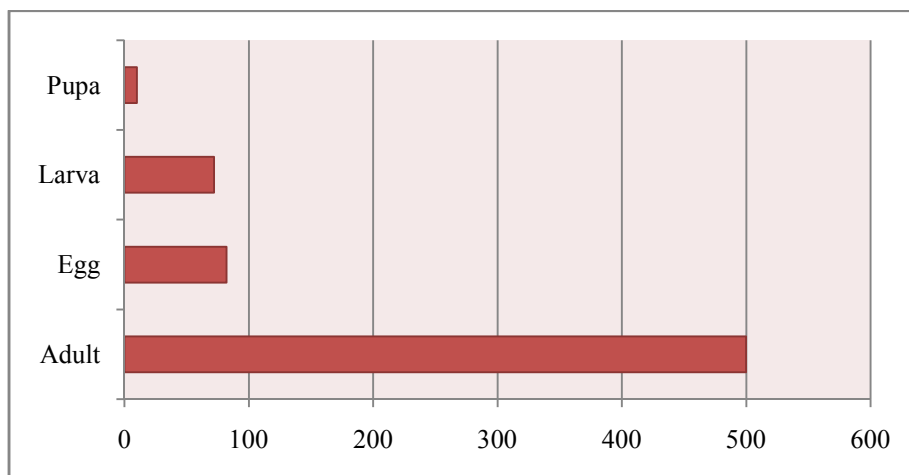


Fig. 2.12: Abundance of pest stages in Kaipad rice fields during October.

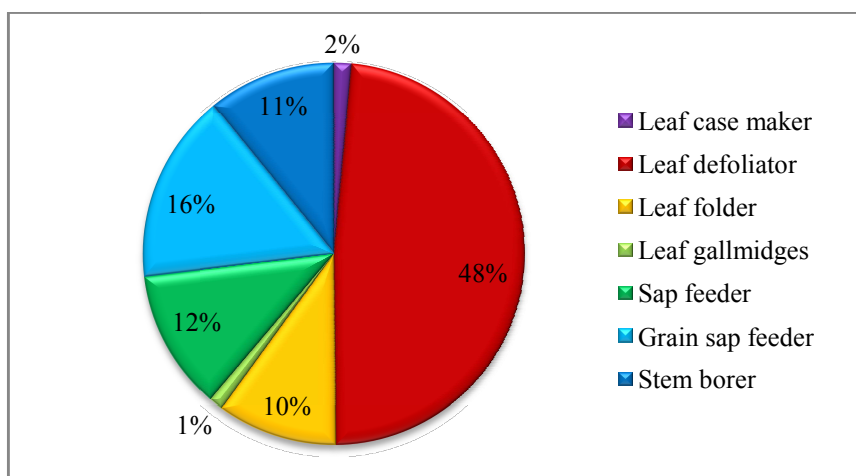


Abundance of different insect pest guilds in Conventional and Kaipad rice fields

In the present study, seven insect pest guilds, namely, leaf case makers (*Parponyxa stagnalis* (Zeller, 1852)), leaf defoliators (*Dicladispa armigera* Olivier, 1808, *Hieroglyphus banian* (Fabricius), *Hydrellia philippina* Ferino, *Melanitis leda* (Linnaeus, 1758), *Oxya chinensis* (Thunberg, 1815), *Pelopidas mathias* (Fabricius, 1798), *Psalis pennatula* (Fabricius, 1793) and *Spodoptera mauritia* (Boisduval)), leaf folders (*Marasmia patnalis* (Bradley, 1981)), leaf gall makers (*Orseolia oryzae* Wood-mason, 1889), sap feeders (*Cofana spectra* (Distant, 1908)), *Nephotettix nigropictus* (Stal), *Nephotettix virescens* (Distant), *Nilaparvata lugens* (Stal, 1854), *Recilia dorsalis* Motschulsky, 1859, *Scotinophara coarctata* (Fabricius), *Sogatella frucifera* Horvath, 1899 and *Stenchaetothrips biformis* (Bagnall)), Grain sap feeders (*Leptocorisa acuta* (Thunberg)) and stem borers (*Scirpophaga incertulas* (Walker, 1863) and *Scirpophaga innotata* (Walker, 1863)) were noted.

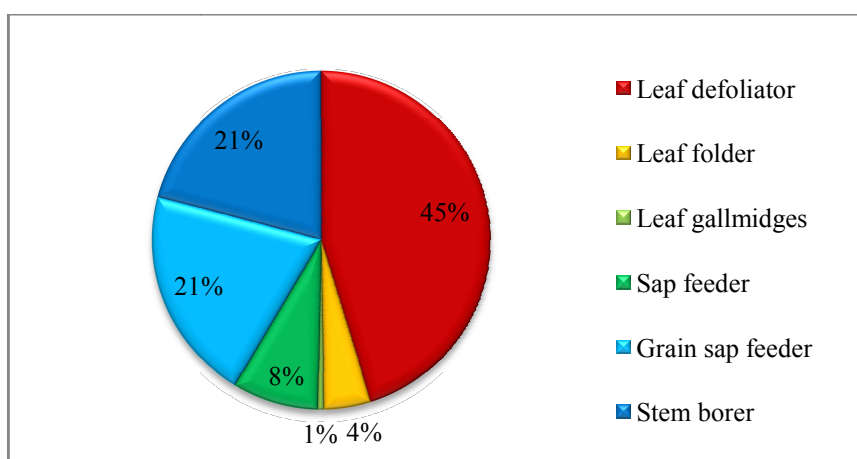
48% of the insect pests collected from Conventional rice fields were leaf defoliators, followed by grain sap feeders (16%), sap feeders (12%), stem borers (11%), leaf folders (10%), leaf case makers (2%) and leaf gall midges (1%)(Fig.2.13).

Fig. 2.13: The abundance of different pest guilds in Conventional rice fields.



The predominant guild in Kaipad rice fields was leaf defoliators (45%), followed by grain sap feeders (21%), stem borers (21%), sap feeders (8%), leaf folders (4%), leaf gall midges (1%) (Fig.2.14).

Fig. 2.14: The abundance of different insect pest guilds in Kaipad rice fields.



Leaf defoliators were the most dominant pest guild in the Conventional rice fields during the study period (Fig. 2.15, 2.16 and 2.17) with leaf case makers and leaf gall midges causing the least damage.

Fig. 2.15: The abundance of different pest guilds in Conventional rice fields during 2015.

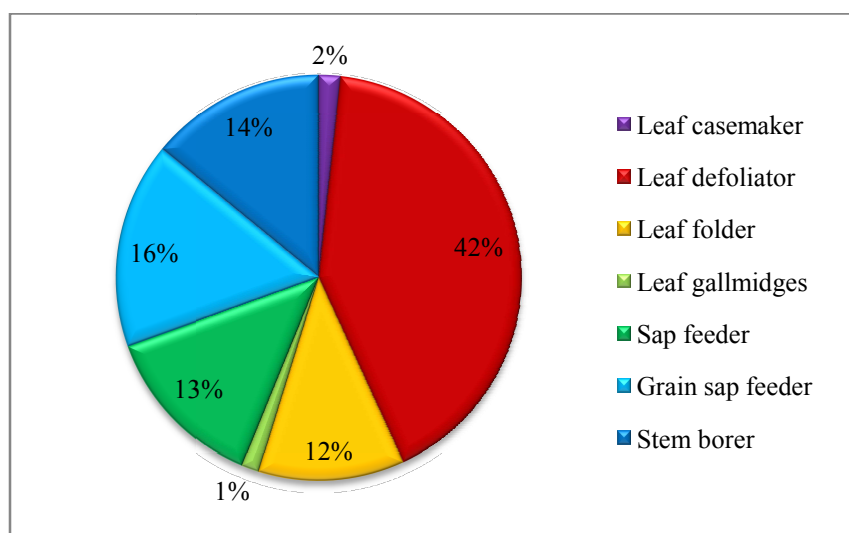


Fig. 2.16: The abundance of different pest guilds in Conventional rice fields during 2016.

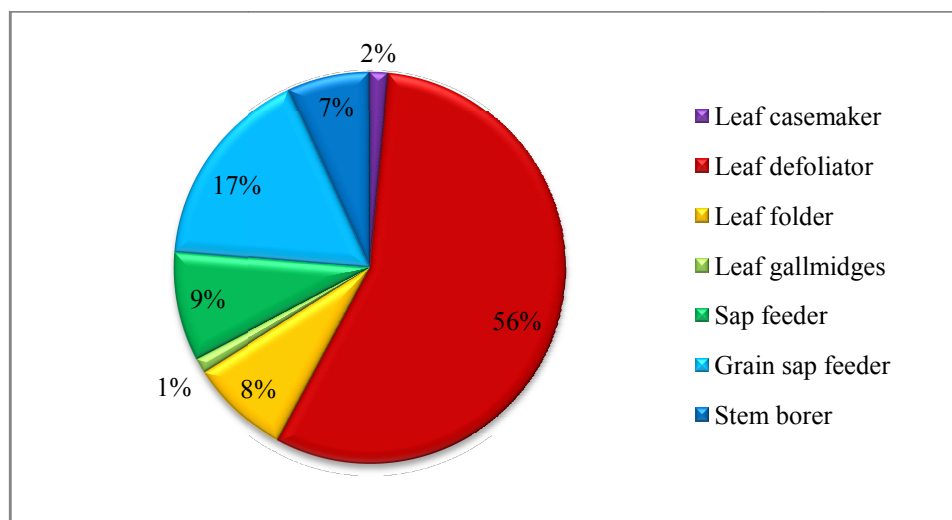
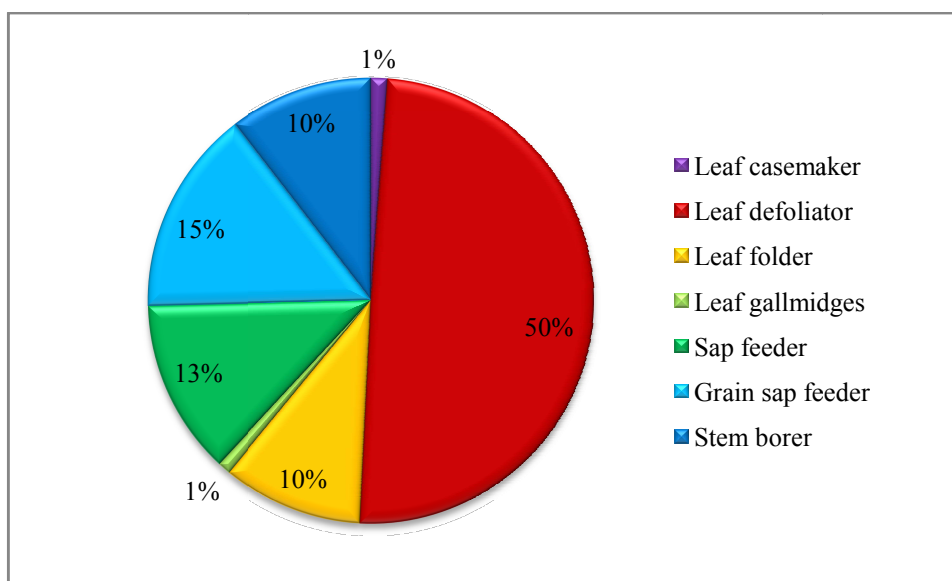


Fig. 2.17: The abundance of different pest guilds in Conventional rice fields during 2017.



In Kaipad rice fields also leaf defoliators were the dominant insect pests during the study period (Fig.2.18, 2.19 and 2.20).

Fig. 2.18: The abundance of different pest guilds in Kaipad rice fields during 2015.

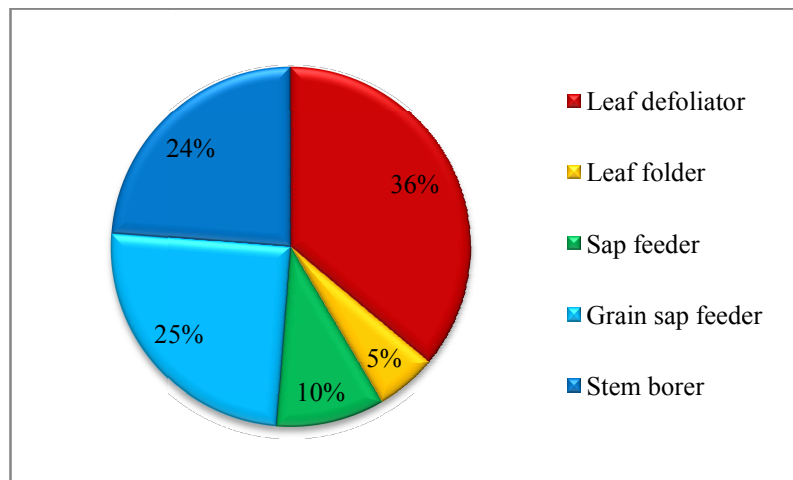


Fig. 2.19: The abundance of different pest guilds in Kaipad rice fields during 2016.

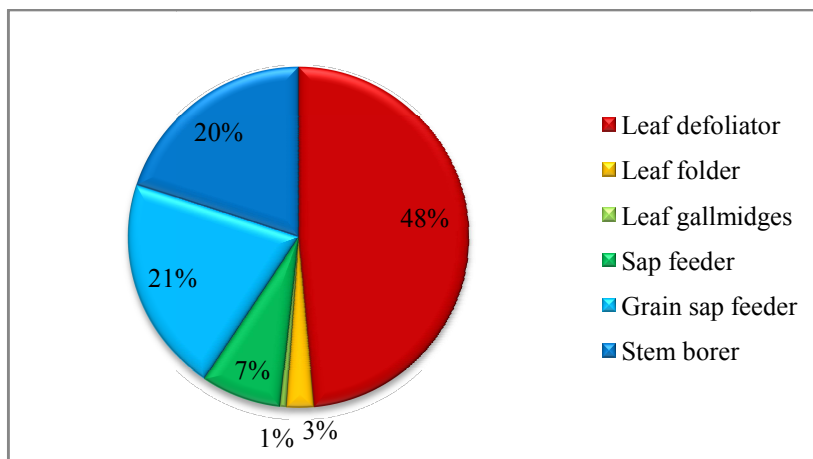
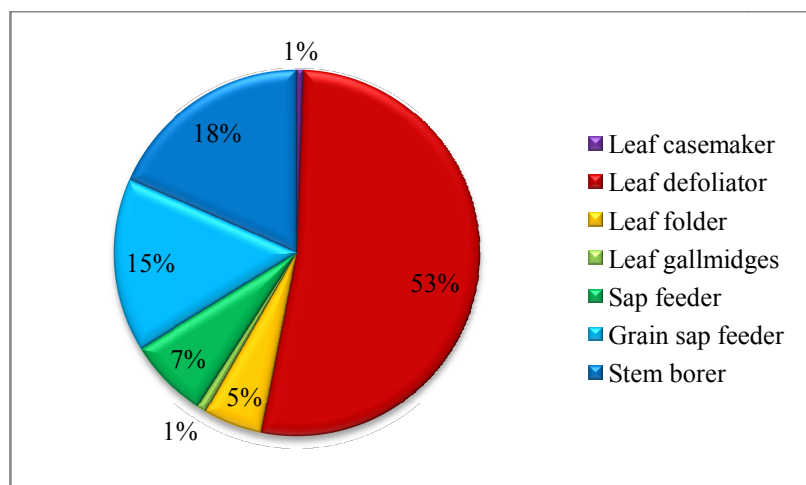


Fig. 2.20: The abundance of different pest guilds in Kaipad rice fields during 2017.



Abundance of different insect pest guilds in Conventional and Kaipad rice fields during different months.

In Conventional rice fields, leaf defoliators were the dominant insect pest guilds during June to October. The percentage composition of the other insect pest guilds during the different months are given in Fig. 2.21, 2.22, 2.23, 2.24 and 2.25.

Fig. 2.21: The abundance of different pest guilds in Conventional rice fields during June.

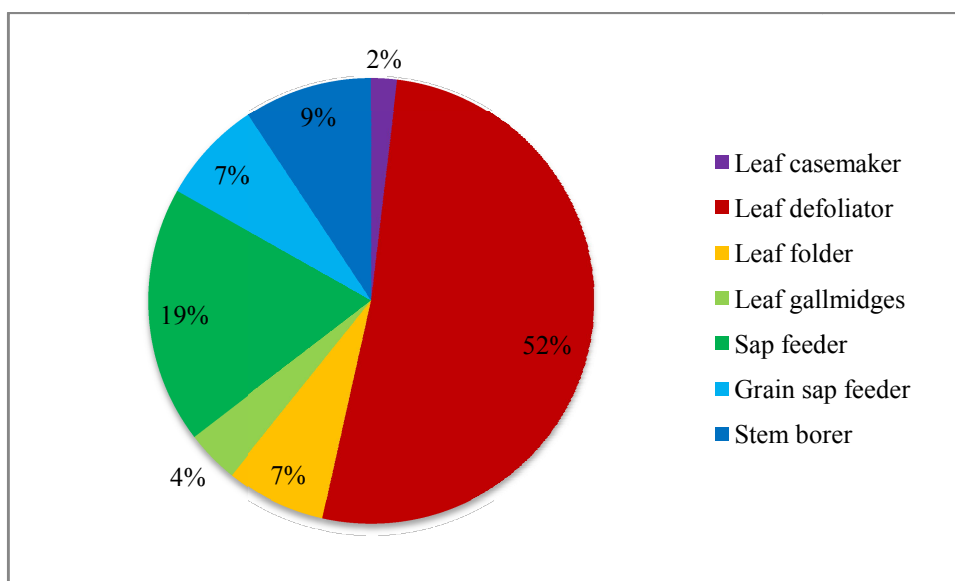


Fig. 2.22: The abundance of different pest guilds in Conventional rice fields during July.

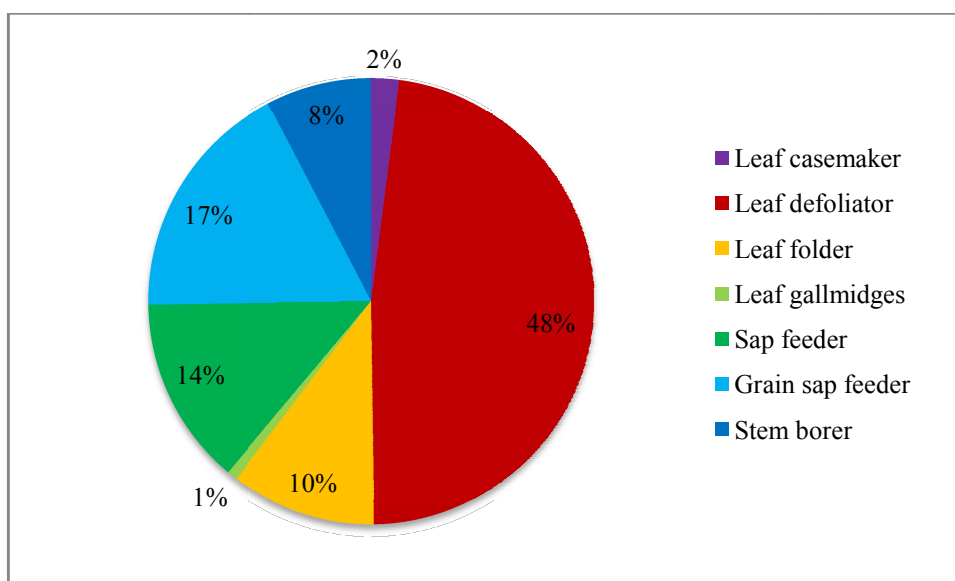


Fig. 2.23: The abundance of different pest guilds in Conventional rice fields during August.

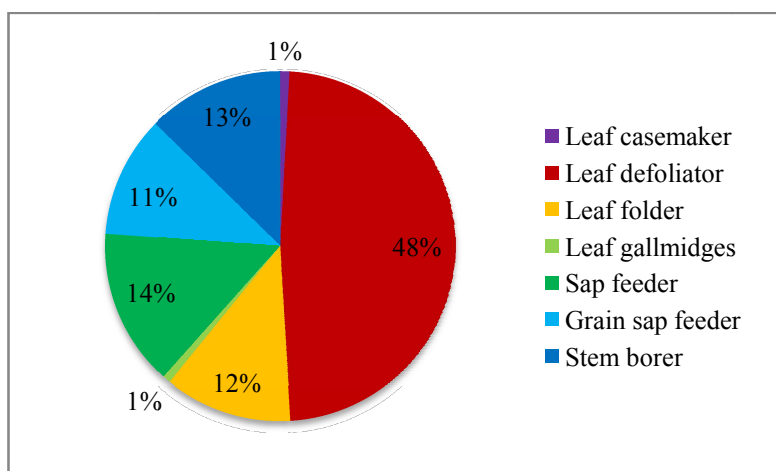


Fig. 2.24: The abundance of different pest guilds in Conventional rice fields during September.

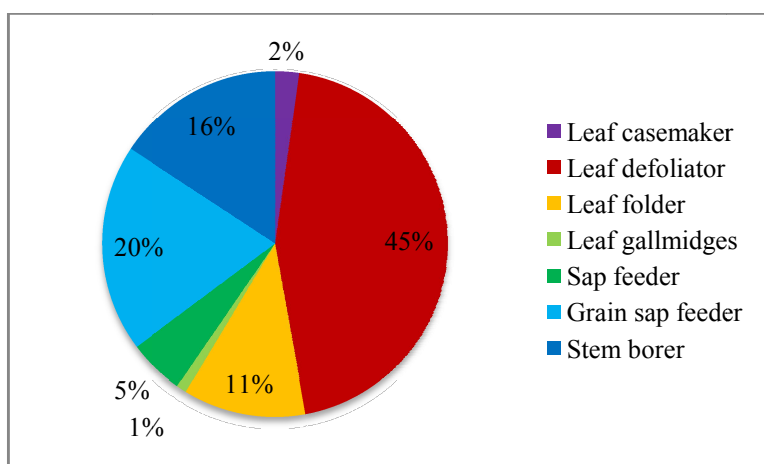
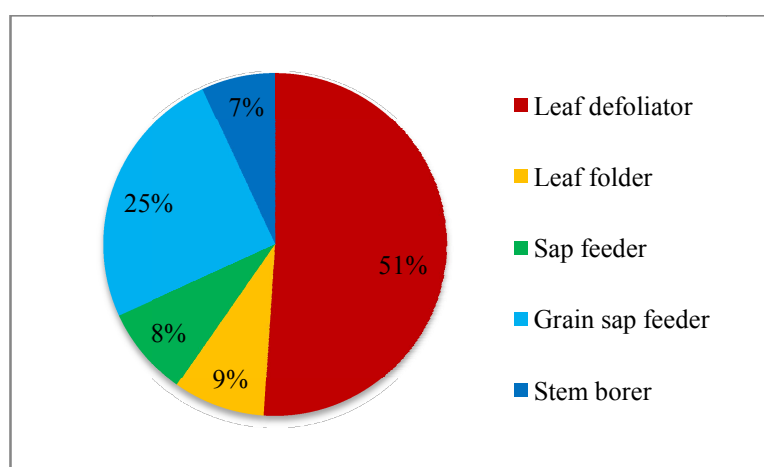


Fig. 2.25: The abundance of different pest guilds in Conventional rice fields during October.



In Kaipad rice fields also, Leaf defoliators were the dominant insect pests during the period June to October (Fig. 2.26, 2.27, 2.28, 2.29 and 2.30).

Fig. 2.26: The abundance of different pest guilds in Kaipad rice fields during June.

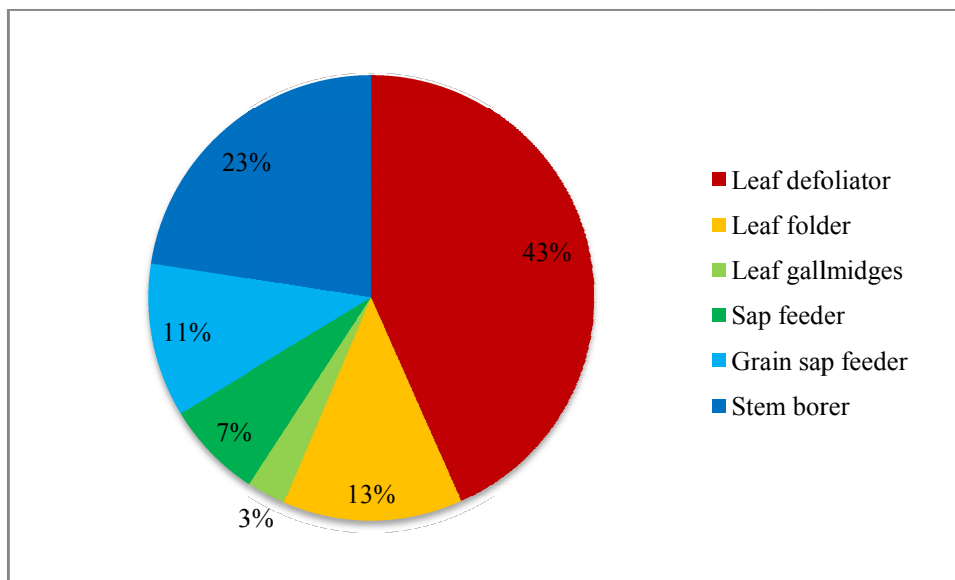


Fig. 2.27: The abundance of different pest guilds in Kaipad rice fields during July.

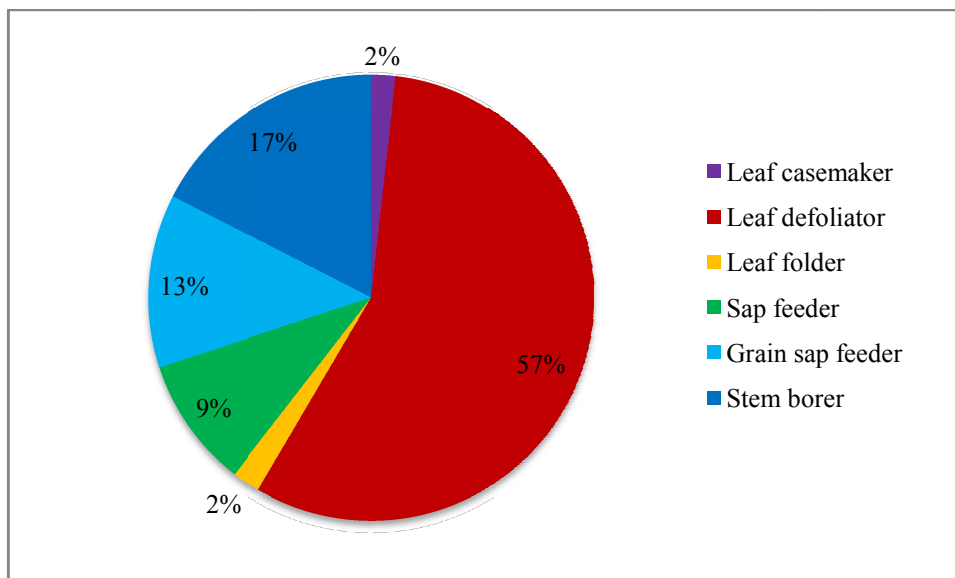


Fig. 2.28: The abundance of different pest guilds in Kaipad rice fields during August.

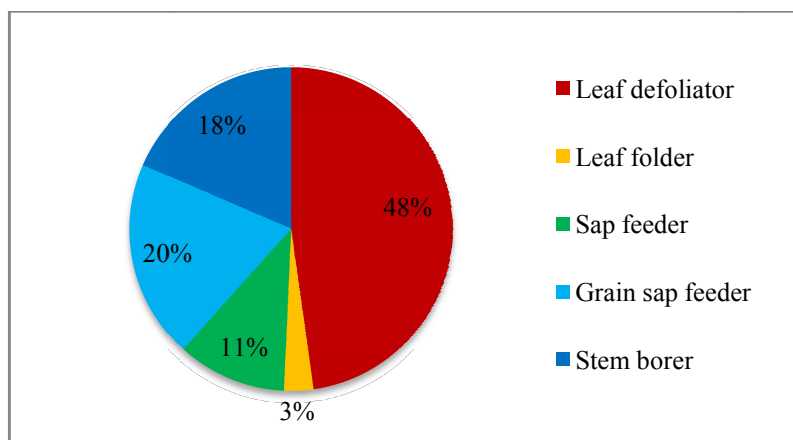


Fig. 2.29: The abundance of different pest guilds in Kaipad rice fields during September.

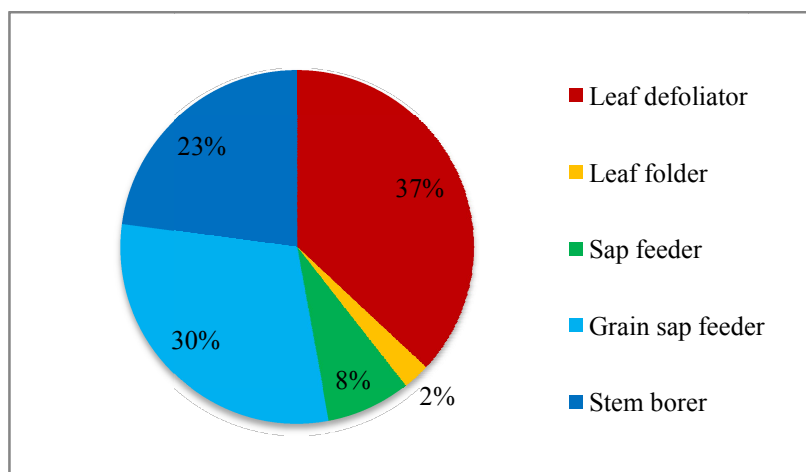
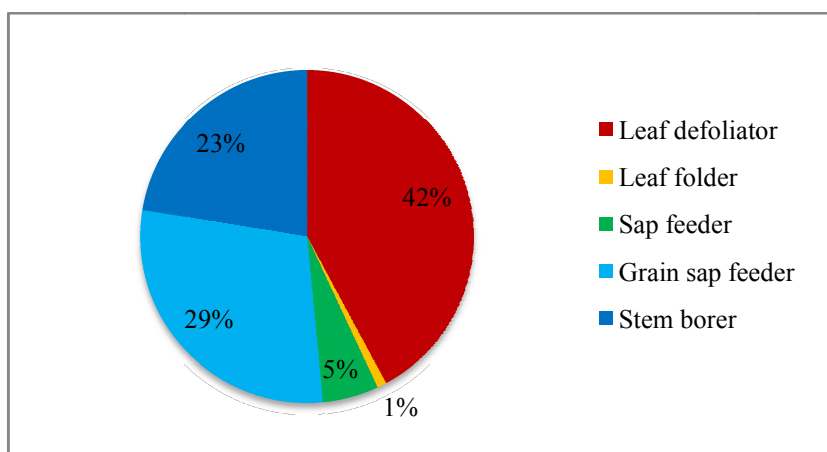


Fig. 2.30: The abundance of different pest guilds in Kaipad rice fields during October.

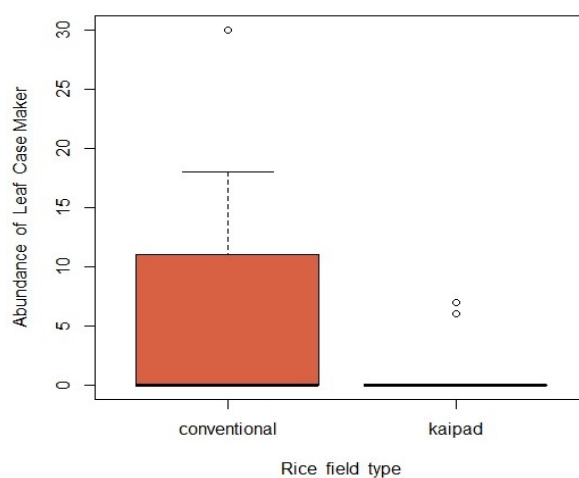


Abundance of rice insect pest guilds in Conventional and Kaipad rice fields.

Leaf case makers

The abundance of leaf case makers was higher in Conventional rice fields than in Kaipad and was significantly different ($p=0.005756$ **) (Fig. 2.31) (Tab. 2.2).

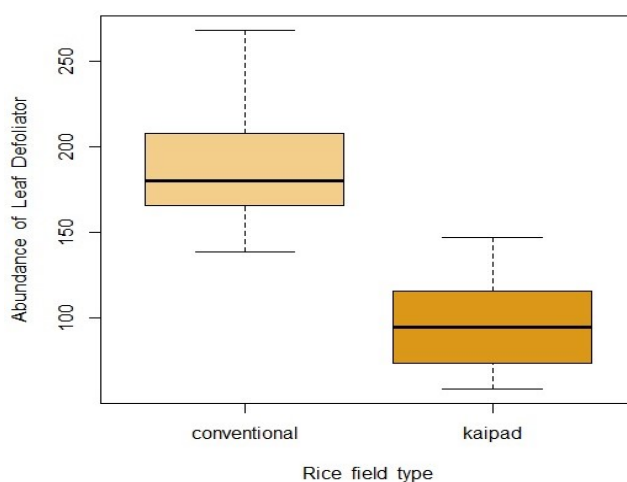
Fig. 2.31: The abundance of rice leaf case makers in Conventional and Kaipad rice fields.



Leaf defoliators

The abundance of the leaf defoliators in Kaipad and Conventional rice fields were significantly different ($p=1.458e-10$ ***) (Tab. 2.2) (Fig.2.32).

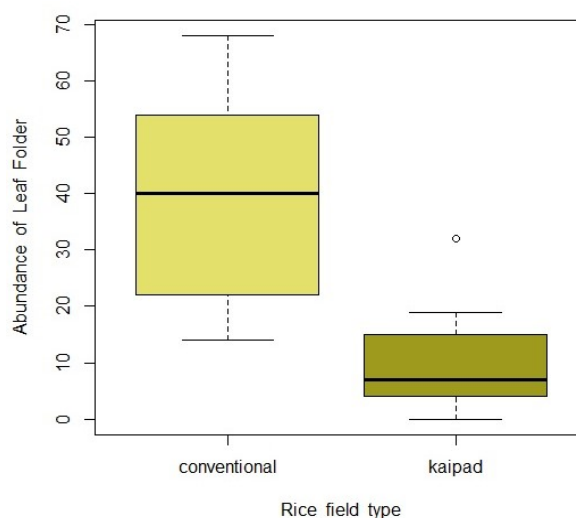
Fig. 2.32: The abundance of rice leaf defoliators in Conventional and Kaipad rice fields.



Leaf folders

The abundance of rice leaf folders was higher in Conventional rice fields when compared to Kaipad and the difference was highly significant ($p=3.32e-08$ ***) (Fig.2.33 & Tab. 2.2).

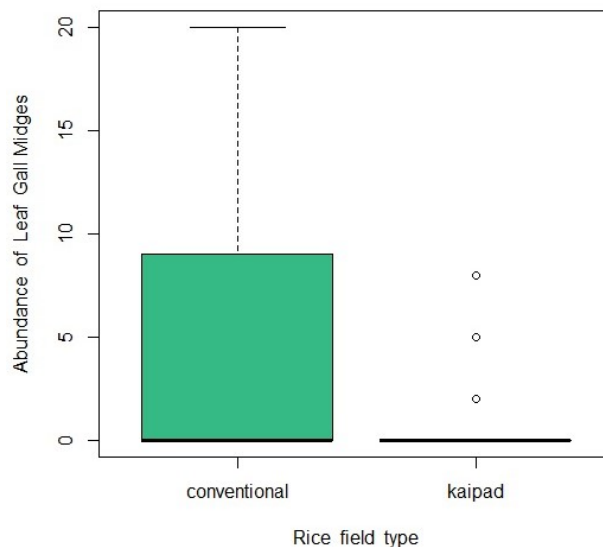
Fig. 2.33: The abundance of leaf folders in Conventional and Kaipad rice fields.



Leaf gall midges

The abundance of leaf gall midges was higher in Conventional rice fields than in Kaipad and was significantly different ($p=0.03474$ *) (Fig.2.34 & Tab. 2.3).

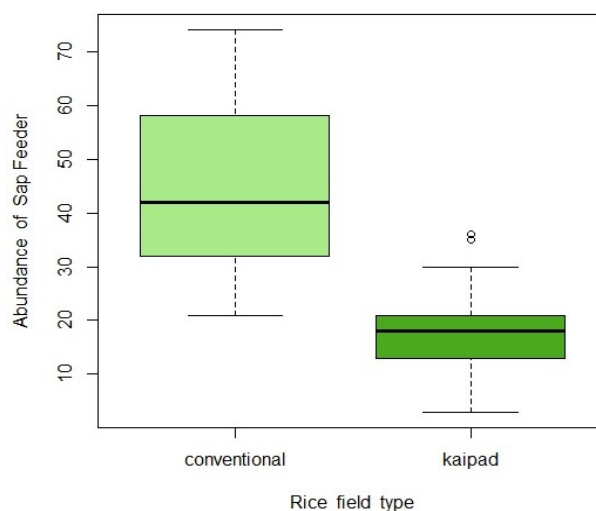
Fig. 2.34: The abundance of leaf gall midges in Conventional and Kaipad rice fields.



Sap feeders

Sap feeders were more abundant in Conventional rice fields than in Kaipad and the difference was significant ($p=2.461e-07$ ***) (Fig.2.35 & Tab. 2.2).

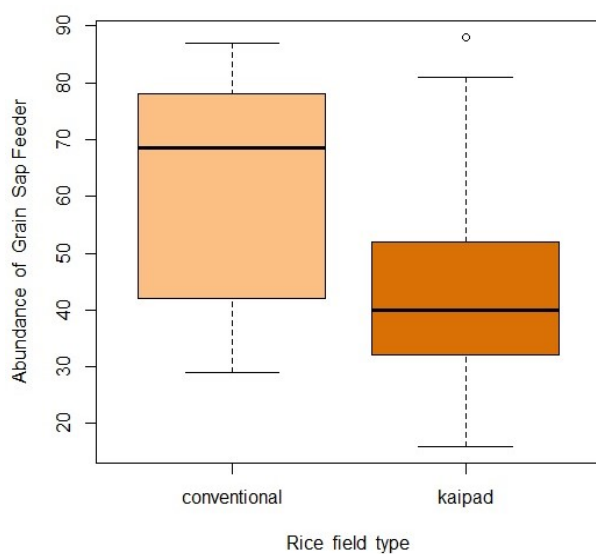
Fig. 2.35: The abundance of Sap feeders in Conventional and Kaipad rice fields.



Grain sap feeders

The abundance of the rice grain sap feeders in Conventional and Kaipad rice fields also showed significant difference ($p=0.01054$ *) (Fig. 2.36 & Tab. 2.2).

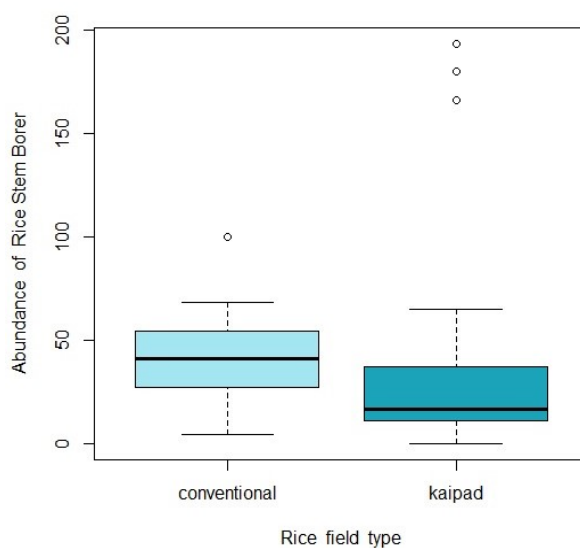
Fig. 2.36: The abundance of Grain sap feeders in Conventional and Kaipad rice fields.



Stem borers

Although the abundance of rice stem borers is slightly higher in Conventional rice fields than in Kaipad rice fields, the difference is not significant ($p=0.8462$) (Fig.2.37 & Tab. 2.2).

Fig. 2.37: The abundance of Rice stem borers in Conventional and Kaipad rice fields.



Tab. 2.2: The ANOVA of insect pest guild abundance between Conventional and Kaipad rice fields

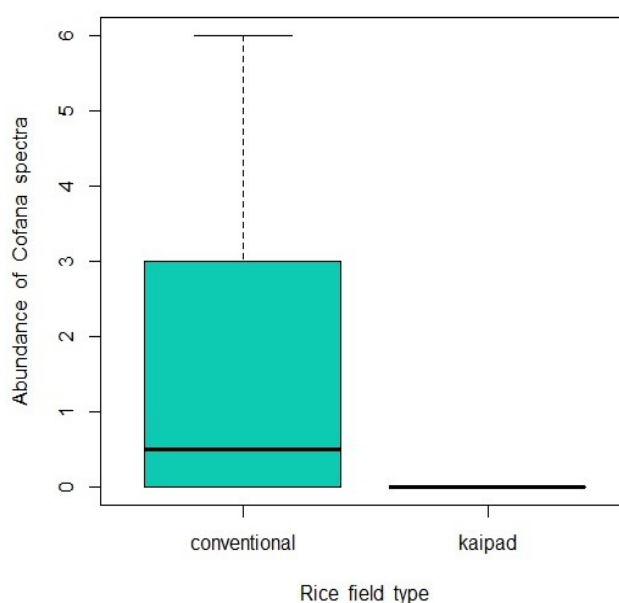
SI. No	Insect Pest Guild	Sum Sq	Df	F value	P value
6	Leaf case maker	80.57	1	8.6869	0.005756 **
7	Leaf defoliator	514.88	1	81.676	1.458e-10 ***
8	Leaf folder	352.34	1	50.437	3.32e-08 ***
9	Leaf gall midges	36.958	1	4.8381	0.03474 *
10	Sap feeder	236.59	1	41.225	2.461e-07 ***
11	Grain Sap feeder	53.583	1	7.3277	0.01054 *
12	Rice Stem Borer	2.0	1	0.0382	0.8462

Abundance of different rice insect pests in Conventional and Kaipad rice fields.

Cofana spectra (Distant, 1908)

The incidence of *Cofana spectra* (Plate XIV.1) is only reported from Conventional rice fields, and the range of their distribution is given in the Fig. 2.38.

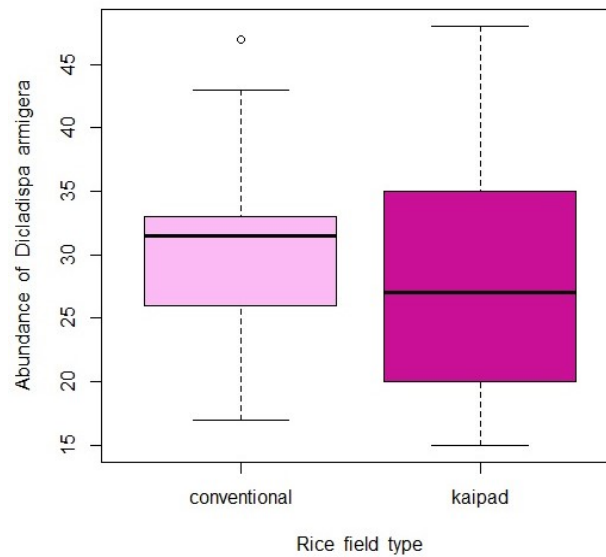
Fig. 2.38: The abundance of *Cofana spectra* in Conventional and Kaipad rice fields.



Dicladispa armigera Olivier, 1808

The abundance of *Dicladispa armigera* (Plate XIV.2) in Kaipad and in Conventional rice fields did not show any significant difference ($p=0.3004$) (Tab. 2.3) (Fig.2.39).

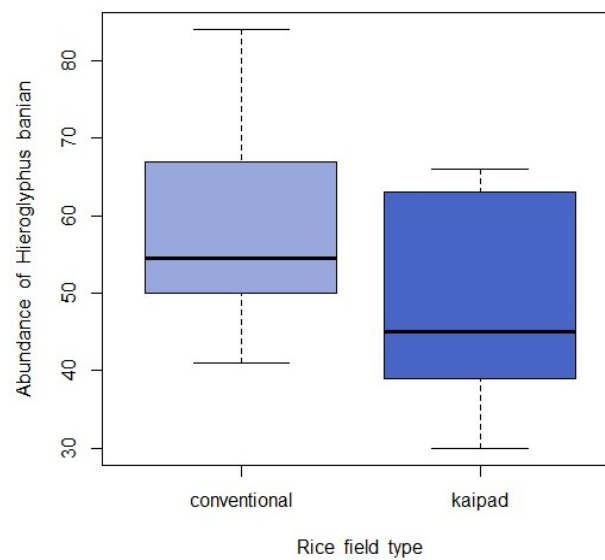
Fig. 2.39: The abundance of *Dicladispa armigera* in Conventional and Kaipad rice fields.



***Hieroglyphus banian* (Fabricius)**

The abundance of the *Hieroglyphus banian* (Plate XIV.3) between Kaipad and Conventional rice fields showed significant difference ($p=0.02479$ *) (Tab. 2.3), with higher abundance in Conventional rice fields (Fig.2.40).

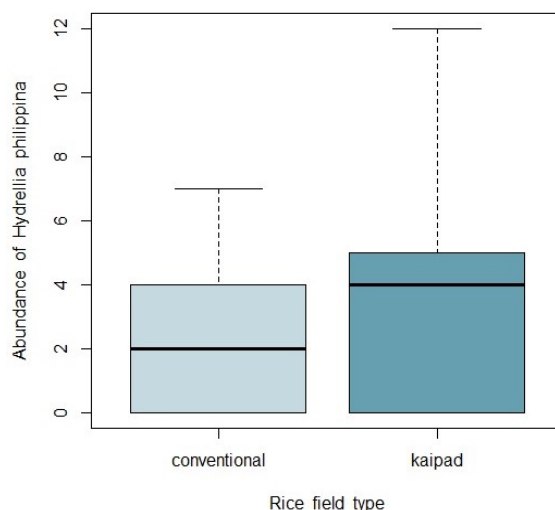
Fig. 2.40: The abundance of *Hieroglyphus banian* in Conventional and Kaipad rice fields.



***Hydrellia philippina* Ferino**

Although the abundance of *H. philippina* was higher in Kaipad rice fields, the difference was not significant ($p=0.1504$) (Tab. 2.3) (Fig.2.41).

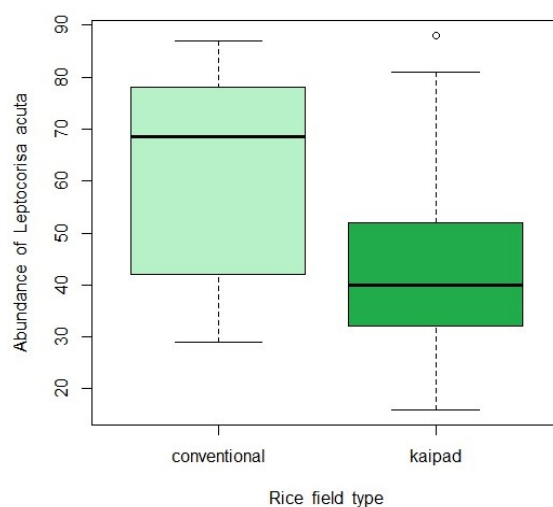
Fig. 2.41: The abundance of *Hydrellia philippina* in Conventional and Kaipad rice fields.



***Leptocoris acuta* (Thunberg)**

The abundance of the *L. acuta* (Plate XIV.5) was higher in Conventional than Kaipad rice fields, and the difference was significant ($p=0.01054$ *) (Tab. 2.3) (Fig.2.42).

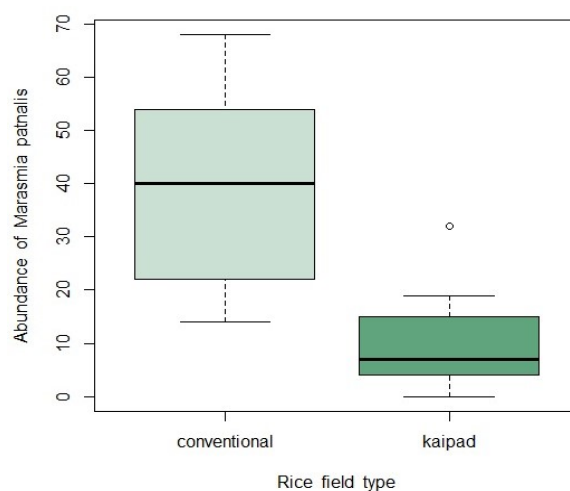
Fig. 2.42: The abundance of *Leptocoris acuta* in Conventional and Kaipad rice fields.



***Marasmia patnalis* (Bradley, 1981)**

The abundance of the *M. patnalis* (Plate XIV.6) in Kaipad and Conventional fields was significantly different ($p=3.32e-08$ ***) (Tab. 2.3) and was higher in Conventional rice fields (Fig. 2.43).

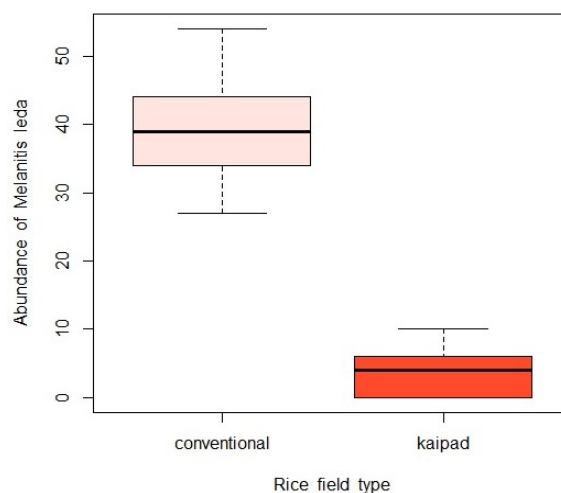
Fig. 2.43: The abundance of *Marasmia patnalis* in Conventional and Kaipad rice fields.



***Melanitis leda* (Linnaeus, 1758)**

Melanitis leda (Plate XIV.8) was highly abundant in Conventional than in Kaipad rice fields and the difference was highly significant ($p=< 2.2e-16$ ***) (Fig.2.44) (Tab. 2.3).

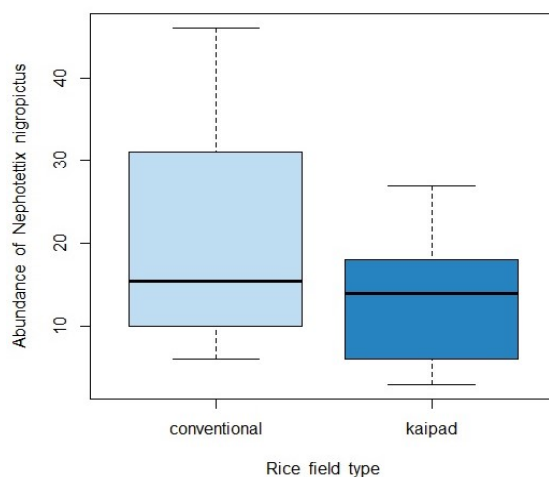
Fig. 2.44: The abundance of *Melanitis leda* in Conventional and Kaipad rice fields.



***Nephotettix nigropictus* (Stal)**

The abundance of the *N. nigropictus* (Plate XV.3) in Kaipad and Conventional rice fields was significantly different ($p=0.04294^*$) (Tab. 2.3) with higher abundance observed in Conventional rice fields (Fig. 2.45).

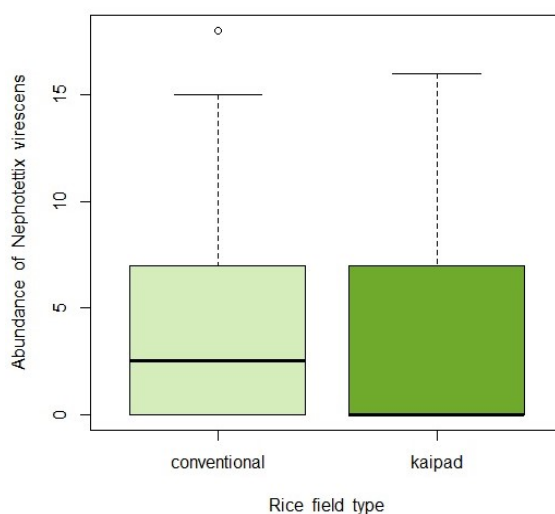
Fig. 2.45: The abundance of *Nephotettix nigropictus* in Conventional and Kaipad rice fields.



***Nephotettix virescens* (Distant)**

There was no significant difference ($p= 0.3286$) in the abundance of *N. virescens* between Conventional and Kaipad rice fields (Fig.2.46) (Tab. 2.3).

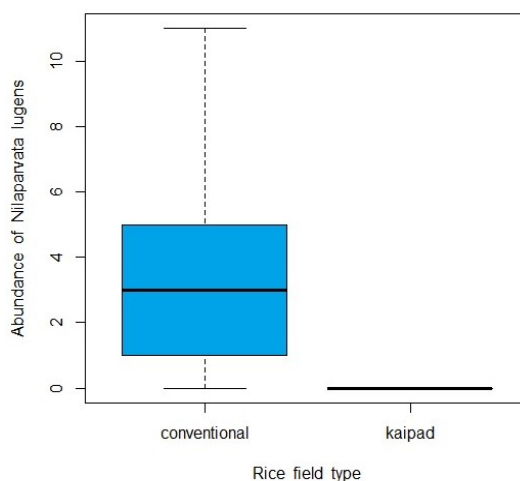
Fig. 2.46: The abundance of *Nephotettix virescens* in Conventional and Kaipad rice fields.



***Nilaparvata lugens* (Stal, 1854)**

N. lugens was only observed in Conventional rice fields, and their range is given in Fig. 2.47.

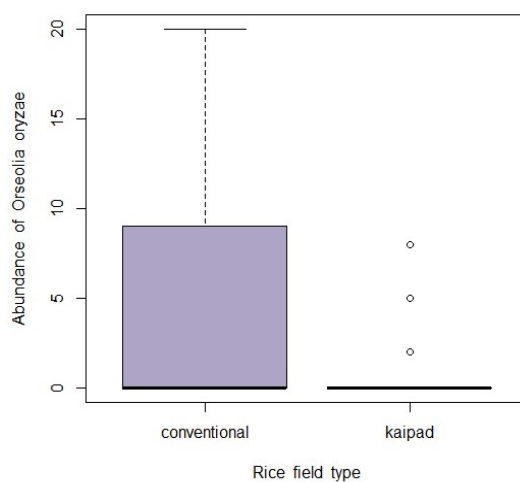
Fig. 2.47: The abundance of *Nilaparvata lugens* in Conventional and Kaipad rice fields.



***Orseolia oryzae* Wood-mason, 1889**

Orseolia oryzae (Plate III.8) was more abundant in Conventional than in Kaipad rice fields and the difference was significant ($p=0.03474$ *) (Tab. 2.3) (Fig. 2.48).

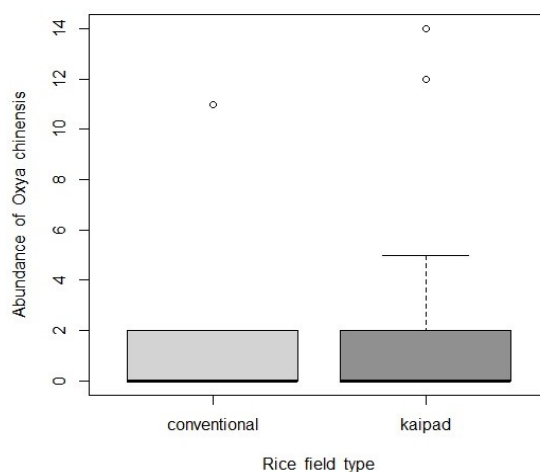
Fig. 2.48: The abundance of *Orseolia oryzae* in Conventional and Kaipad rice fields.



***Oxya chinensis* (Thunberg, 1815)**

The abundance of *O. chinensis* (Plate II.4) between Kaipad and Conventional rice fields did not show any significant difference ($p=1$) (Tab. 2.3) (Fig.2.49).

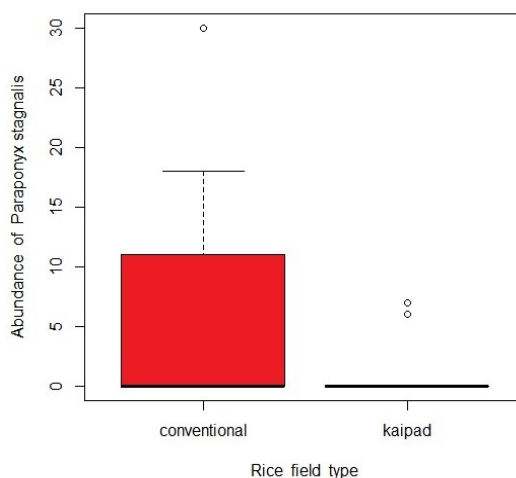
Fig. 2.49: The abundance of *Oxya chinensis* in Conventional and Kaipad rice fields.



***Paraponyx stagnalis* (Zeller, 1852)**

Highly significant difference ($p=0.005756$ **) in the abundance of *P. stagnalis* (Plate II.5) between Kaipad and Conventional rice fields was observed (Tab. 2.3) with higher abundance in Conventional rice fields (Fig.2.50).

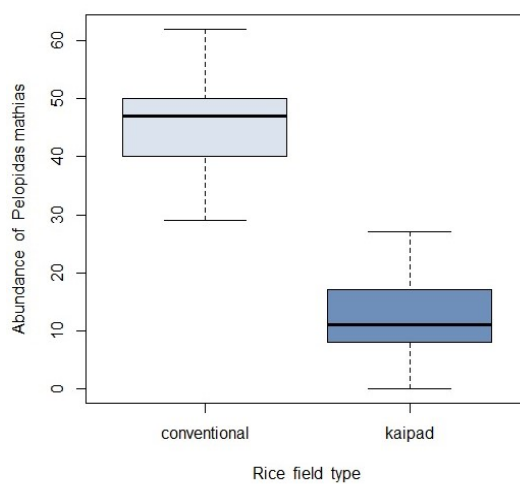
Fig. 2.50: The abundance of *Paraponyx stagnalis* in Conventional and Kaipad rice fields.



***Pelopidas mathias* (Fabricius, 1798)**

The abundance of *P. mathias* (Plate II. 6) was higher in Conventional rice fields than in Kaipad and is significantly different ($p=4.964e-13$ ***) (Tab. 2.3) (Fig.2.51).

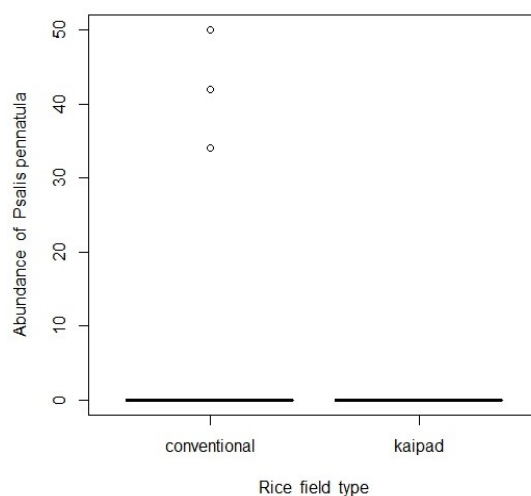
Fig. 2.51: The abundance of *Pelopidas mathias* in Conventional and Kaipad rice fields.



***Psalis pennatula* (Fabricius, 1793)**

The incidence of *P. pennatula* (Plate III.1) is not reported from Kaipad rice fields, and their incidence in the Conventional rice fields is negligible (Fig.2.52).

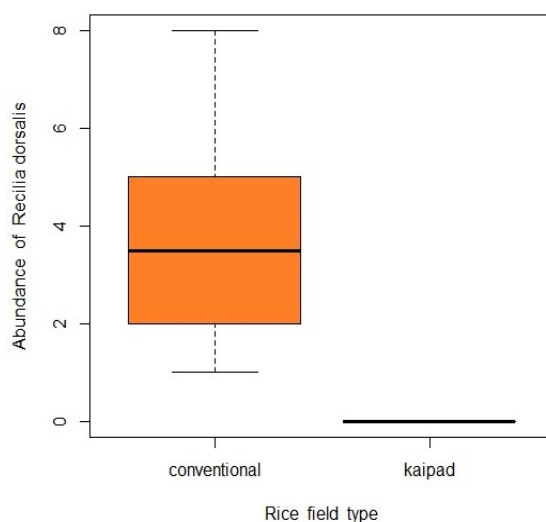
Fig. 2.52: The abundance of *Psalis pennatula* in Conventional and Kaipad rice fields.



***Recilia dorsalis* Motschulsky, 1859**

The occurrence of *R. dorsalis* is only recorded from Conventional rice fields, and their range is given in the Fig. 2.53.

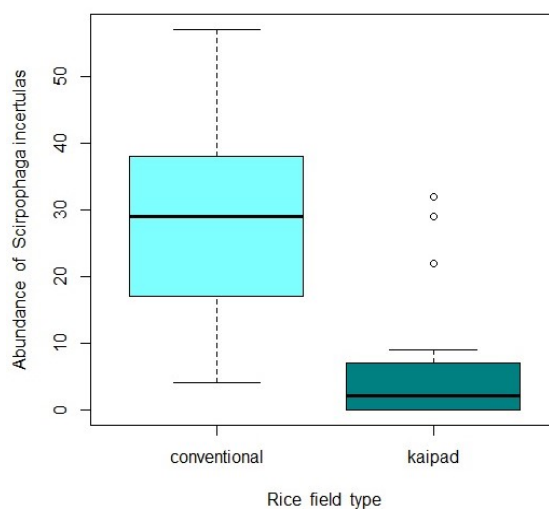
Fig. 2.53: The abundance of *Recilia dorsalis* in Conventional and Kaipad rice fields.



***Scirpophaga incertulas* (Walker, 1863)**

The abundance of *S. incertulas* (Plate III.5) in Kaipad and Conventional rice fields are significantly different ($p=4.143e-05$ ***) (Tab. 2.3), with higher abundance in Conventional rice fields (Fig.2.54).

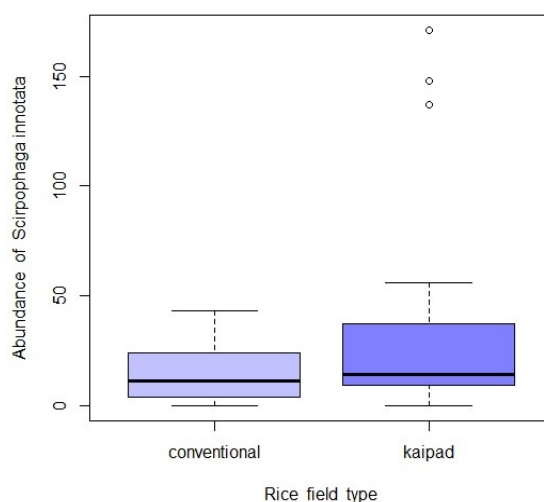
Fig. 2.54: The abundance of *Scirpophaga incertulas* in Conventional and Kaipad rice fields.



***Scirpophaga innotata* (Walker, 1863)**

The abundance of *S. innotata* (Plate III.6) between Conventional and Kaipad rice fields is significantly different ($p=0.0349$ *) (Tab. 2.3) with higher abundance in Kaipad rice fields (Fig. 2.55).

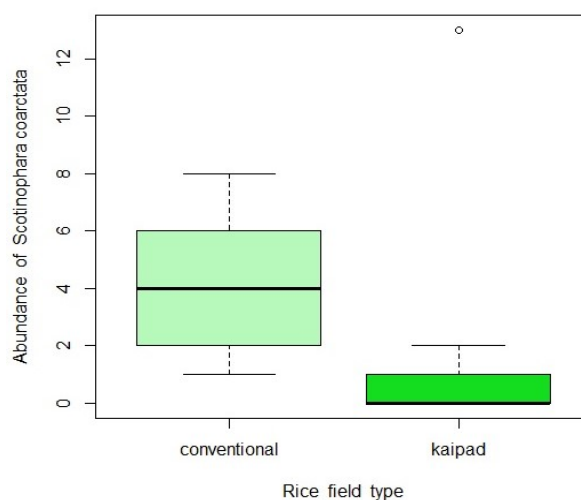
Fig. 2.55: The abundance of *Scirpophaga innotata* in Conventional and Kaipad rice fields.



***Scotinophara coarctata* (Fabricius)**

S. coarctata is more abundant in Conventional rice fields than in Kaipad rice fields and the difference is highly significant ($p=0.008146$ **) (Tab. 2.3) (Fig. 2.56).

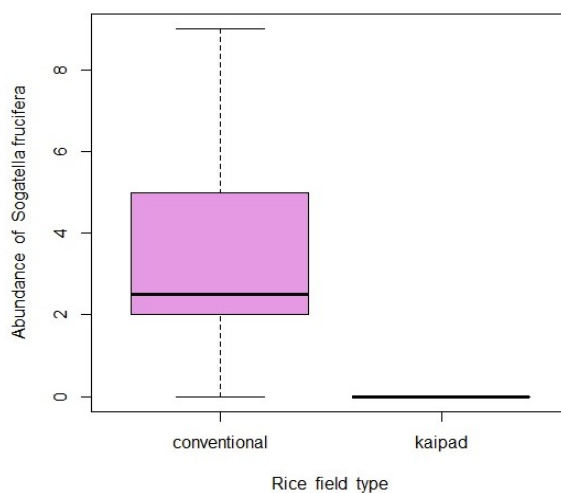
Fig. 2.56: The abundance of *Scotinophara coarctata* in Conventional and Kaipad rice fields.



***Sogatella frucifera* Horvath, 1899**

Sogatella frucifera is only reported from Conventional rice fields and the range of *S. frucifera* are given in Fig. 2.57.

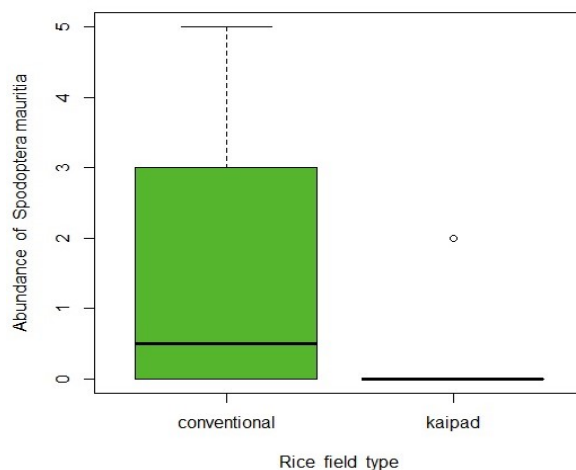
Fig. 2.57: The abundance of *Sogatella frucifera* in Conventional and Kaipad rice fields.



***Spodoptera mauritia* Boisduval**

Spodoptera mauritia is more abundant in Conventional than in Kaipad rice fields and the difference is significant ($p=0.002063$ **) (Tab. 2.3). The incidence of *S.mauritia* in Kaipad rice field is negligible, and their range in Conventional and Kaipad rice fields are given in Fig. 2.58.

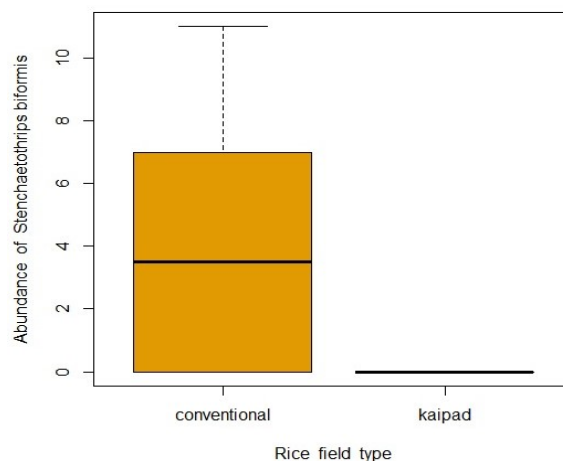
Fig. 2.58: The abundance of *Spodoptera mauritia* in Conventional and Kaipad rice fields.



***Stenchaetothrips biformis* (Bagnall)**

The incidence of *S. biformis* is only reported from Conventional rice fields and, their range is given in the Fig. 2.59.

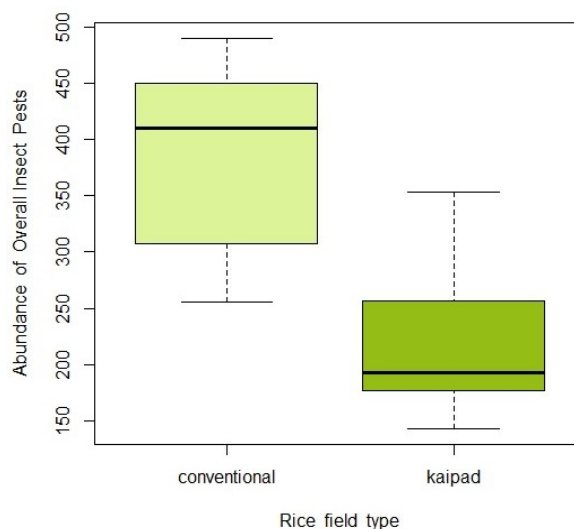
Fig. 2.59: The sum of *Stenchaetothrips biformi* sin Conventional and Kaipad rice fields.



Overall Pests

When the whole insect pest complex in Conventional and Kaipad rice fields are considered, the pests are more abundant in Conventional than in Kaipad rice fields and the difference is highly significant ($p=1.273e-08$ ***) (Tab. 2.3) (Fig.2.60).

Fig. 2.60: The abundance of overall pests in Conventional and Kaipad rice fields.



Tab. 2.3: The ANOVA table of Pest Species abundance between Conventional and Kaipad rice fields

Sl. No	Insect Pest	Sum Sq	Df	F value	P value
1	<i>Dicladispa armigera</i> Olivier, 1808	2.960	1	1.106	0.3004
2	<i>Hieroglyphus banian</i> (Fabricius)	16.526	1	5.5163	0.02479 *
3	<i>Hydrellia philippina</i> Ferino	5.982	1	2.1653	0.1504
4	<i>Leptocorisa acuta</i> (Thunberg)	53.583	1	7.3277	0.01054 *
5	<i>Marasmia patnalis</i> (Bradley, 1981)	352.34	1	50.437	3.32e-08 ***
6	<i>Melanitis leda</i> (Linnaeus, 1758)	614.57	1	314.86	< 2.2e-16 ***
7	<i>Nephotettix nigropictus</i> (Stal)	25.215	1	4.4228	0.04294 *
8	<i>Nephotettix virescens</i> (Distant)	6.574	1	0.9826	0.3286
9	<i>Orseolia oryzae</i> Wood-mason, 1889	36.958	1	4.8381	0.03474 *
10	<i>Oxya chinensis</i> (Thunberg, 1815)	0.00	1	0	1
11	<i>Paraponyx stagnalis</i> (Zeller, 1852)	80.57	1	8.6869	0.005756 **
12	<i>Pelopidas mathias</i> (Fabricius, 1798)	394.34	1	127.1	4.964e-13 ***
13	<i>Scirpophaga incertulas</i> (Walker, 1863)	250.29	1	22.128	4.143e-05 ***
14	<i>Scirpophaga innotata</i> (Walker, 1863)	212.2	1	4.829	0.0349 *
15	<i>Scotinophara coarctata</i> (Fabricius)	38.512	1	7.8993	0.008146 **
16	<i>Spodoptera mauritia</i> Boisduval	25.647	1	11.132	0.002063 **
17	Overall pests	883.29	1	55.248	1.273e-08 ***

Dominance and Diversity indices of insect pests between Conventional and Kaipad rice fields.

H.banian (D=0.1233) and *L. acuta* (D=0.17) are the most dominant dominant pests in Kaipad and Conventional rice fields respectively. According to the Simpson diversity index and Shannon diversity index more insect pest diversity is recorded from Conventional rice fields than Kaipad rice fields (Tab. 2.4).

Tab. 2.4: The diversity indices and dominance of insect pests in Conventional and Kaipad rice fields in overall years

Parameters	Conventional	Kaipad
Taxa_S	22	16
Dominance_D	0.1233	0.17
Simpson_1-D	0.8767	0.83
Shannon_H	2.453	2.034

Dominance and Diversity indices of insect pests in Kaipad rice fields during different months.

In Kaipad rice fields, *H. banian* is dominating during June (D=0.1451), July (D=0.1407) and August (D=0.1768), but in September (D=0.2159) and October (D=0.2294), *L. acuta* is the dominant pest. As per the Simpson diversity index, July shows the highest insect pest diversity (0.8593), followed by June (0.8549), August (0.8232), September (0.7841) and October (0.7706). According to Shannon diversity index also, July (2.223) has more pest diversity than other months (Tab. 2.5).

Dominance and Diversity indices of insect pests in Kaipad rice fields during different Years.

Leptocorisa acuta is the most dominant insect pest species during 2015 (D=0.178) in Kaipad rice fields, but in 2016 (D=0.1948) and 2017 (D=0.1667), *H. banian* dominates. According to Simpson and Shannon diversity indices insect diversity was highest in 2017 followed by 2015 and 2016 in Kaipad rice fields (Tab. 2.6).

Tab. 2.5: The diversity indices and dominance of insect pests in Kaipad rice fields in different months

Parameters	June	July	August	September	October
Taxa_S	13	14	11	8	9
Dominance_D	0.1451	0.1407	0.1768	0.2159	0.2294
Simpson_1-D	0.8549	0.8593	0.8232	0.7841	0.7706
Shannon_H	2.195	2.223	1.918	1.679	1.638

Tab. 2.6: The dominance and diversity indices of insect pests in Kaipad rice fields in different years

Parameters	2015	2016	2017
Taxa_S	15	15	15
Dominance_D	0.178	0.1948	0.1667
Simpson_1-D	0.822	0.8052	0.8333
Shannon_H	1.981	1.868	2.076

Dominance and Diversity indices of insect pests in Conventional rice fields during different months.

In Conventional rice fields, *H. banian* is dominating during June (D=0.1044) and August (D=0.1063), but in July (D=0.1183), September (D=0.1561) and October (D=0.1851), *L. acuta* is the dominant insect pest species. As per the Simpson diversity index, the highest insect pest diversity is estimated in June (0.8956), followed by August (0.8937), July (0.8817), September (0.8439) and October (0.8149). According to Shannon diversity index also, diversity of insect pests was more in June (2.591) followed by July, August, September and October (Tab. 2.7).

Dominance and Diversity indices of insect pests in Conventional rice fields during different years.

The insect pest, *L. acuta* is the most dominant insect pest species during 2015 (0.1172) and 2016 (0.1485), but in 2017 (0.1211), *H. banian* is the most dominating insect pest. According to the Simpson diversity index, 2015 (0.8828) denotes the year with more insect pest diversity, and followed by 2017 (0.8789) and 2016 (0.8515). The Shannon diversity index value indicate that 2017 shows high diversity of rice insect pests in this area followed by 2015 and 2016 (Tab. 2.8).

Tab. 2.7: The diversity indices and dominance of insect pests in Conventional rice fields in different months

Parameters	June	July	August	September	October
Taxa_S	19	22	21	15	12
Dominance_D	0.1044	0.1183	0.1063	0.1561	0.1851
Simpson_1-D	0.8956	0.8817	0.8937	0.8439	0.8149
Shannon_H	2.591	2.518	2.514	2.125	1.987

Tab. 2.8: The dominance and diversity indices of insect pests in Conventional rice fields in different years

Parameters	2015	2016	2017
Taxa_S	22	22	22
Dominance_D	0.1172	0.1485	0.1211
Simpson_1-D	0.8828	0.8515	0.8789
Shannon_H	2.448	2.337	2.46

DISCUSSION

The abundance and diversity of insect pests shows variation within and between Kaipad and Conventional rice fields, and between years and months in both Kaipad and Conventional rice fields during the three years of study.

The results indicate that Conventional rice fields harbor more number of insect pests than Kaipad in the three years of sampling. During the present study, the incidence of *Scirpophaga incertulas*, *Nephotettix virescens*, *Nilaparvata lugens*, *Marasmia patnalis*(*Cnaphalocrocis medinalis*), *Sogatella frucifera* and *Pelopidas mathias* were higher in Conventional rice fields (pesticides sprayed), when compared with Kaipad rice fields (unsprayed). Similar observation was made in rice fields of Karnataka by Vijaykumar and Patil (2003). Development of resistance to pesticides and the resultant outbreak of pests may be the reason for higher abundance of pests in Conventional rice fields. Kajimura et al., (1993) also supported the present study by reporting lower population densities of *N. lugens* and *S.furcifera* in an organically farmed than in chemically fertilized rice fields. The pests, *M.patnalis* (= *C.medinalis*), *Scirpophagha* sp., *Parapoynx stagnalis* (= *Nymphula depunctalis*) and *Scotinophara coarctata* reported in Kaipad rice fields during the present study were also reported from rice-fish farming areas in Indonesia by Siregar and Matondang (2017).

The pest species, its development stage and mode of feeding are synchronized with the development stage of the crop. During the present study, the total pest count increased as growth stage of rice progressed and decreased in harvesting stage. Minimum number of pests are observed in early tillering stage, and harvesting stage in Conventional rice fields. Similar trend of pest incidence was also noticed by several authors (Labe et al., 2016; Nair, 1978; Ajayakumar, 2000 and Smithagopan, 2004). Bakar and Khan (2016) also observed that the diversity indices of insect pests differed according to crop growth stages. Similar findings was reported by Bambaradeniya and Edirisinghe (2008) during a study in Sri Lanka i.e., Species diversity of terrestrial arthropods during vegetative, reproductive and grain ripening stages and the fallow period were significantly different. In the present

insect pest survey, *Marasmia patnalis*, *Orseolia oryzae*, *Oxya chinensis*, *Scirpophaga incertulas*, *Scotinophara coarctata* and *Spodoptera mauritia* are the most abundant insect pests in Kaipad rice fields during early to late tillering. The major active insect pests from flowering to harvesting stage were *Leptocorisa acuta*, *Nephotettix nigropictus* and *Scirpophaga innotata*. In Conventional rice fields, the active insect pests during early to late tillering stage were, *Dicladispa armigera*, *Hieroglyphus banian*, *Nephotettix nigropictus*, *N. virescens*, *Nilaparvata lugens*, *Hydrellia philippina*, *S. coarctata*, *Oxya chinensis*, *Recilia dorsalis*, *Sogatella frucifera*, *O. oryzae*; *S. innotata* and *Stenchaetothrips biformis*. All these pest species are mostly leaf defoliators, sap suckers and stem borers, and they prefer young leaves and stem for feeding, sucking and boring respectively. *H. banian* shows its active presence throughout the seasons in both categories of rice fields as it is a general defoliator.

Saini et al., (2015) noted *S. frucifera* during panicle initiation to milky stage as a minor pest and occurrence of *L. acuta* during flowering to harvesting stage. In the present study, *S. frucifera* is recorded as a minor pest, and their peak incidence was noticed during early tillering stage. As already mentioned, *S. frucifera* are sap feeders and they prefer young leaves and stem for sap sucking. This is may be reason behind their higher abundance in early tillering stage. But in the case of *L. acuta*, it was a major pest in both categories of rice fields, the presence of adults and nymphs of *L. acuta* is high during flowering to panicle stage in Kaipad and Conventional rice fields, and agrees with the observation of Saini et al., (2015). The incidence of *S. incertulas*, *M. patnalis* (= *C. medinalis*) and *D. armigera* was noted from early tillering stage onwards in Kaipad and Conventional rice fields during the present study. Maximum adult population of *S. incertulas* and *M. patnalis* in Kaipad rice fields are observed during early tillering stage, and *D. armigera* during panicle initiation and flowering. But in Conventional rice fields, maximum abundance of *S. incertulas* (panicle initiation and flowering), *M. patnalis* (flowering and milky stage) and *D. armigera* (late tillering stage) was associated with their respective feeding stages of the plant. Dogra and Choudhary (2005) noted their presence from late tillering onwards, which shows dissimilarity in the first time incidence of these pests

in both studies. They also reported maximum population of these pests in panicle initiation stage, which is similar to the present study in case of *D. armigera* in Kaipad rice fields, and *S. incertulas* in Conventional rice fields.

The damages and yield loss in rice fields depends on which stage of the pest occur in the fields, commonly larval stages cause the more observable damage as leaf defoliators, leaf folders, leaf case makers, stem borers, while nymphs and adults of bugs cause damage as sap feeders and grain sap feeders. In the present study, adults are the dominant pest stage, followed by larva, pupa and egg in Conventional rice fields. The huge number of *H. banian* and *L. acuta* adults may be the reason for adult dominance in Conventional and Kaipad rice fields.

In Conventional and Kaipad rice fields, the abundance of adult stem borers are higher in late tillering stage and least in harvesting stage. The egg mass abundance is higher during late tillering stage in Conventional rice fields; and early tillering stage in Kaipad rice fields. The emerged larvae needs tender stems for boring, which may be the reason for the incidence of adults and eggs of *S. incertulas* in tillering stages.

Adults of leaf gall midges are more abundant during early tillering stage in Conventional and Kaipad rice fields. The preference of the adults of the leaf gall midges for the soft plant tissue for sucking the sap and the larvae to rasp the soft plant tissue, explains the abundance of these two development stages of the leaf gall midges during the early tillering stage of the rice plant.

In Conventional and Kaipad rice fields, the adults and nymphs of sap feeders and grain sap feeders are higher during early tillering to panicle initiation and flowering stage. The adults and nymphs of sap feeders' feeds on cell sap from leaf sheath, leaf blade and stems of rice, and hence, their higher abundance during early tillering and growth stage of the rice plant. While the adults and nymphs of grain sap feeders are more abundant in flowering and milky stage and least in early tillering stage. This observation reaffirms the synchronization of the feeding behavior with the growth stages of the rice plant.

The leaf case maker, *Paraponyx stagnalis* although reported from both categories of rice fields, are less abundant in Kaipad rice fields which may be due to the presence of their pupal parasitoids *Tetrastichus paraponyxi* which is not recorded in Conventional rice fields. In Kaipad rice fields, the adult of *P. stagnalis* is recorded in late tillering stage only, but in Conventional fields, it is recorded in all cultivating months except maturity and harvesting stage of the crop, with peak incidence in late tillering stage. This difference in abundance of *P. stagnalis* in the Conventional and Kaipad rice fields may be due to the difference in method of rice cultivation and the rice varieties used in these two fields. During a study in Philippines, Dale (1994) also reported that *P. stagnalis* attack was severe in early vegetative stage, and the transplanted young seedlings suffer heavy damage.

In Conventional rice fields, the adults of *Melanitis leda* are noted throughout the crop, while they are reported in late tillering and mature and harvesting stage in Kaipad rice fields. Similar trend was noticed by Parasappa et al., (2017) in rice ecosystems of Karnataka, i.e., *M. leda* was active at the tillering stage of the crop and declined with the advancement in the crop stage.

In Conventional and Kaipad rice fields, adult *H. philippina*, a leaf miner was abundant during tillering stage. Litsinger et al., (2013) also observed damage by *H. philippina* during the tillering stage where new leaf unfurls and damage peaks at 4-5 weeks after transplanting.

The larval and pupal parasitoids were also having higher abundance in Conventional rice fields. Adult *P. mathias* are seen throughout the crop season, and had higher abundance during flowering and milky stage and lower incidence in early tillering. The nectar feeding habit of the adult may be the reason for the presence of the adults in more numbers during the flowering stage. The incidence of larvae of *P. mathias* - which is the destructive stage- in Conventional and Kaipad rice fields are noted throughout the cultivation period with higher abundance during late tillering to panicle initiation and flowering stage. Their larval parasitoid, *Aphanogamus* sp. is not recorded during panicle initiation and flowering stage in both categories of rice fields, and during the same period, lower abundance of *Pediobius* sp. is found in

Kaipad rice fields. Another larval parasitoid, *Charops* sp. is absent in Conventional and Kaipad rice fields during panicle initiation- flowering stage and in late tillering stage respectively. These factors may be reasons for higher abundance of *P. mathias* larvae during late tillering to panicle initiation and flowering stage in both categories of rice fields.

Psalis pennatulae was collected from Conventional rice fields only, and their abundance is higher during late tillering to flowering stage - the growth stage of the rice plant which is fed upon by the larvae of *P. pennatula*. The lower abundance of their larval parasitoid *Microplitis pennatulae* may also have contributed to the higher abundance of *P. pennatula* in Conventional rice fields. The absence of *P. pennatula* from Kaipad rice fields maybe due to the unsuitability of the rice varieties cultivated in Kaipad for feeding.

The abundance of *H. banian* recorded from the rice fields was higher during flowering and milky stage and least during harvesting stage in both categories of rice fields, although their incidence was recorded during the whole cropping season during the present study. Saini et al., (2015), Kashyap (2013), Singh and Singh (2014), Gangwar et al., (2015) and Jhansi et al., (2018) have also noted that *H.banian* remained active throughout the crop season in Tamil Nadu, and is a polyphagous pest.

Several studies reported *D. armigera* as one of the major pests in paddy growing areas of India (Bhattacharjee and Ray, 2010; Hazarika et al., 2005; Chakraborty and Deb, 2012 and Prakash, 2013). The incidence of adult *D. armigera* was found throughout the rice cultivating period, and was seen higher during early tillering to flowering and milky stage with peak incidence in late tillering stage in Conventional rice fields. In Kaipad rice fields also, the adults are seen throughout, with higher incidence during late tillering to milky stage with peak number in panicle initiation and flowering stage. *D. armigera* normally prefers young leaves than mature ones, and the presence of healthy green leaves during late tillering and even in panicle initiation stage may be the reason for the higher abundance of *D. armigera* in Conventional and Kaipad rice fields. The larvae of *D. armigera* are only

reported from Kaipad rice fields during flowering and milky, which may be due to the absence of their larval parasitoid *Scutibracon* sp. While the presence of the parasitoids *Scutibracon* sp. and *Trichomalopsis apanteloctena* in Conventional rice fields may be the reason for the negligible presence of the larvae of *D. armigera*. While Mukherjee and Khan (2017), BRRI (1985) and Jhansi et al., (2018) have observed that *D. armigera* population showed the highest abundance at seedling stage. As per Amit et al., (2001) their abundance was the highest at mid tillering stage which is more or less similar to the present study.

In the present survey, larvae and adult of *S. mauritia* were recorded during late tillering stage to flowering and milky stage, and peak number was at late tillering stage in Conventional rice fields, while in Kaipad rice field, the pest was recorded only in late tillering stage. Prakash et al., (2014), considered *S. mauritia* as a major pest in Odisha, Bihar and Jharkhand and the pest destroyed paddy crop in tillering stage. But, Saini et al., (2015) recorded *S. mauritia* as minor pest during late tillering to flowering stage.

Marasmia patnalis was observed in higher numbers in both categories of rice fields with higher abundance in Conventional rice fields during the present study. The difference in physico-chemical conditions, rice varieties used, and impact of natural enemies may be reason for lower abundance in Kaipad rice fields. The abundance of their egg parasitoids (except *Trichogrammatoidea* sp. and *Trichogrammatoidea bactrae*), larval and pupal parasitoids are higher in Conventional rice fields. Bisen et al., (2019) also recorded that the abundance of *M. patnalis* increases at the time of flowering stage. In Kaipad rice fields, the abundance of adult *M. patnalis* was recorded throughout the crop season with peak and least incidence during early tillering stage and harvesting stage respectively. But in Conventional fields, even though they are present throughout the crop period, flowering and milky stage (September) showed the highest adult abundance, and least abundance was during early tillering stage. The presence of flowers as a source of nectar may be the reason for the higher abundance of the adults during the flowering stage. The peak abundance of larval stages in Kaipad and Conventional

rice fields were noted during early tillering stage and late tillering stage respectively; and least abundance was in mature and harvesting stage, which synchronizes with their feeding stage (early tillering and late tillering) of the rice plant. The incidence of larval parasitoids in the fields may also influence the abundance of larvae of *M. patnalis*. In 2002, Samui et al., recorded that kharif rice crop is infested heavily by *M. patnalis* year after year. On average, 15 to 20% damage was reported by Karthikeyan (2002) due to the *M. patnalis* in rice fields; and Kakde and Patel (2018) observed the leaf damage due to *M. patnalis* after stem elongation and booting stage, which reached highest during flowering stage and was recorded till dough grain stage. Ram (1986) and Kushwaha (1988) noted their incidence during booting to panicle emergence stage and their infestation at grain filling stage was more injurious. Farooq et al., (2014) also recorded *M. patnalis* as one of the major pests of rice and its severe infestation coincides with susceptible crop growth stages (maximum tillering to booting), and they occur in all rice environments and were more in numbers during the rainy seasons, and areas where rice was heavily fertilized. The activity of adult *M. patnalis* in Conventional rice fields in the present study was similar to the report of Vidyawati (2012) during Kharif season in Raipur, i.e. their count was less during first three months compared to September. During a survey, Samui, et al., (2007) also noted maximum infestation of *M. patnalis* between the 39th (24-30th September) to 47th (19- 25th November) standard week in Kharif season which is almost similar to the findings of the present study in Conventional rice fields in which maximum incidence is noted during September (flowering and milky stage). The presence of flowers for adult feeding and other physico-chemical conditions during September may be the reason for higher adult abundance in Conventional rice fields.

The leaf gall midges are also a major pest of rice, and its abundance is higher in Conventional rice fields than in Kaipad rice fields. Prasad (2011) reported incidence of *O. oryzae* in some parts of Kerala, Orissa, Andhra Pradesh, Madhya Pradesh, Jharkhand and Bihar. The abundance of *O. oryzae* is higher in Conventional rice fields, hence the number of their egg parasitoid, *Platygaster* sp; larval parasitoids, *Eurytoma* sp., *Propicroscytus mirificus*, *P. oryzae*, *Tetrastichus* sp.;

and pupal parasitoid, *Aprostocetus* sp. are higher in Conventional rice fields than Kaipad rice fields. During the present study in Kaipad rice fields, the incidence of *O. oryzae* are seen only in early tillering stage; but their incidence is noted during early tillering to milky stage in Conventional rice fields, while it is absent during harvesting stage. Their larvae prefer tender stems to bore and feed, and adults emerge after 15-20 days, i.e. early tillering stage itself. Pasalu et al., (2005) recorded *O. oryzae* as a major insect pest of rice during the crop tillering stage which is similar to the present findings. While, Jhansi et al., (2018) reported their incidence from September to November with peak incidence during the first week of October.

Plant hoppers and leaf hoppers which feed on the plant sap are destructive as nymphs and adults. According to Zhang et al., (2013) plant hoppers and leafhoppers were the most important components of the phytophagous fauna in Organic rice fields. Tsutsui et al., (2018), revealed that plant hoppers and leafhoppers exhibited a gradual decrease in abundance with the time since transition to organic farming.

The present study only recorded two species of green leaf hoppers, i.e., *N. nigropictus* and *N. virescens*, and both of them showed higher abundance in Conventional rice fields than Kaipad rice fields. Tsutsui et al., (2018), revealed that plant hoppers and leafhoppers exhibited a gradual decrease in abundance with transition to organic farming.

N. nigropictus was more dominant than *N. virescens* in both categories of rice fields. Parasappa et al., (2017) had also reported the green leaf hoppers throughout the period of crop growth. In 2018, Kakde and Patel reported that the population and infestation of green leaf hopper commenced during heading stage and was highest during flowering and milk grain stages and their presence was noticed till the maturity of the crop which is similar to the trend of the present study. While, Saini et al., (2015) recorded the occurrence of *N. virescens* during panicle initiation-flowering stage to milky stage, which disagrees with the observation made in the present study.

Nilaparvata lugens was reported only from Conventional rice fields, and the unfavorable physico-chemical conditions, difference in chemical constituents of

plants sap and incidence of their egg parasitoids viz. *Oligosita* sp., *Panstenon* sp., *Greyon* sp. and *Mymar taprobanicum* throughout the crop season may be the cause behind the absence of *N. lugens* in Kaipad rice fields. Farooq et al., (2014) also observed higher abundance of *N. lugens* from Conventional rice fields than from Organic rice fields. The nymphs and adults suck the plant sap from stem and leaf sheath, and prefer young healthy plant, and this may be the basis for their higher abundance in early tillering stage. According to Jhansi et al., (2018), *N. lugens* incidence was observed from October to November and the population decreased as the crop reached the harvesting stage in Telengana.

Recilia dorsalis was reported from Conventional rice fields only. The unsuitability of the rice varieties, physico-chemical parameters, presence of their egg parasitoids like *Gonatocerus aegyptiacus* (throughout crop season), *Mymar taprobanicum* (except early tillering stage), and *Anagrus* sp. (early tillering stage only) may have contributed to their absence in Kaipad rice fields.

Scotinophara coarctata is a minor pest in Kaipad and Conventional rice fields during the present survey, with comparatively more numbers of eggs, nymphs and adults recorded from Conventional rice fields. Adalla and Alzona (2007) reported *S. coarctata* as the dominant species in Philippines and infested paddy at the various stages of its development and was predominant at the active tillering stage of the paddy plants, which is similar to the trends noted in the present study.

During the present study, the incidence of sap feeder, *S. frucifera* was noticed in Conventional rice fields only. The varietal difference of the rice plants cultivated in Kaipad rice fields and activity of their egg parasitoids *Anagrus* sp., *Mymar taprobanicum*, *Oligosita* sp., and especially highly abundant *Tetrastichus* sp. throughout season in Kaipad rice fields may be the cause for absence of *S. frucifera* in Kaipad rice fields. Their peak incidence, least incidence and absence was noticed during early tillering stage, late tillering stage and flowering and milky stage respectively in Conventional rice fields. They suck the plant sap from stem and leaf tissues by preferring young healthy plants, and absence and lower abundance of their parasitoids *Mymar taprobanicum* and *Anagrus* sp. are noted during early tillering

stage of the crop. Dale (1994) observed that the serious incidence of *S. frucifera* coincides with early stages of plant growth with appearance of 'hopper burn' symptoms towards crop maturity as observed in the present study. Saini et al., (2015) recorded *S. frucifera* in August - September as minor pest in Uttar Pradesh, India. But they are absent during September (flowering and milky stage) in the present study. As per Jhansi et al., (2018), *S. frucifera* population decreased as the crop reached the harvesting stage as observed in the present study.

The occurrence of *Stenchaetothrips biformis* was noted only from Conventional rice fields during early tillering stage to milky stage with higher abundance during late tillering stage and lower incidence in flowering and milky stage. Their absence from Kaipad rice fields may be due to the unique rice cultivation methods adopted in Kaipad rice fields, especially the rice varieties used. Kharbangar et al., (2014) had collected five species of thrips from rice crops in Meghalaya, and *S. biformis* was the dominant species with 68% abundance.

In the present study, the incidence of adult *L. acuta* in both categories of rice fields was found throughout the cultivation but the infestation was higher at flowering and milky stage. Mukherjee and Khan (2017) reported highest incidence of *L. acuta* incidence at panicle initiation stage and Tsueda et al., (2002) reported *L. acuta* peak abundance at heading to early ripening stage. In 1985, Rao and Kulshreshtha also reported increased infestation of *L. acuta* during the milky stage which supports the results of the present survey in both categories of rice fields. The studies in Thiruvananthapuram by Ajayakumar (2000) and Smithagopan (2004); and studies in Kollam by Nandakumar et al., (2002) also reported *L. acuta* as a major pest. Their feeding habit, i.e. grain sap sucking may be the grounds for their peak incidence during flowering and milky stage of rice.

The egg masses and adults of *Scirpophaga incertulas* was more abundant in Conventional rice fields. The higher abundance of their egg parasitoids, *Trichogramma* sp., *T. japonicum*, *T. chilonis*, *Telenomus* sp., *Tetrastichus schoenobii*; larval parasitoids, *Propicroscytus mirificus*, *Temelucha* sp., *Isotima* sp., *Ishnojoppa* sp., *Charops bicolor*, *Tetrastichus* sp., *T. schonobii*, *Tropobracon luteus*,

Myosoma sp., *Cotesia* sp., *Apanteles* sp.; and pupal parasitoid *Trichomalopsis apanteloctena* in conventional rice fields may be due to the presence of their specific host stages in these fields. The reduction in number of egg/larval/pupal parasitoids are noted in Kaipad rice fields due to comparatively lower number of hosts. In Conventional rice fields, the egg mass of *S. incertulas* incidence was observed throughout the crop with peak incidence in flowering and milky stage and adult of *S. incertulas* was also reported throughout the crop period, but their higher incidence was noted during panicle initiation and flowering stage. This indicates that the activity of stem borers are more during panicle initiation to milky stage in Conventional rice fields. In Kaipad rice fields, the egg mass and adult dominance of *S. incertulas* are higher during flowering and milky stage; and early tillering stage respectively. The present study recorded higher dominance of *S. incertulas* than *S. innotata* in Conventional rice fields, which is similar to the survey results of Kanagaraj et al., (2019). The studies by Bisen et al., (2019) support the case in Conventional rice fields, i.e. *S. incertulas* infestation was highest after 45 days (in and after late tillering stage as per present study) of transplantation in rice fields of Balaghat district of Madhya Pradesh. While in Kaipad, the highest infestation of *S. incertulas* was recorded before late tillering stage, i.e. in June (early tillering stage), which is different from survey results of Bisen et al., (2019). The physico- chemical characteristics of Kaipad rice fields may be the reason for this difference in infestation time. Tripathy et al., (1999) reported peaks of *S. incertulas*, during the last week of September and second week of November which coincided with the dough stage of rice. Sankpal (2011) observed peak level of *S. incertulas* at vegetative and reproductive stage.

The adults and egg masses of *S. innotata* have higher abundance in Kaipad rice fields than in Conventional rice fields, while their egg parasitoid, *Trichogramma* sp. are noted more in Conventional rice fields. The egg parasitoids are recorded throughout the crop season, and it may be due to presence of *S. innotata* egg mass in entire season in both categories of rice fields. In Conventional and Kaipad rice fields, the egg mass and adult of *S. innotata* are seen throughout the crop season with adult peak incidence in tillering stage. In Titabar (Assam), *S. innotata* was

dominant during early and late tillering stage as we noticed in both categories of rice fields. In Kaipad rice fields, the abundance of egg masses of *S. innotata* is more on the trap plant *Eleocharis dulcis* than on rice.

The present study concludes that, the abundance of insect pests are higher in Conventional rice fields than in Kaipad rice fields. But during a survey in California, Hesler et al., (1993) noted there was no significant difference in abundance or in level of damage between Conventional and organic treatments. Ovawanda et al., (2016) also noted higher species richness in non-organic than in organic rice fields which is supported by the present study. Hepperly et al., (2009) reported Conventional rice system adds a lot of synthetic inputs that would trigger an explosion of insect pests. This may be the reason behind the higher abundance and diversity of insect pests in Conventional fields during the present study. And some studies documented that organic farming system was able reduce the abundance of herbivores (Padmavathi et al., 2009; Mukerji, 2009). David et al., (2005) reported that organic rice cultivation systems can suppress thrips abundance. In the present study also, the presence of thrips, *Stenchaetothrips biformis* is not reported from Kaipad which is organic. While, several studies documented organic agro-ecosystems have a greater richness of arthropod species than Conventional ones which is just opposite to the present findings (Wilson et al., 2008; Dritschilo and Wanner 1980; Brown and Adler 1989; Goh and Lange 1989; Kromp 1989, 1990). But Yuan et al., (2019) noticed that the species richness of plant hoppers was higher in organic rice fields than Conventional rice fields in China. Labe et al., (2016) noted Organic field carries comparatively more insect pests in Philippines. Finding of these two studies are just opposite to the present study. While, Dinesh et al., (2018) supported the present study in case of species diversity. i.e., insect diversity was higher in inorganic rice fields in both studies than that of Organic one. Similar finding was reported by Ovawanda et al., (2016), i.e. the highest species richness occurred in non-organic rice fields, dominated by herbivorous insects in Indonesia. The present study shows that lower number of pests recorded in Kaipad system of rice cultivation when compared to organic fields may be due to the uniqueness of the Kaipad system, especially in physico-chemical parameters and

rice varieties used, which may not be suitable for the establishment and multiplication of insect pests.

As per the Simpson and Shannon indices, the diversity of pest species in Kaipad rice fields decreased with the growth phase of paddy plant. Norela et al., (2013) also revealed that, the overall insect diversity and richness decreased in tandem with the growth phase of the paddy plant. In Conventional rice fields also, the early tillering stage shows high diversity of insect pests as per the Simpson and Shannon diversity index. And this is supported by Bakar and Khan (2016), by recording higher diversity in terms of diversity index in early tillering stage compared to the other three stages. The explanation for this may be the active incidence and feeding of leaf defoliators and sap suckers during this period of time.

The difference in the composition of species associated with rice agro-ecosystems in different places may be a result of variation in physico-chemical characteristics of the fields where the surveys were conducted, as well of the influences exerted by native natural areas surrounding the farming systems (Altieri, 1999). Regannold et al., (1990) also noted that the organic rice field has been regarded as a sustainable system because it avoids problems such as pest resistance, resurgence, and pesticides residue. It has also been shown that adding various organic manures to soil can suppress insect pest populations and damage to plants growing in amended soils (Paramasiva et al., 2020a & b), and these things may be a relevant reason for reduction in the pest count in the case of Kaipad rice fields, where a unique form of rice cultivation is practiced.

The present study provides a base line data of the various pests infesting rice at different stages of rice plant growth, when it is cultivated conventionally and in Kaipad rice fields. This will help the farmers, researchers and Krishi bhavans to formulate proper methods of pest control before the specific pest establishes in the field.

CHAPTER 3

TO EVALUATE THE DIFFERENCE IN ABUNDANCE AND DIVERSITY OF HYMENOPTERAN PARASITOIDS IN KAIPAD AND CONVENTIONAL RICE FIELDS

INTRODUCTION

This chapter comprises an inventory and a comparison of the abundance and diversity of parasitic Hymenoptera in Kaipad and Conventional rice fields of North Kerala, which are two differently managed rice ecosystems. Studies on the biological control, abundance and diversity of parasitic Hymenoptera in Kaipad rice fields have not been carried out.

Biological control usually refers to the action of parasitoids (parasites in the original definition), predators and pathogens in maintaining another organism's population density at a lower average than would occur in their absence (DeBach, 1964). Implicit in this definition is the wish to understand how those parasitoids, predators, and pathogens act on their prey. However, in the last century, this empirical approach was replaced with a desire to find out effective parasitoids and predators for possible introduction into a new area where a pest has been moved.

Many biological control experimental programs were conducted in Indian agricultural crops, mainly in cereals, vegetables, pulses etc. The history of biological control of weeds, dates back to the seventeenth century and since then a great deal of success has been achieved in biological methods of weed/ pest control. In fact, the first unintentional outstanding success of biological control of prickly pear in India during 1795 by cochineal insect led the world to use natural enemies against exotic weeds (Sushilkumar, 1993; Singh, 2004).

Parasitoids are one of the most used biological control agents and the adult parasitoids lay their eggs singly or in groups into the body of the host insect stages (egg, larva and pupa). The egg/eggs of the parasitoid hatch inside the host body, and

their instars to feed on the fat bodies of the host until the parasitoid complete their life cycle, and later emerged as adult parasitoids, eventually killing the host. Few parasitoids live within their host bodies, the so-called endoparasitoids, while others feed on them from the outside, and hence are ectoparasitoids. We have solitary parasitoids (one per host) and gregarious parasitoids (many per host). Monophagous and polyphagous parasitoids, depending on how many different kinds of host a species can successfully attack (Gauld and Bolton, 1988).

Faunal studies of parasitoids constitute the major base lines upon which further applicative studies are based (Tomanovic et al., 2014; Petrovic et al., 2019). As many parasitoids are able to attack several host species or to specialize on a certain host species, their population dynamics depends on their hosts' abundance, and thus, they are of major importance in controlling pests (Hassell and May 1986; Barbosa, 1998). The studies related to comparison of abundance and diversity of parasitic hymenoptera in organic and inorganic rice fields are few (Agus et al., 2007; Gnanakumar et al., (2012) and Ovawanda et al., (2016).

Parasitic Hymenoptera is the most diverse group within the order, comprising 50% or more of the total described species (La Salle and Gauld, 1993), and comprises the major insect families viz. Braconidae, Ichneumonidae, Platygasteridae, Pteromalidae, Chalcididae, Mymaridae, Trichogrammatidae, Eulophidae, Euclyptidae, Eurytomidae, Eupelmidae, Elasmidae, Encyrtidae, Diapriidae, Bethyidae, Ceraphronidae, Aphelinidae, Evaniidae and Torymidae.

They are represented by nearly 25% of all arthropods in both temperate and tropical ecosystems (Stork, 1988), and one of the most important groups of biological control agents in the control of pest insect populations in agricultural systems, both by the natural occurrence of the species in the environment and by their use in classic biological control programs (Hanson and Gauld, 2006). They are more susceptible to extinction than phytophagous arthropods, and their loss can have highly destructive effects on ecological stability and community balance. Biodiversity in agricultural land has received growing attention because it plays a

significant role in agro-ecosystem function by keeping the pest populations under check (Jervis et al., 2007).

Braconidae is the second largest family of Hymenoptera, with about 46 subfamilies and nearly 20,000 valid species in the world (Yu et al., 2012). They are mostly parasitoids of larvae of Lepidoptera, Coleoptera and Diptera (Wharton, 1997). These parasitoids play a significant ecological role in controlling populations of other insects many of which could be damaging to agro-ecosystems if their numbers are not contained and is being applied increasingly in programs of biological control (Quick, 2015). Studies by Gauld and Bolton, (1996) noted that, the Braconidae shows significant specificity in host relationship at the level of subfamily and the success of them were reflected in their diversity of lifestyles.

The Ichneumonidae is one of the most species-rich families of all organisms with an estimated 60,000 species in the world (Townes, 1969), and according to Gauld (1991) many authorities regard this figure as an underestimate. They make use of a diverse array of insects and arachnids as their hosts and play an indispensable role in the normal functioning of most ecosystems, indicating the need to recording their diversity. They have been used successfully as biocontrol agents and given the largely undocumented fauna there is a huge potential for their utilization in managed biocontrol programmes (Gupta, 1991).

Platygastridae is the family under Super family Platygastroidea and the third largest superfamily of parasitic Hymenoptera (Austin et al., 2005) and has five subfamilies (Austin et al., 2005) namely, Telenominae, Teleasinae, Scelioninae, Sceliotrachelinae and Platygastrinae, out of which the first three, are exclusive egg parasitoids (Austin et al., 2005). Platygastridae is the most abundant family of parasitic Hymenoptera in rice ecosystems in southern India (Rajmohana, 2014; Shweta and Rajmohana 2015 a&b). Based on several studies of parasitic Hymenoptera from different habitats including paddy ecosystems, it has been observed that Scelioninae is the most abundant subfamily under Platygastridae Family (Rajmohana, 2014).

Pteromalidae is one of the sizeable and taxonomically difficult families of Chalcidoidea and are primary or secondary parasitoids attacking a wide range of insect under different orders in their various stages of development thereby playing a key role in the control of insect pests in agro-ecosystems (Sureshan, 2011). Most pteromalids parasitize various arthropods including insect pests, and have been exploited to control pests (Boucek and Rasplus, 1991).

The family Eulophidae is the largest family of super family Chalcidoidea consisting of 297 genera and 4472 species (Noyes, 2008). Several species of Eulophidae are important in biocontrol programs throughout the world (Noyes, 2008). They are promising parasitoids for the control of insect pests of agricultural importance all over the world. This family is ecologically and economically most significant and largest family consisting of about 350 genera and more than 3,000 species of parasitoids for controlling the herbivorous pests and the members of the family are promising parasitoids for the control of insect pests of agricultural importance all over the world and maintain the agro-eosystems. Noyes (2004) recorded that the Eulophidae was the largest family in the super family Chalcidoidea consisting of 297 genera and 4472 species, and among these 150 genera were found in the Indo-Australian region and about 60 genera in the Indian subcontinent (Narendran and Fousi, 2002).

Eurytomidae are a moderately large, cosmopolitan family (ca. 75 genera, 1,100 species). They attack Coleoptera, Hymenoptera, Diptera, Lepidoptera, and are mostly parasitoids with some facultative hyper parasitoids.

Chalcididae is a moderate sized, cosmopolitan family of 40 genera and 1,500 species. All species are parasitic, either primary or hyper parasitoids of Holometabola, particularly Lepidoptera and to a lesser extent Diptera, Coleoptera and other Hymenoptera. They are mainly hyper parasitoids of Tachinidae and parasitic Hymenoptera. Development is typically as solitary endoparasitoids of last instar larvae and pupae. The genus *Brachymeria* is used widely in biological control. Members of the family Chalcididae are generally beneficial endoparasites of several pests of economic importance and they play a notable role reducing the pest levels in

the ecosystems of various economically important crops and thus, their role cannot be underestimated (Cowan, 1979; Ubaidillah, 1996).

Mymaridae are a cosmopolitan, moderately large family (ca. 95 genera, 1,200 nominal species), and are small to minute, nonmetallic colored. Studies by Rajesh et al., (2019) reported the importance of mymarids in biological control and new distributional records of fairy flies in rice eco systems of Kerala.

Trichogrammatidae is a moderate sized (ca. 75 genera, 600 nominal species), cosmopolitan group, and are primary, solitary or gregarious endoparasitoids of host eggs. They display an extensive host spectrum that include Holometabola, Hemiptera and Thysanoptera orders and they are widely used in biological control programs.

The family Bethyridae is known as a group of primitive aculeate Hymenoptera (Brothers and Carpenter 1993), which is represented by 7 subfamilies, 97 genera and 2,216 species (Azevedo and Bruno, 2006; Lotfalizadeh et al., 2012). They are cosmopolitan, but majority of the species occur in tropical areas (Azevedo, 1999).

Ceraphronids are very small sized, dark bodied, nonmetallic wasps, and their biology is very rarely studied, but species apparently develop as endoparasitoids of larval Diptera such as Cecidomyiidae and their pupation occurs inside the mature larva. Few of their species attack thrips, Lepidoptera (larva & pupa), Chrysopidae and Coniopterygidae (Askew, 1971).

In this study, the variation in abundance and diversity of parasitic Hymenoptera in Kaipad and nearby Conventional rice fields is analysed.

REVIEW OF LITERATURE

Conventional agricultural practices have damaging effects on the environment, human health and food security, including pesticide contamination of food, insect pest resistance to insecticides and the harm they inflict on non-target organisms, including pollinators and beneficial insects (Adler and Hazzard, 2009),

resulting in a shift to alternative management strategies, namely biological control for insect pests (McCaffery, 1998).

Biological control using parasitoids is an alternative pest control method that is currently being developed to replace the role of pesticides that tend to harm the environment and public health. Yaherwandi (2012) reported that Practical and more logical methods of biological control were introduced to enhance the role of parasitoid complex through habitat management and it is necessary to maximize the role of hymenopterous parasitoids to control the insect pests in rice ecosystem. A large number of biocontrol agents were recorded on rice pests and many minor or sporadic pests were kept in check by the action of these biocontrol agents.

Biological control studies conducted earlier by Anonymous (2004) revealed that *Trichogramma japonicum* was promising for the control of leaf folder and stem borer in Kole rice cultivation. Lyla et al., (2010) through large scale release of *Trichogramma japonicum* against rice stem borer and leaf folder in Kole lands and conventional rice fields observed that dead heart and white ear head incidences were matched in the two systems of cultivation, but in the case of *Cnaphalocrocis medinalis* significantly lower incidence was observed.

Ueno (2012b) revealed that the insect natural enemies present in rice fields have a major role in rice production systems as agents of ‘ecosystem services’ because they play a key role in lowering pests and the abundance and diversity of natural enemies can be a good index reflecting the ‘healthiness’ of agro-ecosystem services in rice paddies. Several authors also mentioned that the beneficial organisms like natural enemies serve agro-ecosystem function by managing pest populations (Barbosa, 1998; Hajek, 2004; Jervis, 2005).

Biodiversity of such groups is a key resource to encourage the productivity and sustainability in rice fields, conservation of such individuals should be an important approach for sustainable rice production (Ueno, 2010; Ueno, 2012 a). Several studies have demonstrated that the presence of diverse species of natural enemies can enhance the control of pest populations through their complementary function (Kruess and Tschardtke, 1994; Bianchi et al., 2006; Crowder et al., 2010).

Of the natural enemies used in insect pest management, the parasitic hymenopterans have been the most successful bio-control agents (Noyes, 1985 and Greathead, 1986). Most of them attack the egg, larval or pupal stages of their hosts and they carry virulence and some other parasitic factors to modify hosts' physiology and immunity, to change hosts' metabolism, to destruct hosts' endocrine and reproductive structures, and finally kill the hosts for their own development (Pennacchio and Strand, 2006; Shi and Chen, 2015; Zhao et al., 2017; Gao et al., 2016).

Two significant families for biological control of rice pests are Eulophidae and Encyrtidae. For rice, Gurr et al., (2011) listed *Aprostocetus formosanus* (Timberlake, 1921) as parasitoids of Delphacidae in the Philippines, Vietnam, Malaysia and Thailand. Other authors have also reported Eulophidae species in rice crops (Nacro et al., 1997; Williams et al., 1999; Bayegan et al., 2015), and Gumovsky et al., (2006) described a new species of Eulophidae genus *Closterocerus*, parasitoid of *Diuraphis armigera* (Olivier, 1808), a major rice pest in Southeast Asia and Australia. Fritz et al., (2011) also recorded Eulophidae as the most abundant parasitoid family controlling Curculionidae, Pentatomidae, Delphacidae and Cicadellidae.

Shweta and Rajmohana (2016) noted that the members of the subfamily Scelioninae are known to parasitize mainly arthropod groups like Orthoptera, Hemiptera and spiders (Galloway and Austin 1984; Austin et al., 2005), and more than 75 percent of them have orthopterans as their hosts.

Mymaridae are known to attack mostly, Auchenorrhyncha (Hemiptera), and they also attack Coleoptera, Orthoptera and other Hemiptera (Hanson and Gauld, 2006). They were recorded as egg parasitoids of rice pests in Delphacidae family in Asia and Oceania (India, China, Japan, Malaysia, Singapore, Vietnam, Sri Lanka, the Philippines, Thailand, Korea, Taiwan, and Indonesia) (Gurr et al., 2011). All mymarids are egg parasitoids (Huber et al., 2009) and as reported earlier by Dupo and Barrion, 2009, the egg parasitoids attacking delphacid planthopper pests of rice are predominantly mymarids.

The members of the Family Trichogrammatidae are small with short development period and can parasitize over 300 species belonging to at least eight insect orders (Schmidt, 1994) they oviposit predominantly in the eggs of Lepidoptera (Huang and Gordh, 1998; Losey and Calvin, 1995) including a large number of important agricultural and forest pests (Dang et al., 2005; Hassan, 1993; Jalali and Singh, 1992). They represent a large group of minute parasitic wasps, which mainly attacks the eggs of Lepidoptera and of Hemiptera, Orthoptera and Thysanoptera (Goulet and Huber, 1993; Navik and Varshney, 2018). One of the most important genus which parasitize the eggs are *Trichogramma* with more than 230 species worldwide (Jalali et al., 2016). Among species of *Trichogramma* the most dominant and common species were *Trichogramma chilonis* Ishii, *T. japonicum* Ashmead, *T. achaeae* Nagaraja and Nagarkatti and *T. pretiosum* Riley (Lalitha et al., 2017).

Narendran et al., (2008) listed seven new species, *Elasmus alaris* Narendran, *E. bathyskius* Narendran, *E. caligneus* Narendran, *E. neoflavescens* Narendran, *E. neoflavocarpus* Narendran & Hema, *E. scutellofurvus* Narendran and *E. zatonus* Narendran & Sheeba) of the family Eulophidae from south-eastern Indian rice fields. Gurr et al., (2011) listed two eulophids, *Ootetrastichus* and *Tetrastichus* as parasitoids of Delphacidae hosts in the Philippines, Vietnam, Malaysia and Thailand.

According to an earlier study by Grissel and Schauff (1990), the majority of Chalcidoidea are parasitoids, attacking egg or larval stage of the host and with an important role in ecosystem. Noyes (2008) also studied that the superfamily Chalcidoidea (Hymenoptera) is a hyper-diverse group of insects and almost all species are parasitoids of insects, with many attacking economically important pests such as whiteflies, aphids, and scale insects.

Drechsler and Settele (2001) showed that parasitoids can play a major role in controlling hopper pests in rice agroecosystems (Cook and Perfect, 1989, Kenmore et al., 1984). Moreover, other studies found egg parasitism rates was higher in Southeast-Asian rice fields (Fowler et al., 1991; Nishida et al., 1976; Watanabe et

al., 1992), indicating high levels of biological control through egg parasitoids throughout Southeast Asia.

Ahangama and Gilstrap (2007) reported some hymenopteran parasitoids as the natural enemies of *S. incertulas* (Walker) in Sri Lanka. They also noticed that some parasitoids were controlling *O. oryzae* (Wood Mason) and *N. lugens* (Stal) in Sri Lanka. Perera et al., (2015) reported that biological control of *C. medinalis* was encouraged due to harmful effects of insecticide application on rice ecosystem in Sri Lanka, and they noted the presence of an egg parasitoid against *C. medinalis* in those rice fields.

In India, many studies were made to record the incidence of rice insect pests and their natural enemies in Andhra Pradesh (Rao and Ali, 1976), Gujarat (Pandya et al., 1995), Karnataka (Naganagoud et al., 1999), Bihar (Rai et al., 2000), Uttaranchal (Pushpakumari and Tiwari, 2005), Kerala (Ranjith et al., 2015; Rajesh et al, 2019), Pusa, Bihar (Shiriti Moses, 2018) and Tamil Nadu (Kathirvelu, 2019; Daniel et al., 2019; Daniel and Ramaraju, 2017 and 2019).

Yadav et al., (2018) conducted a survey in rice fields of Jharkhand and Parasappa et al., (2017) in different rice ecosystem of Cauvery command areas of Karnataka. They also noted that some of natural enemies were found throughout the crop growing period, some were more during the vegetative stage of the crop and reproductive stage of the crop.

Subharani et al., (2010) recorded many hymenopteran parasitoids from Manipur and Srivastava et al., (2015) reported a new larval parasitoid on *Dicladispa armigera* in Himachal Pradesh for the first time. Daniel and Ramaraju (2019), recorded several parasitic hymenopteran families from the high rainfall zone of rice tracts of Tamil Nadu. Chakraborty (2012) documented *Telonomus rowani*, Gahan, *Tetrastichus schoenobii*, Ferriere and *Trichogramma chilonis*, Ishii as egg parasitoids of *S. incertulas* from insecticide free paddy fields at Raiganj, Uttar Dinajpur, West Bengal.

A hymenopteran parasitoid survey conducted by Shweta and Rajmohana (2015b) in lawns of Kerala and Menon et al., (2016) reported eleven parasitoid families from rice fields of Palakkad district, Kerala. Ranjith et al., (2015) studied the diversity, abundance and host-parasitoid association of Microgastrine (Hymenoptera: Braconidae) wasps in rice fields of Kerala. Rajesh et al., (2019) reported new distributional records of fairyflies (Hymenoptera: Chalcidoidea: Mymaridae) from rice–agroecosystems of Kerala.

Several authors documented that many natural enemies of *N. lugens* were present in rice fields all the time (Chiu, 1979, Yasumatsu et al., 1983, Watanabe et al., 1992, Gurr et al., 2011). Sann et al., (2018 a&b) pointed out that the egg parasitoids were among the most important natural enemies of rice hoppers and might be promoted with effective habitat management.

Triapitsyn (2013) recorded the most common parasitoids of Auchenorrhyncha (Hemiptera) and noted that the families Mymaridae and Trichogrammatidae which represent egg parasitoids were mostly responsible for the biological control of leafhopper (Cicadellidae), Planthopper (Delphacidae), and treehopper (Membracidae) species including economically important pests.

Gurr et al., (2010) communicated that rice planthoppers were attacked by a large range of parasitoids from Strepsiptera, Diptera and, they listed out Dryinidae which is used as bio control agents against planthoppers in different parts of the World. They also reported that mymarid parasitoids are used to control planthoppers in Asian regions.

Rani et al., (2007) documented that, the egg parasitoids, larval parasitoids and Pupal parasitoids were prevalent in the rice ecosystem on rice leaf folders. Amongst hymenopterans *Cardiochiles philippinensis*, *Macrocentrus philippinensis*, *Brachymeria* spp., *Ischnojoppa luteator*, *Temelucha stangli*, *Trichomma cnapalocrocis* and *Trichogramma* spp. were considered particularly to be significant parasitoids of *C. medinalis* (Barrion et al., 1991). Guo and Zhao (1992) and de Kraker et al., (1999a and 1999b) noted that the normal larval densities of *C. medinalis* were usually well below three per hill as a result of natural biological

control. Manisegaran et al., (1997) reared seven parasitoids from natural population of rice leaf folder, *Cnaphalocrocis medinalis* (Guenee), and *Goniozus* sp. and *Elasmus johnstoni* Ferriere were the most effective. They also reported *Pediobius bruchicida* (Rondani) for the first time on *C. medinalis*. Rao (1964) and Abraham et al., (1973) reported seven parasitoid species associated with *Cnaphalocrocis medinalis* from India. Sangha et al., (2018) studied impact of Trichogrammatids against lepidopteran pests, *S. incertulas* (Walker) and *C. medinalis* (Guenee) in organic basmati rice and they suggested as a viable option for the ecofriendly management of key rice pests under organic farming. Earlier studies revealed that *Trichogramma japonicum* was good for the management of leaf folder and stem borer in rice (Anonymous, 2004) and in 1992, Rajendran also found that *T. japonicum* reduced the leaf folder incidence. *Trichogrammatoidea bactrae* Nagaraja was used against *C. medinalis*, and considered as an effective bio control agent (Perera et al., 2015).

Many studies were undertaken to identify effective control methods for *Orseolia oryzae* and biological control seems to be the most promising option of controlling them. Ogah et al., (2009) recorded that diverse complexes of bio control agents of *O. oryzae* were identified in Nigeria and other West African countries. Field surveys of natural enemies of *O. oryzae* reported the activities of *P. diplosisae* as an important bio-control agent (Umesh and Joshi, 1993; Ogah et al., 2009) and parasitism caused by these two parasitoids can reach as high as 77% of the immature populations of the pest (Ba, 2003; Ogah et al., 2009). Furthermore, Sriratanasak et al., (2007) also recorded that *Aprostocetus* sp. attacked pupae of the rice, *Orseolia oryzae* (Wood-Mason).

Several bio control agents of *Nilaparavata lugens* were always present in paddy fields especially *Anagrus* spp. (Hymenoptera: Mymaridae) and *Oligosita* spp. (Hymenoptera: Trichogrammatidae), and are the dominant parasitoids of *N. lugens* (Chiu, 1979; Yasumatsu et al., 1983; Watanabe et al., 1992; Gurr et al., 2011). *Ooencyrtus nezarae* Ishii, 1928 and *Xenoencyrtus niger* Riek, 1962 were introduced in the Neotropics as the parasitoids of Pentatomidae eggs (Hanson and

Gauld, 2006). The genera *Telenomus* and *Trissolcus*, in the Platygasteridae are important biological control agents of Pentatomidae in rice crops (Maciel et al., 2007; Riffel et al., 2010).

Pathak and Khan (1994) and Gurr et al., (2011) reported that *Ootetrastichus* and *Tetrastichus* were egg parasitoids of *N. lugens* and *Sogatella furcellata* (Horvath) and distributed in many countries including Thailand. Vungsilabutr et al., (2002) and Sriratanasak et al., (2007) reported that *Tetrastichus* sp is a significant ectoparasitoid that parasitized *N. lugens* eggs.

Gumovsky et al., (2006) described a new species, *Closterocerus oryzamyntor* Gumovsky & Zhu, a larval endoparasitoid of *Dicladispa armigera*. Srivastava et al., (2015) reported another eulophid, *Chrysonotomyia* species as larval parasitoid on *D. armigera* in Himachal Pradesh for the first time, and it was earlier reported from Bangladesh and West Bengal along with another species *Bracon hispae* (Bhattacharyya et al., 2000). Several workers reported the association of many hymenopteran parasitoids with eggs and grubs of *D. armigera*. Bhattacharyya et al., (2000) also reared *Bracon hispae* and *Chrysonotomyia* sp. from the larvae of *D. armigera*. Bhattacharjee and Ray (2010) also reared *Bracon hispae* and *Chrysonotomyia* sp. from the grubs of *D. armigera*. Polaszek et al., (2002) reported and described *Trichogramma zahiri* Polaszek from *Dicladispa armigera* for the first time.

Tang et al., (2017) assessed two *Trichogramma* species for their effectiveness against *S. incertulas* and suggested potentially higher effectiveness on their eggs after at least one generation on the target host.

On a global scale, of the 6 species of egg parasitoids reported from black bugs on rice, 3 species belong to *Telenomus*: *T. triptus* Nixon, *T. chloropus* (Thomson, 1860) and *T. gifuensis* Ashmead, 1937 (Polaszek and Rajmohana, 2007) and further *Telenomus oryzae* was reported from Kerala and Tamil Nadu (Rajmohana and Nisha, 2013).

Way and Heong, (1994) stated that, in most instances, the species richness and abundance of natural enemy population may be greater than that of the pest populations, when little or no insecticides were used.

Kandibane et al., (2006) compared the abundance and diversity of hymenopteran parasitoids in weeded and partially weeded rice fields. They noticed the similarity of parasitoids was found to be less during tillering and flowering stages of the crop (third, fourth, fifth, and sixth week) and the weed plants present in partially weeded rice plot provided pollen and nectar, which was more useful to conserve parasitoids when the population of herbivores was low.

Anonymous (2002) reported that the egg parasitoids such as *Trichogramma* sp. were widely utilized as biocontrol agents and the hymenopterous egg parasitoids; *Oligosita* sp. and *Anagrus* sp. performed 29-91% control of brown planthoppers (Claridge et al., 1999). Abudulai and Shepard (2003) also noted that those parasitoids parasitized on a variety of hosts, killing more pests than commercial insecticides do.

Karthikeyan et al., (2007) observed that egg parasitism is effective in the biological suppression of *S. incertulas* (Walker) and *C. medinalis* (Guenee) in rice and they summarised that the release of egg parasitoids not only reduces the infestation by stem borer and leaf folder but also increases grain yield, indicating their high efficacy in rice pest management. Nadeem and Hamed (2011) noted the egg parasitoids *Tetrastichus schoenobii*, *Telenomus rowani*, *Telenomus dignus*, and *Trichogramma japonicum* as biological control agents and were widely distributed in the rice field and *Trichogramma* can survive at a wide range of temperature and can successfully manage lepidopteran pests of many crops.

Yasumatsu et al., (1975) reported four mymarid parasites viz., *Anagrus optabilis* (Perkins), *Mymar taprobanicum* Ward, *Polynema* sp. and, *Gonatocerus* sp., which contributed much in the reduction of plant hoppers in Thailand in rice ecosystem.

Studies by several authors demonstrated enhanced insect pest control in the presence of diverse species of parasitoids through their complementary function (Kruess and Tscharntke, 1994; Bianchi et al., 2006; Crowder et al., 2010). Noyes (1982) reported that, inspite of their importance, our understanding of their diversity is clearly insufficient, partly because of their small size and difficulty in collection and study. Therefore, biodiversity surveys will enable the identification of hotspots of species richness (Graham, 1987).

The comparative studies on Parasitic hymenoptera abundance and diversity in Organic and Inorganic rice fields are scanty, and no studies on parasitoids of Kaipad rice fields have been undertaken. Earlier studies by Agus et al., (2007) observed that the diversity of natural enemies community, comprising Parasitic hymenoptera were higher in organic agroecosystem than in conventional one. They also added that the Species diversity and community structure of parasitic hymenoptera were more complex in organic than conventional agroecosystems and the most abundant Hymenopteran parasitoids in organic and Conventional agroecosystems were Ichneumonids, Braconids and Scelionids. Gnanakumar et al., (2012) reported the organic rice fields contained more species of hymenopteran egg parasitoids than the conventional rice fields. The studies by Ovawanda et al., (2016) also noted that higher species richness of hymenopteran parsitoids were reported from non-organic rice fields during Augut- May.

The loss of non-crop habitats, habitat fragmentation and detrimental effects of pesticides on non-target organisms (Crowder and Harwood, 2014;Tscharntke et al., 2007) can cause fall off of bio control agents leading to a depletion in biological pest control (Bianchi et al., 2006; Thies et al., 2011).

Limited number studies are there regarding the abundance and diversity of parasitic hymenoptera in rice agro ecosystems of Kerala. The present study is the first of its kind on the presence and distribution of hymenopteran parasitoids in Kaipad rice fields.

MATERIALS AND METHODS

Area of the study

12 rice fields were selected for insect pest survey, in which 6 were Kaipad rice fields and other 6 are conventional rice fields. The Kaipad rice fields were selected from Ezhome (12°01'59.6"N 75°17'30.7"E), Munderi Kadavu (11°56'13.0"N 75°25'48.5"E), Kaitheel (12°00'04.6"N 75°19'22.2"E), Vellikkeel (11°59'52.1"N 75°20'18.0"E), Mullool (12°00'44.4"N 75°19'30.3"E), and Pattuvam (12°00'58.6"N 75°18'23.0"E).

The conventional rice fields were located in Kaively (12°03'01.0"N 75°19'40.7"E), Munderimotta (11°56'13.2"N 75°26'52.6"E), Keezhara (12°00'00.5"N 75°19'35.1"E), Periyadu (11°59'48.3"N 75°20'48.8"E) and Kuthirappuram (12°00'53.6"N 75°19'32.4"E) and Mangalassery (Kavungal) (12°01'45.2"N 75°19'06.1"E) of Kannur district.

Time of the study

The present study was carried out for five months (June, July, August, September and October) for three years (2015, 2016 and 2017) during the rice cultivating seasons in Kaipad and other nearby Conventional rice fields.

Materials of the study

Insect Sweep net: Insect Sweep nets are made up of a triangle frame with diamension of (58 cm x 58 cm x 42 cm), and very small mesh size used to collect the hymenoptera parasitoids. This triangle frame is attached to a telescopic or simple handle made of steel or aluminum. Instead of round frame, the triangle frame has more area of contact with the surface. And it is better to prefer aluminium framed and handled sweep net than the one with steel frame and handle to reduce weight during transportation.

Aspirator: It is a device used to collect small insects made up of glass or plastic vial. The basic design of an aspirator includes a vial (plastic or glass) and a tight fitting rubber cork, rubber stopper, or other cap with two metal tubes running

through it. One of the tubes has a rubber hose several inches long connected to it and a piece of fine mesh affixed to the other end of the tube by tying the same inside of the vial. To collect hymenopteran parasitoids, one sucks air through the rubber hose and points the other end of the tube on the insect and the insect is sucked into the vial. Because the end of the tube that is used to draw air through has mesh over its end, insects in the vial are not sucked into our mouth.

Collection vials: The clear glass/plastic vials were used to collect the aspirated hymenopteran parasitoids, and are perfect for collecting small insects like parasitoids.

Compound Microscope: In the present study compound microscopes were used to sort out the parasitic hymenoptera from collected sample vials. The sorted parasitoids were transferred singly to eppendorf tube which filled with 70% alcohol.

Stereo Microscope: The stereo microscopes used for this study were Leica S8 APO Stereo zoom trinocular microscope (Leica, Heerburg, Switzerland) with 1–8x magnification and Leica M205A with DMC2900 camera. Multiple images with different focal levels were combined into a single image using Leica Automontage Software V4.7. Images were edited in Adobe Photoshop CS3 to remove artifacts formed during stack processing.

DSLR Camera: The field photographs of insects were taken using Canon 700D with 18-55mm and 55-250mm lens.

Methods of the study

In Conventional rice fields, the sweeping was done 25 meter along the bunds of rice field and 3 meter inside from edges. In Kaipad rice fields, during early months the sweeping was done on 10 “Koonas” in the four corners and during later months the sweeping was done for 25-meter-along the bunds of rice fields and 3 meter inside from edges. During sweeping, swept once in the figure of eight, and after locking the sweep net, the trapped insects were collected using an aspirator. A primary sorting for the aspiration of hymenopteran parasitoids were done from the sweep net itself, later they were transferred into the labeled collection bottles containing 70% alcohol. The collected specimens were brought to the laboratory,

later sorted in to the separate families using compound / stereo zoom microscope. The sorted parasitoids/ morphospecies were transferred in to separate labeled eppendorf tubes/ glass vials which contains 70% alcohol. During mounting, the parasitoids were dried and card mounted on rectangular point cards using water soluble glue for further identification process. Hexamethyl disilazane (HMDS) was employed as the drying agent during mounting. The entomological pins (Size: 3) purchased from ENTO SPHINX s.r.o, Hostovická, Czech Republic were used for the mounting. Mounted specimens with appropriate labels were stored in wooden insect box. Naphthalene balls and Para- dichlorobenzene were fixed in insect box to reduce the attack of entomophagous insects and fungi. Insect identification was carried out up to Genus/species level with help of experts in various institutes. The photographs of identified parasitoids were taken using Leica M205A with DMC2900 camera from Biosystematics laboratory, Department of Zoology, Malabar Christian College, Kozhikode. Multiple images with different focal levels were combined into a single image using Leica Auto montage Software V4.7. Images were edited in Adobe Photoshop CS3 to remove artifacts formed during stack processing.

Data analysis:

We used generalized linear model to study the effect of rice field type on the parasitoid abundance. We did that for Insect parasitoid guilds (Egg, Larval, Pupal and Overall parasitoids), and individual insect parasitoid species of every reported families. We took Rice field type as the independent variable and insect parasitoid abundance of the respective group (Insect parasitoid guilds, Overall parasitoids, and each insect parasitoid species) as the dependent variable. We used Poisson distribution as the error factor, and log as a link function. The significance of the model was checked using one One-Way ANOVA using the R package *car*.

The dominance and diversity indices of insect parasitoid species in Conventional and Kaipad rice fields during different months and Years are calculated using the statistical software PAST 3.22 version (Paleontological Statistics software package for education and data analysis) (Hammer et al., 2001);

and the Simpson's Dominance index, Simpson's diversity index, and Shannon's diversity index are checked.

RESULTS:

The hymenopteran parasitoids recorded from Conventional and Kaipad rice fields during the present study are given in the Tab. 3.1.

Tab. 3.1: The hymenopteran parasitoids reported from Kaipad and Conventional rice fields

Sl.No	Parasitoid species	Family	Rice field type
1	<i>Goniozus</i> sp.	Bethylidae	Both
2	<i>Aleiodes</i> sp.	Braconidae	Both
3	<i>Amyosoma chinensis</i> (Szépligeti, 1902)	Braconidae	Both
4	<i>Apanteles</i> sp.	Braconidae	Both
5	<i>Apanteles</i> sp.1	Braconidae	Both
6	<i>Apanteles</i> sp.2	Braconidae	Conventional only
7	<i>Aspidobracon noyesi</i> van Achterberg, 1984	Braconidae	Both
8	<i>Aspidobracon</i> sp.	Braconidae	Both
9	<i>Bracon brevicornis</i> Wesmael, 1838	Braconidae	Both
10	<i>Bracon</i> sp.	Braconidae	Both
11	<i>Bracon</i> sp.1	Braconidae	Conventional only
12	<i>Bracon</i> sp.2	Braconidae	Conventional only
13	<i>Cardiochiles</i> sp.	Braconidae	Both
14	<i>Chelonus</i> sp.	Braconidae	Both
15	<i>Cotesia</i> sp.	Braconidae	Both
16	<i>Cotesia</i> sp.1	Braconidae	Both
17	<i>Dacnusine</i> sp.	Braconidae	Conventional only
18	<i>Dolichogenidea</i> sp.	Braconidae	Both
19	<i>Dolichogenidea</i> sp. 1	Braconidae	Conventional only
20	<i>Exoryza schoenobii</i> Wilkinson, 1932	Braconidae	Both
21	<i>Exoryza</i> sp.	Braconidae	Both
22	<i>Glyptapanteles</i> sp.	Braconidae	Both
23	<i>Gnamtodon</i> sp.	Braconidae	Both
24	<i>Macrocentrus philippinensis</i> Ashmead	Braconidae	Conventional only

25	<i>Macrocentrus</i> sp.	Braconidae	Both
26	<i>Microplitis</i> sp.	Braconidae	Both
27	<i>Myosoma</i> sp.	Braconidae	Both
28	<i>Opiine</i> sp.	Braconidae	Conventional only
29	<i>Opiine</i> sp.1	Braconidae	Both
30	<i>Opiine</i> sp.2	Braconidae	Both
31	<i>Opiine</i> sp.3	Braconidae	Both
32	<i>Orgilonia ashmeadi</i> (Viereck, 1911)	Braconidae	Both
33	<i>Parapanteles</i> sp.	Braconidae	Both
34	<i>Scutibracon</i> sp.	Braconidae	Conventional only
35	<i>Rhaconotus</i> sp.	Braconidae	Kaipad only
36	<i>Tropobracon luteus</i> Cameron, 1905	Braconidae	Both
37	<i>Ceraphron</i> sp.	Ceraphronidae	Both
38	<i>Aphanogamus</i> sp.	Ceraphronidae	Both
39	<i>Antrocephalus phaeospilus</i> Waterston, 1922	Chalcididae	Both
40	<i>Antrocephalus</i> sp.	Chalcididae	Both
41	<i>Brachymeria excarinata</i> Gahan, 1925	Chalcididae	Both
42	<i>Brachymeria jambolana</i> Gahan, 1942	Chalcididae	Both
43	<i>Brachymeria lasus</i> (Walker, 1841)	Chalcididae	Both
44	<i>Brachymeria nephantidis</i> Gahan, 1930	Chalcididae	Both
45	<i>Brachymeria</i> sp.	Chalcididae	Both
46	<i>Dirhinus anthracia</i> Walker 1846	Chalcididae	Conventional
47	<i>Hockeria aligharensis</i> Roy & Farooqi, 1984	Chalcididae	Both
48	<i>Hockeria</i> sp.	Chalcididae	Conventional only
49	<i>Kriechbaumerella pulvinata</i> (Masi, 1932)	Chalcididae	Conventional only
50	<i>Aprostocetus</i> sp.	Eulophidae	Both
51	<i>Aprostocetus uthonia</i> Narendran	Eulophidae	Conventional
52	<i>Asecodes</i> sp.	Eulophidae	Conventional
53	<i>Chrysonotomyia</i> sp.	Eulophidae	Both
54	<i>Derostenoides</i> sp.	Eulophidae	Conventional
55	<i>Elasmus hyblaeae</i> Ferriere	Eulophidae	Conventional only
56	<i>Elasmus</i> sp.	Eulophidae	Both

57	<i>Elasmus viridiscutellatus</i> Verma et Hayat, 2002	Eulophidae	Conventional only
58	<i>Elasmus zatonus</i> Narendran&Sheeba, 2008	Eulophidae	Conventional only
59	<i>Entedon</i> sp.	Eulophidae	Conventional
60	<i>Euplectrus</i> sp.	Eulophidae	Both
61	<i>Hemiptarsenus</i> sp.	Eulophidae	Conventional
62	<i>Minotetrastichus</i> sp.	Eulophidae	Conventional
63	<i>Neotrichoporoides</i> sp.	Eulophidae	Conventional
64	<i>Omphale</i> sp.	Eulophidae	Kaipad
65	<i>Pediobius</i> sp.	Eulophidae	Both
66	<i>Quadrastichus dicleus</i> Narendran, 2007	Eulophidae	Conventional
67	<i>Stenomesus</i> sp.	Eulophidae	Conventional
68	<i>Tetrastichus paraponyxi</i> Santhosh	Eulophidae	Kaipad
69	<i>Tetrastichus schoenobii</i>	Eulophidae	Both
70	<i>Tetrastichus sissoo</i> Khan, Agnihotri & Sushil, 2005	Eulophidae	Conventional
71	<i>Tetrastichus</i> sp.	Eulophidae	Both
72	<i>Anastatus</i> sp.	Eupelmidae	Both
73	<i>Eupelmus</i> sp.	Eupelmidae	Conventional only
74	<i>Neanastatus</i> sp.	Eupelmidae	Both
75	<i>Eurytoma</i> sp.	Eurytomidae	Both
76	<i>Anomalon</i> sp.	Ichneumonidae	Both
77	<i>Atropha</i> sp.	Ichneumonidae	Both
78	<i>Atropha</i> sp1.	Ichneumonidae	Conventional only
79	<i>Caenopimpla</i> sp.	Ichneumonidae	Conventional only
80	<i>Caenopimpla</i> sp1.	Ichneumonidae	Conventional only
81	<i>Casitaria pedunculata</i> (Szepligeti, 1908)	Ichneumonidae	Both
82	<i>Casitaria</i> sp.	Ichneumonidae	Conventional only
83	<i>Charops bicolor</i> (Szepligeti, 1906)	Ichneumonidae	Both
84	<i>Charops</i> sp.	Ichneumonidae	Both
85	<i>Diadegma</i> sp.	Ichneumonidae	Both
86	<i>Goryphus</i> sp.	Ichneumonidae	Both
87	<i>Gotra</i> sp.	Ichneumonidae	Both
88	<i>Ishnojoppa</i> sp.	Ichneumonidae	Both
89	<i>Isotima</i> sp.	Ichneumonidae	Both
90	<i>Javra</i> sp.	Ichneumonidae	Both

91	<i>Leptobatopsis indica</i> (Cameron, 1897)	Ichneumonidae	Both
92	<i>Leptobatopsis</i> sp.	Ichneumonidae	Both
93	<i>Lusius</i> sp.	Ichneumonidae	Both
94	<i>Menaforia</i> sp.	Ichneumonidae	Both
95	<i>Pristomerus</i> sp.	Ichneumonidae	Both
96	<i>Scenocharops</i> sp.	Ichneumonidae	Both
97	<i>Sinophorus</i> sp.	Ichneumonidae	Conventional only
98	<i>Skeatia</i> sp.	Ichneumonidae	Both
99	<i>Temelucha</i> sp.	Ichneumonidae	Both
100	<i>Theronia</i> sp.	Ichneumonidae	Both
101	<i>Trathala flavoorbitalis</i> (Cameron, 1907)	Ichneumonidae	Both
102	<i>Trathala</i> sp.	Ichneumonidae	Both
103	<i>Xanthopimpla flavolineata</i> Cameron, 1907	Ichneumonidae	Both
104	<i>Xanthopimpla punctata</i> (Fabricius, 1781)	Ichneumonidae	Both
105	<i>Xanthopimpla</i> sp.	Ichneumonidae	Both
106	<i>Anagruss</i> sp.	Mymaridae	Both
107	<i>Gonatocerus aegyptiacus</i> Soyka, 1950	Mymaridae	Both
108	<i>Gonatocerus longicornis</i> Nees 1834	Mymaridae	Both
109	<i>Gonatocerus meghalayensis</i> Nees von Esenbeck, 1834	Mymaridae	Conventional only
110	<i>Gonatocerus shamimi</i> Subba Rao & Hayat, 1986	Mymaridae	Both
111	<i>Lymaenon aureus</i> Girault, 1911	Mymaridae	Both
112	<i>Lymaenon delhiensis</i> Narayanan & Subba Rao, 1961	Mymaridae	Conventional only
113	<i>Lymaenon munnarus</i> Walker	Mymaridae	Both
114	<i>Lymaenon narayani</i> Subba Rao & Kaur, 1959	Mymaridae	Conventional only
115	<i>Mymar schwanni</i> Girault, 1912	Mymaridae	Conventional only
116	<i>Mymar</i> sp.	Mymaridae	Conventional only
117	<i>Mymar taprobanicum</i> Ward, 1875	Mymaridae	Both
118	<i>Baryconus</i> sp.	Platygastridae	Kaipad only
119	<i>Calliscelio</i> sp.	Platygastridae	Both
120	<i>Cremastobaeus</i> sp.	Platygastridae	Both

121	<i>Duta indica</i> Mukerjee, 1994	Platygastridae	Conventional only
122	<i>Duta</i> sp.	Platygastridae	Both
123	<i>Fusicornia</i> sp.	Platygastridae	Both
124	<i>Greyon</i> sp.	Platygastridae	Both
125	<i>Habroteleia</i> sp.	Platygastridae	Conventional only
126	<i>Idris</i> sp.	Platygastridae	Both
127	<i>Macroteleia</i> sp.	Platygastridae	Both
128	<i>Odontocolus</i> sp.	Platygastridae	Conventional only
129	<i>Opisthacantha</i> sp.	Platygastridae	Both
130	<i>Palpoteleia</i> sp.	Platygastridae	Both
131	<i>Paratelenomus</i> sp.	Platygastridae	Conventional only
132	<i>Paridris</i> sp.	Platygastridae	Both
133	<i>Platygaster</i> sp.	Platygastridae	Both
134	<i>Probaryconus</i> sp.	Platygastridae	Both
135	<i>Psillanteris</i> sp.	Platygastridae	Conventional only
136	<i>Scelio</i> sp.	Platygastridae	Both
137	<i>Synopeas</i> sp.	Platygastridae	Both
138	<i>Telenomus</i> sp.	Platygastridae	Both
139	<i>Trimorus</i> sp.	Platygastridae	Both
140	<i>Trissolcus</i> sp.	Platygastridae	Both
141	<i>Callitula anguloclypea</i> Sureshan, 2002	Pteromalidae	Conventional only
142	<i>Callitula peethapada</i> Narendran & Mohana, 2001	Pteromalidae	Both
143	<i>Callitula</i> sp.	Pteromalidae	Conventional only
144	<i>Callitula travancorensis</i> Sureshan 2002	Pteromalidae	Conventional only
145	<i>Notoglyptus scutellaris</i> (Dodd & Girault, 1915)	Pteromalidae	Both
146	<i>Notoglyptus</i> sp.	Pteromalidae	Conventional only
147	<i>Panstenon</i> sp.	Pteromalidae	Both
148	<i>Propicroscytus mirificus</i> (Girault, 1915)	Pteromalidae	Both
149	<i>Propicroscytus oryza</i> (Subba Rao, 1973)	Pteromalidae	Both
150	<i>Propicroscytus</i> sp.	Pteromalidae	Conventional only
151	<i>Trichomalopsis acarinata</i> Sureshan & Narendran, 2001	Pteromalidae	Both
152	<i>Trichomalopsis apanteloctena</i> (Crawford, 1911)	Pteromalidae	Both

153	<i>Trichomalopsis neelagastra</i> Sureshan and Narendran, 2001	Pteromalidae	Both
154	<i>Trichomalopsis nigra</i> Sureshan and Narendran, 2001	Pteromalidae	Conventional only
155	<i>Trichomalopsis ovigastra</i> Sureshan and Narendran, 2001	Pteromalidae	Both
156	<i>Trichomalopsis</i> sp.	Pteromalidae	Both
157	<i>Trichomalopsis thekkadiensis</i> Sureshan and Narendran, 2001	Pteromalidae	Both
158	<i>Trichomalopsis travancorensis</i> Sureshan and Narendran, 2001	Pteromalidae	Both
159	<i>Trichomalus kannurensis</i> Sureshan and Narendran, 2001	Pteromalidae	Both
160	<i>Trichomalus</i> sp.	Pteromalidae	Conventional only
161	<i>Chaetostricha</i> sp.	Trichogrammatidae	Both
162	<i>Lathromeroidea</i> sp.	Trichogrammatidae	Conventional only
163	<i>Oligosita</i> sp.	Trichogrammatidae	Both
164	<i>Trichogramma achaeae</i> Nagaraja & Nagarkatti, 1970	Trichogrammatidae	Kaipad only
165	<i>Trichogramma chilonis</i> Ishii, 1941	Trichogrammatidae	Both
166	<i>Trichogramma hebbalensis</i>	Trichogrammatidae	Both
167	<i>Trichogramma japonicum</i> Ashmead, 1904	Trichogrammatidae	Both
168	<i>Trichogramma</i> sp.	Trichogrammatidae	Both
169	<i>Trichogrammatoidea bactrae</i> Nagaraja 1979	Trichogrammatidae	Both
170	<i>Trichogrammatoidea</i> sp.	Trichogrammatidae	Both
171	<i>Tumidiclava</i> sp.	Trichogrammatidae	Both

The most abundant family in Conventional rice fields during 2015 was Platygasteridae (26%), followed by Eulophidae (19%), Pteromalidae (18%) and Braconidae (15%), and the less dominant families were Ceraphronidae and Eupelmidae (Fig. 3.1).

PLATE XVII

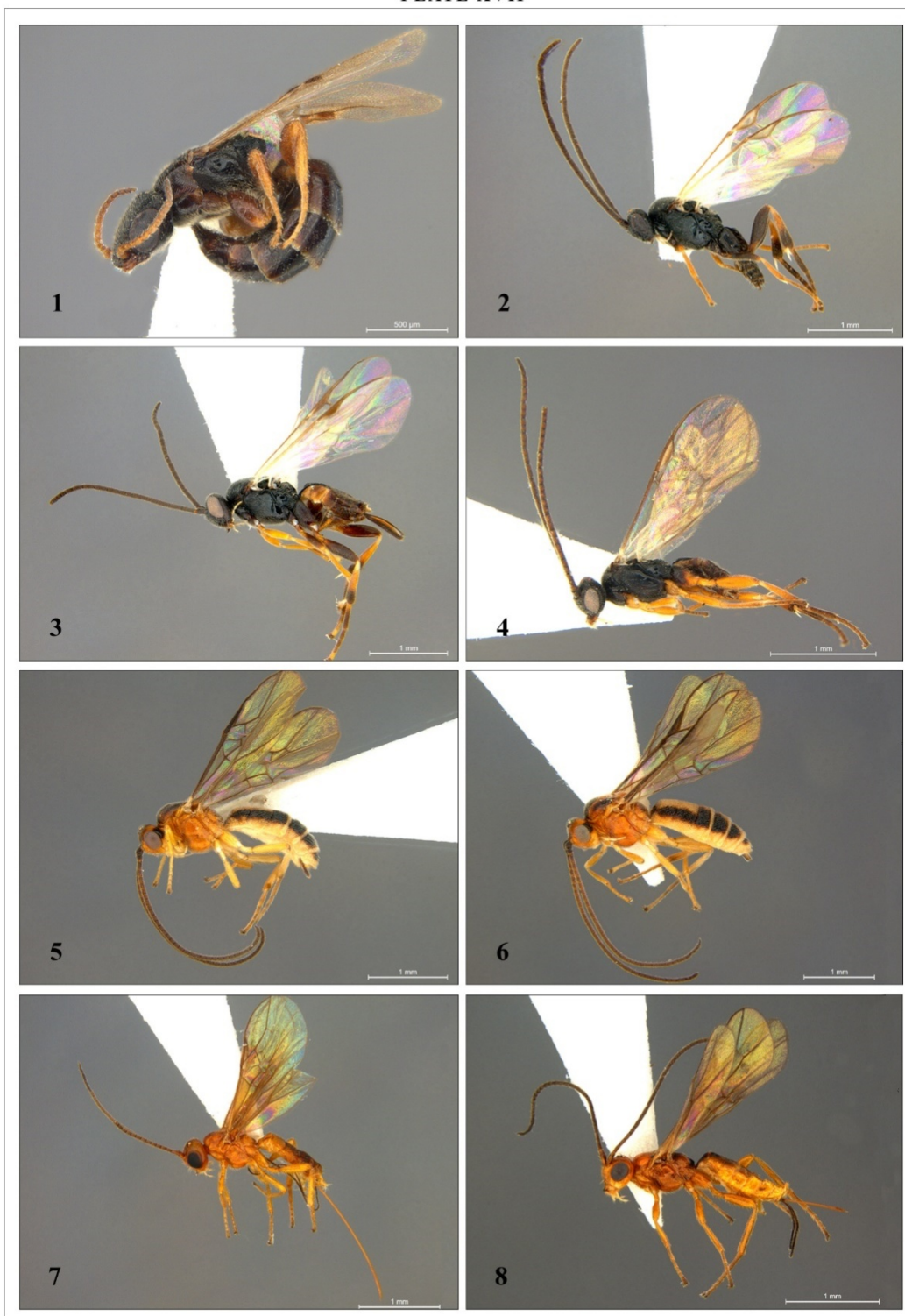
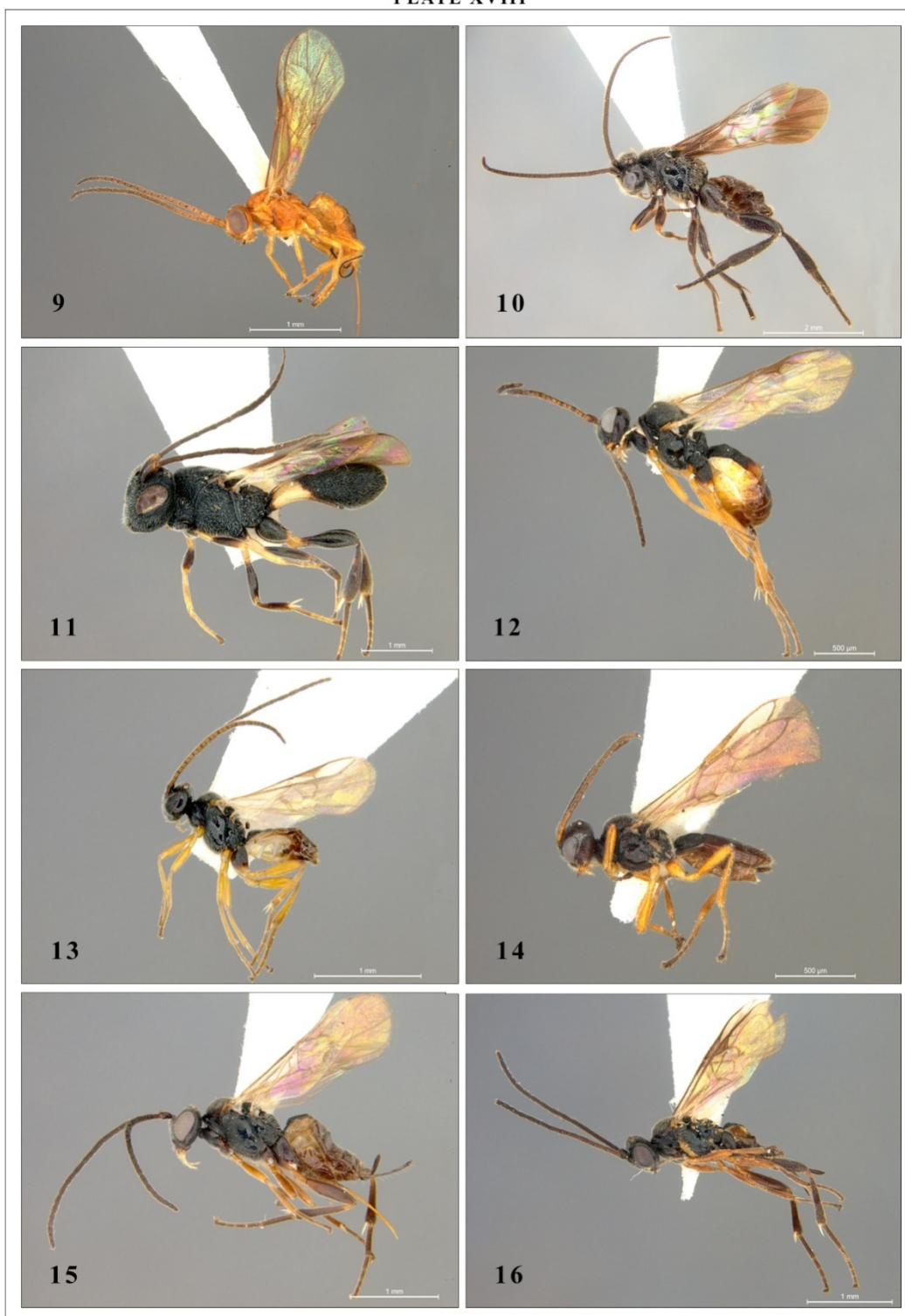


FIG.1. FAM. BETHYLIDAE. 1. *Goniozus* sp.

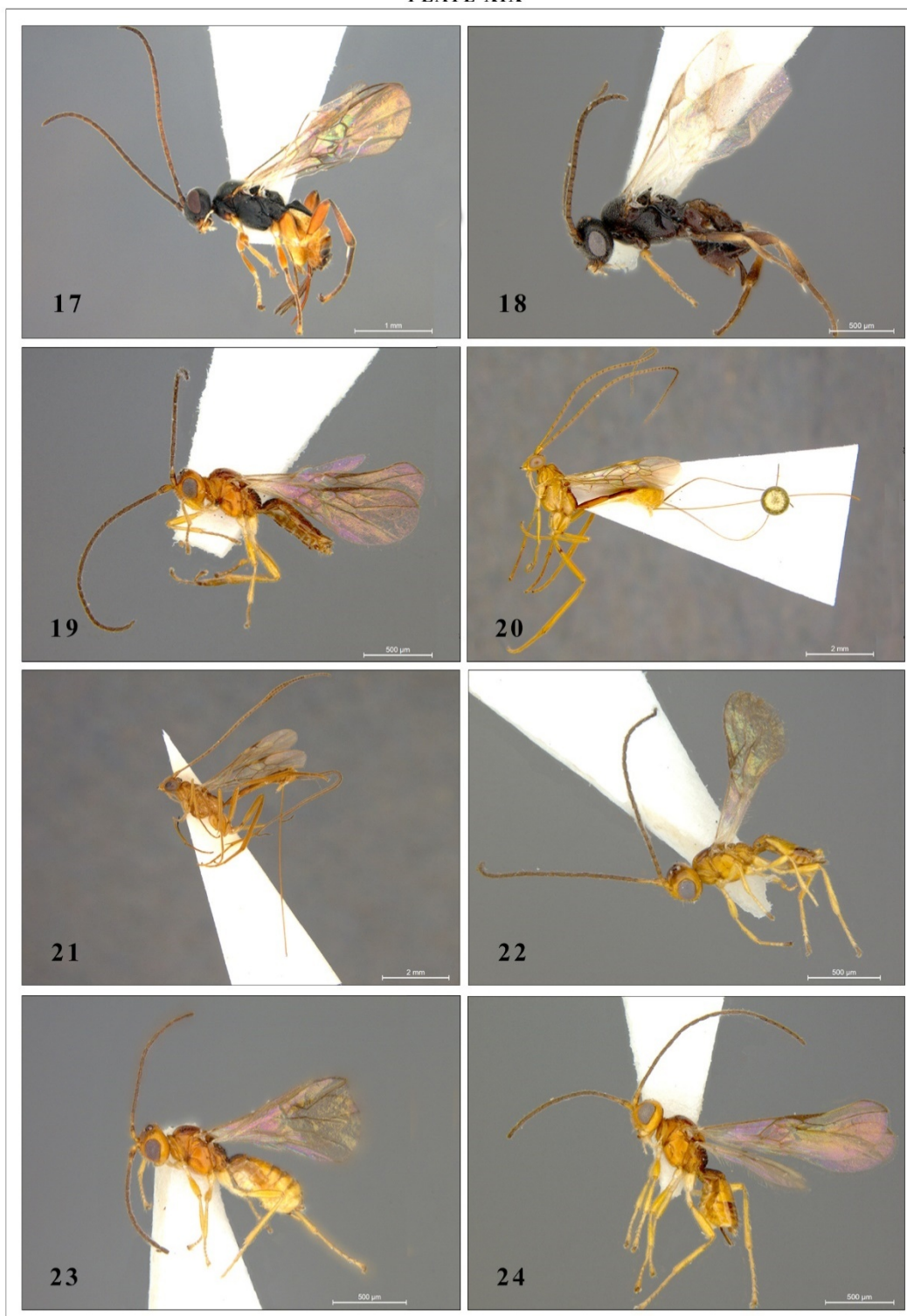
FIGS 2–8. FAM. BRACONIDAE. 2. *Apanteles* sp.; 3. *Apanteles* sp.1; 4. *Apanteles* sp.2;
5. *Aspidobracon noyesi* van Achterberg; 6. *Aspidobracon* sp.; 7. *Bracon* sp.; 8. *Bracon* sp.1

PLATE XVIII



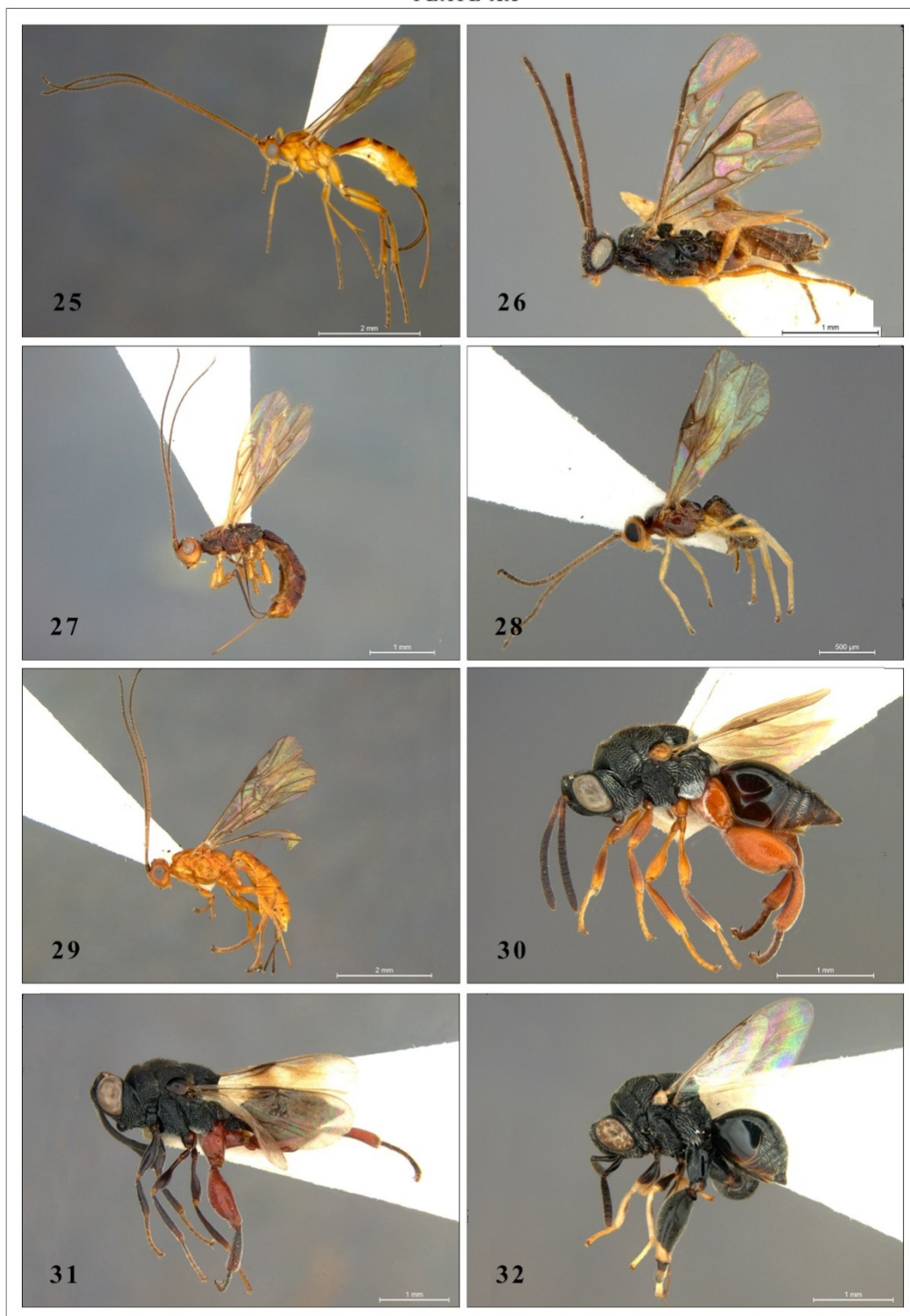
FIGS 9–16. FAM. BRACONIDAE. 9. *Bracon* sp. 2; 10. *Cardiochiles* sp.; 11. *Chelonus* sp.; 12. *Cotesia* sp.; 13. *Cotesia* sp. 1; 14. *Dacnusine* sp.; 15. *Dolichogenidea* sp.; 16. *Dolichogenidea* sp. 1

PLATE XIX



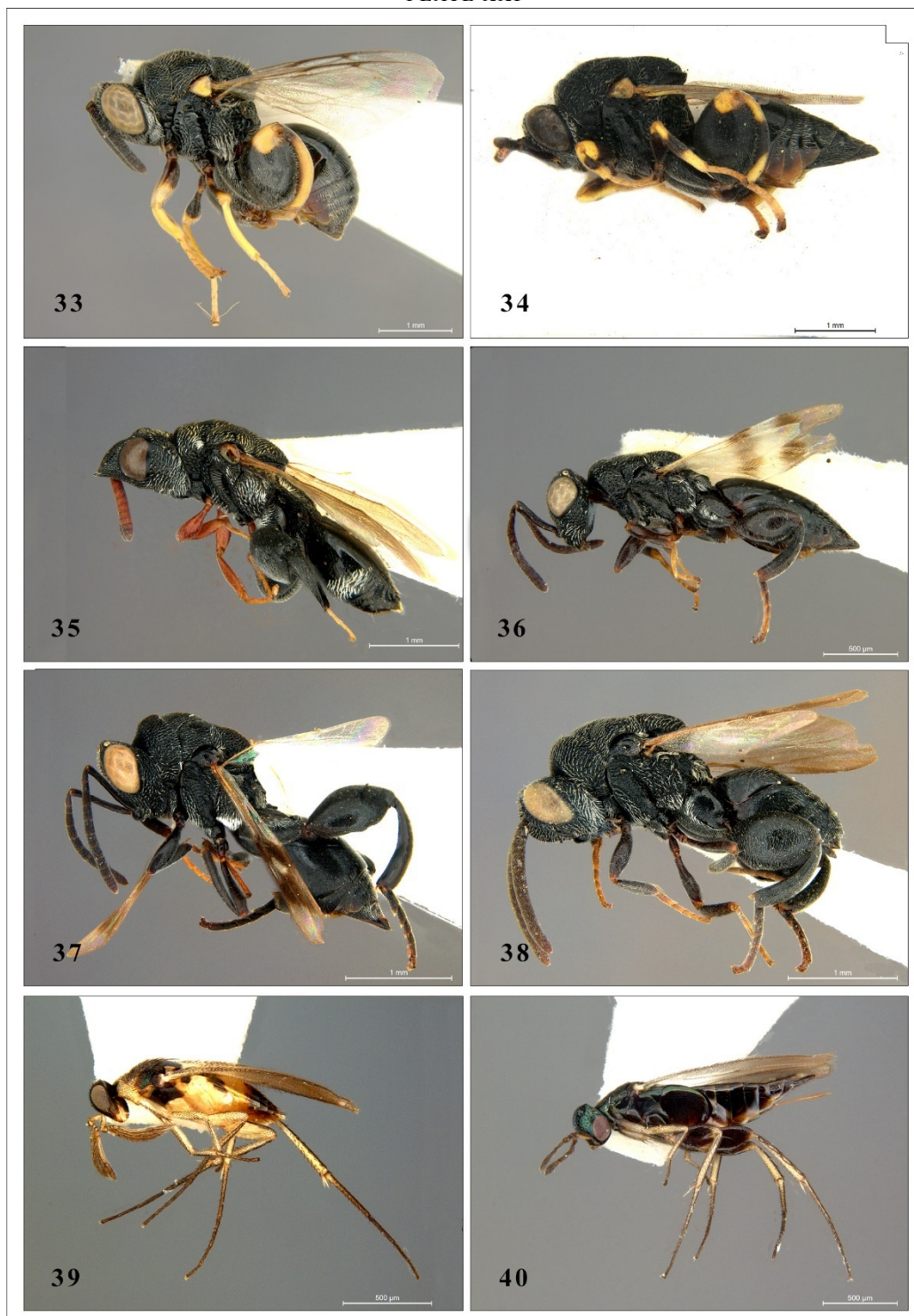
FIGS 17–24. FAM. BRACONIDAE. 17. *Exoryza schoenobii* Wilkinson; 18. *Glyptapanteles* sp.; 19. *Gnamtodon* sp.; 20. *Macrocentrus philippinensis* Ashmead.; 21. *Macrocentrus* sp.; 22. *Opiine* sp.; 23. *Opiine* sp.1; 24. *Opiine* sp.2

PLATE XX



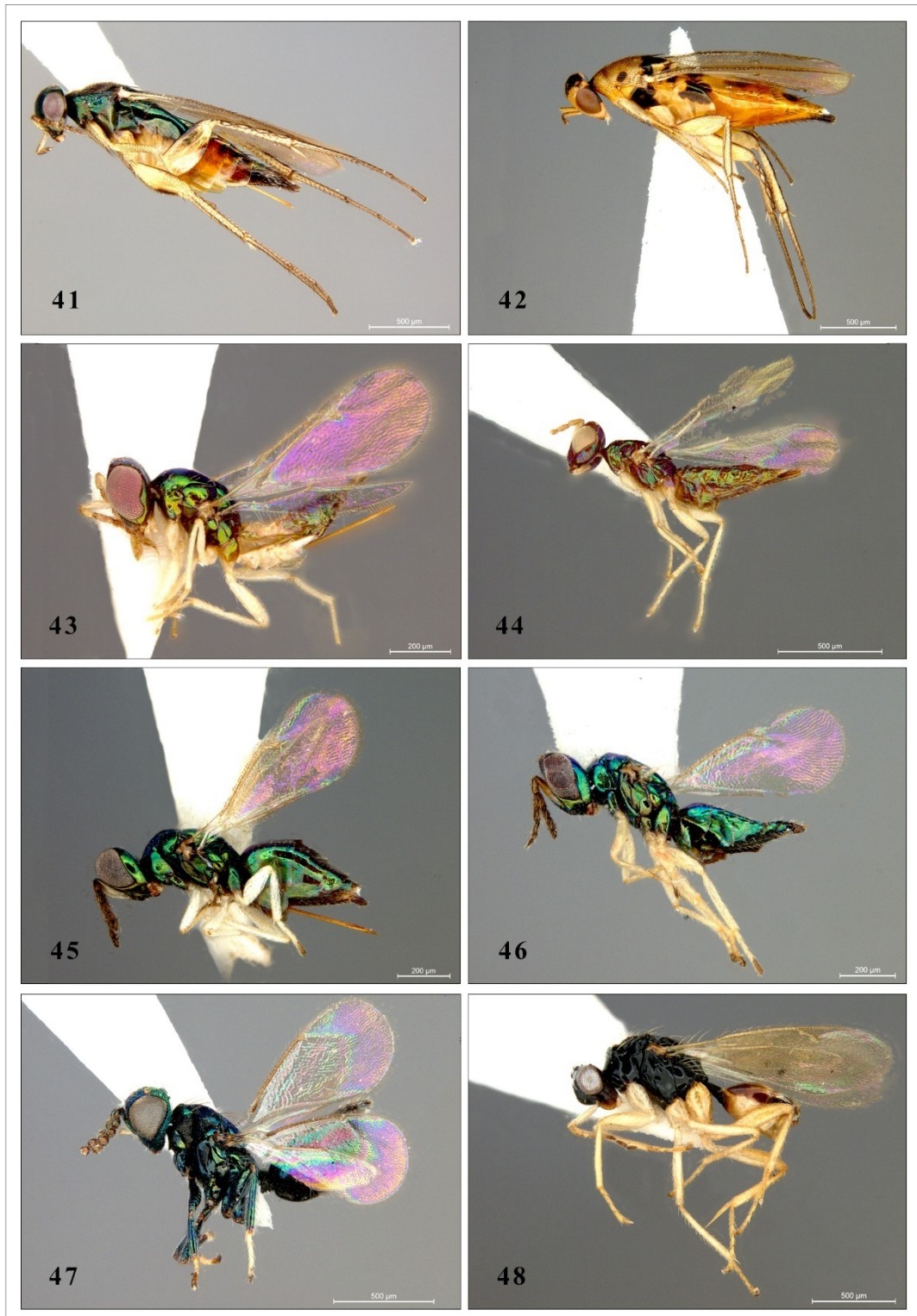
FIGS 25–29. FAM. BRACONIDAE. 25. *Orgilonia ashmeadi* (Viereck); 26. *Parapanteles* sp.; 27. *Rhaconotus* sp.; 28. *Scutibracon* sp.; 29. *Tropobracon luteus* Cameron; FIGS 30–32. FAM. CHALCIDIDAE. 30. *Antrocephalus phaeospilus* Waterston.; 31. *Antrocephalus* sp.; 32. *Brachymeria excarinata* Gahan

PLATE XXI



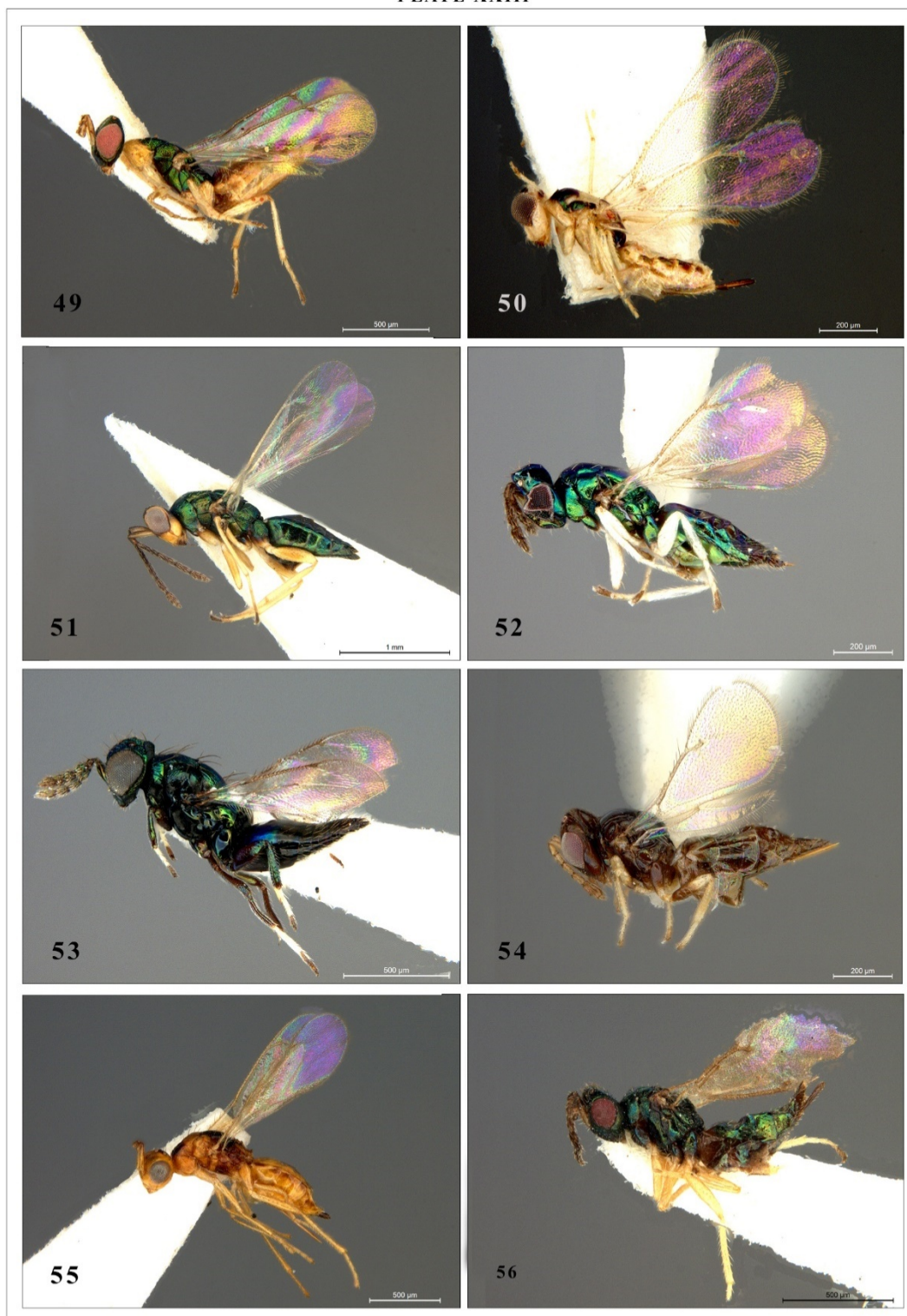
FIGS 33–38. FAM. CHALCIDIDAE. 33. *Brachymeria lasus* Walker; 34. *Brachymeria nepantidis* Gahan; 35. *Dirhinus anthracia* Walker; 36. *Hockeria aligharensis* Roy & Farooqi; 37. *Hockeria* sp.; 38. *Kriechbaumerella pulvinata* Masi; FIGS 39–40. FAM. EULOPHIDAE. 39. *Elasmus* sp.; 40. *Elasmus hyblaeae* Ferriere

PLATE XXII



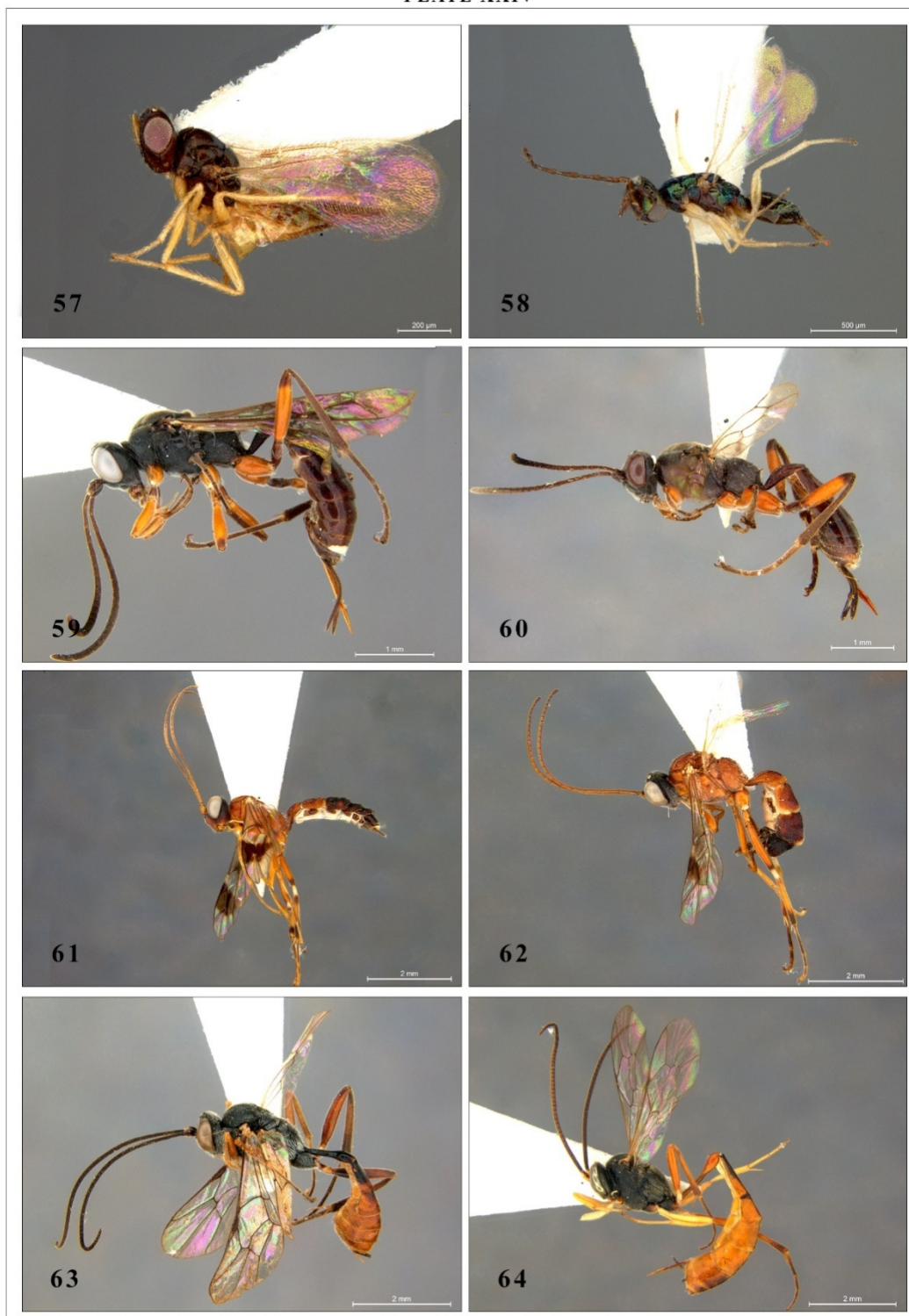
FIGS 41–48. FAM. EULOPHIDAE. 41. *Elasmus viridiscutellatus* Verma & Hayat sp.; 42. *Elasmus zatonus* Narendran & Sheeba; 43. *Aprostocetus uthonia* Narendran; 44. *Aprostocetus* sp.; 45. *Asecodes* sp.; 46. *Derostenoides* sp.; 47. *Entedon* sp.; 48. *Euplectrus* sp.

PLATE XXIII



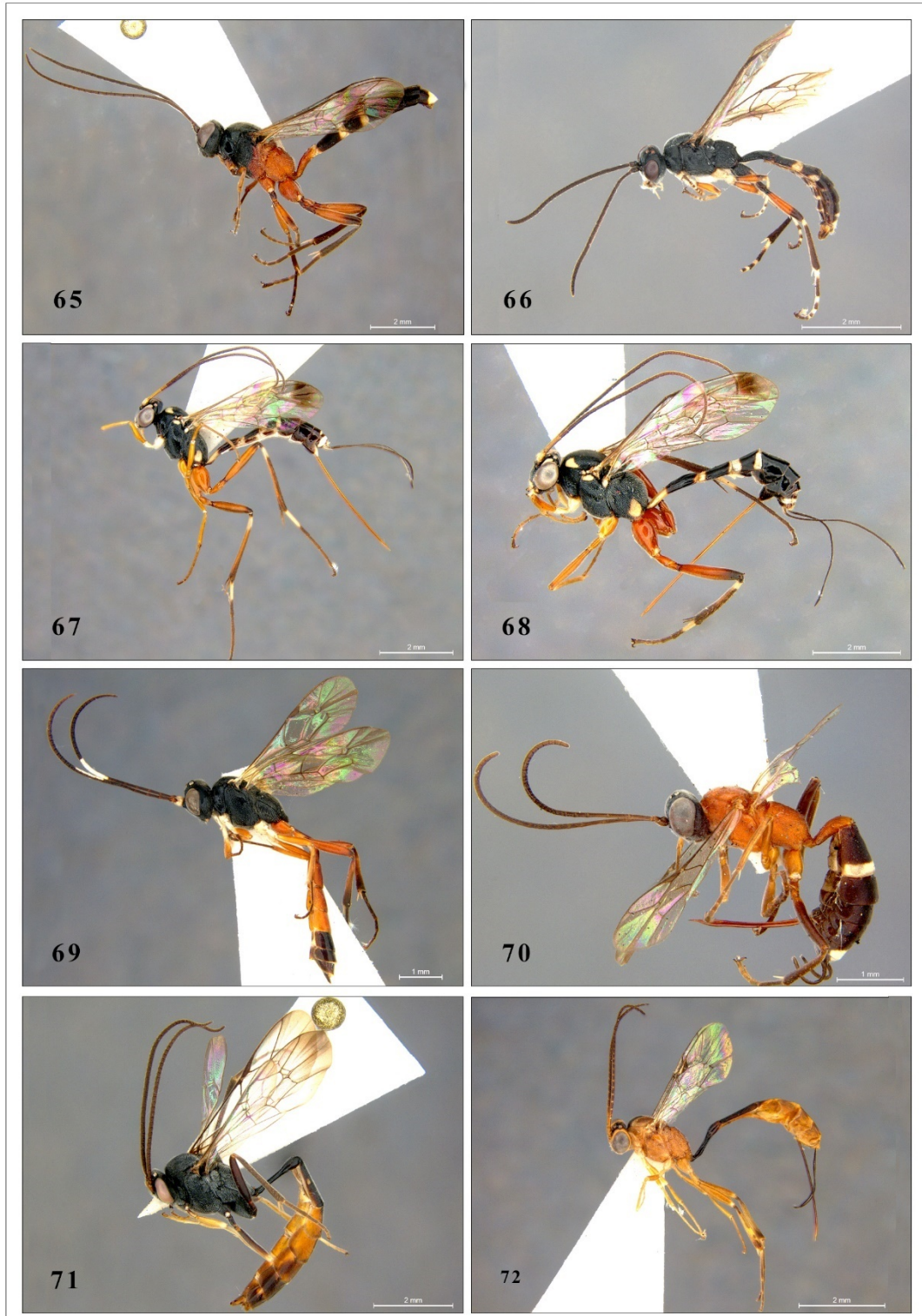
FIGS 49–56. FAM. EULOPHIDAE. 49. ; *Hemitarseus* sp.; 50. *Minotetrastichus* sp.; 51. *Neotrichoporoides* sp.; 52. *Omphale* sp.; 53. *Pediobius* sp.; 54. *Quadrastichus dicleus* Narendran; 55.. *Stenomeseus* sp.; 56. *Tetrastichus paraponyxi* Santhosh

PLATE XXIV



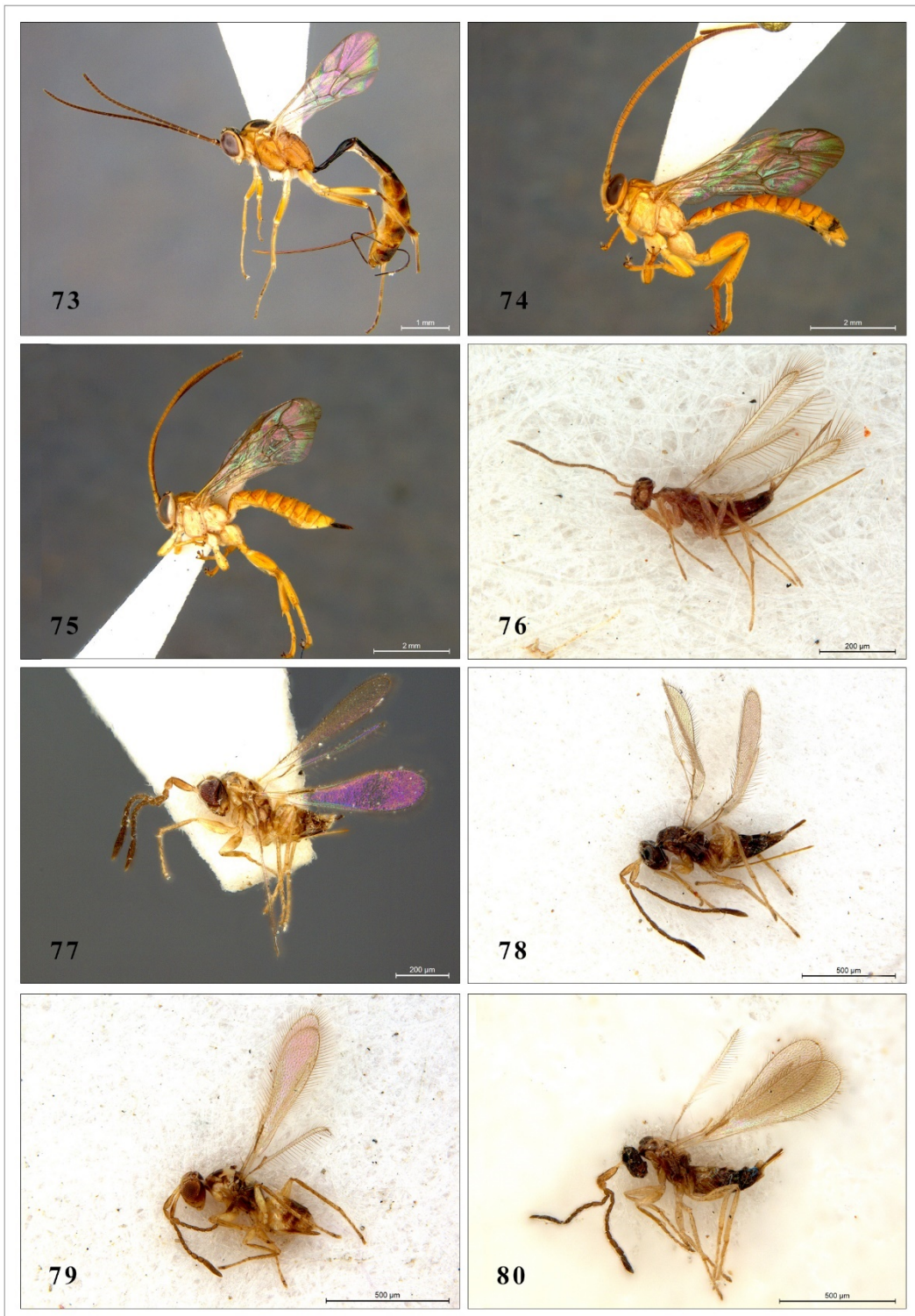
FIGS 57–58. FAM. EULOPHIDAE. 57. *Tetrastichus sissoo* Khan, Agnihotri & Sushil; 58. *Tetrastichus* sp.; FIGS 59–64. FAM. ICHNEUMONIDAE. 59. *Atropha* sp.1; 60. *Atropha* sp.1; 61. *Caenopimpla* sp.; 62. *Caenopimpla* sp.1; 63. *Casinaria pedunculata* Szepligeti; 64. *Charops bicolor* Szepligeti

PLATE XXV



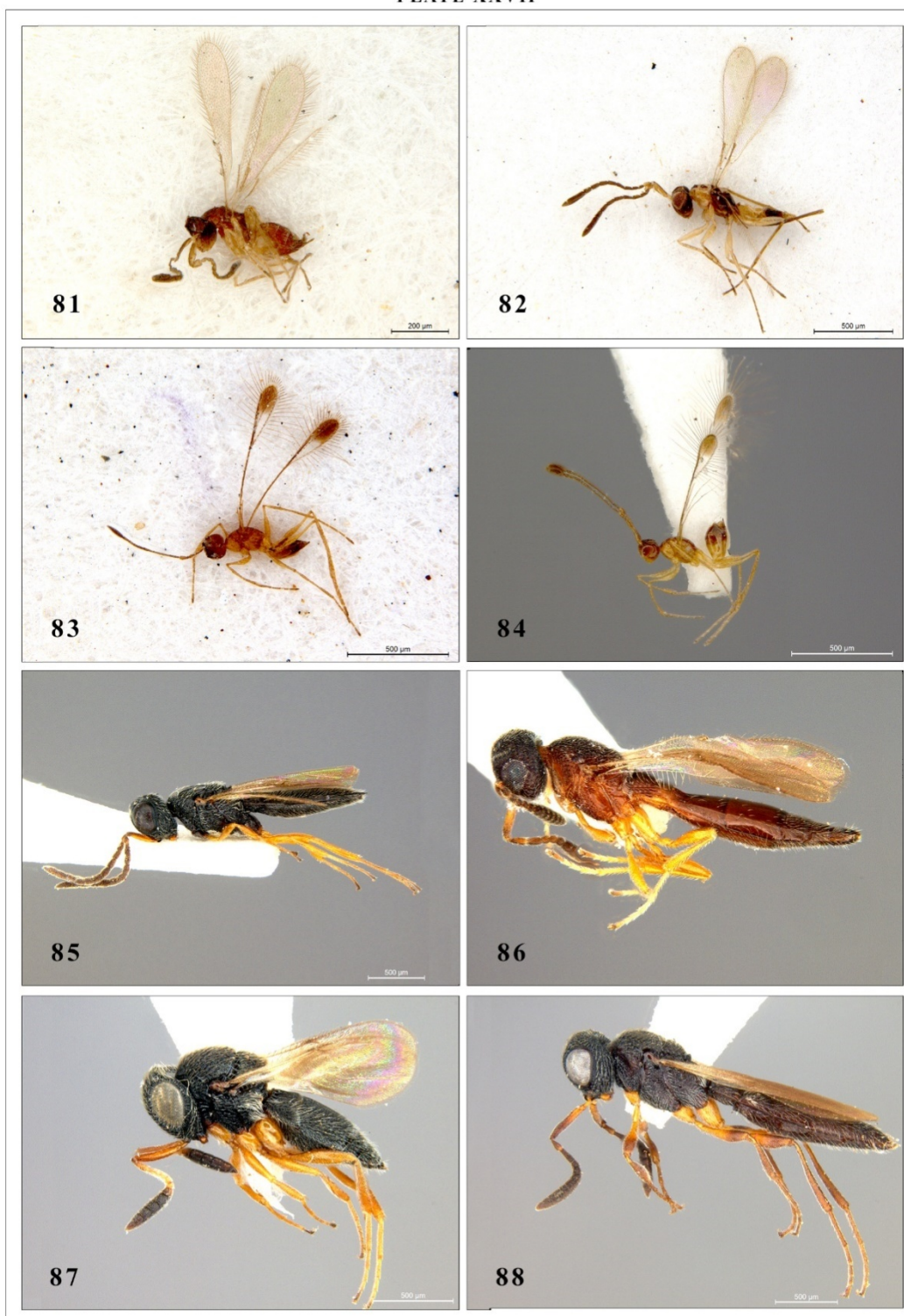
FIGS 65–72.FAM. ICHNEUMONIDAE. 65. *Isotima* sp.; 66. *Javra* sp.; 67. *Leptobatopsis indica* Cameron.; 68. *Leptobatopsis* sp.; 69. *Lusius* sp.; 70. *Menaforia* sp.; 71. *Sinophores* sp.; 72. *Trathala flavoorbitalis* Cameron

PLATE XXVI



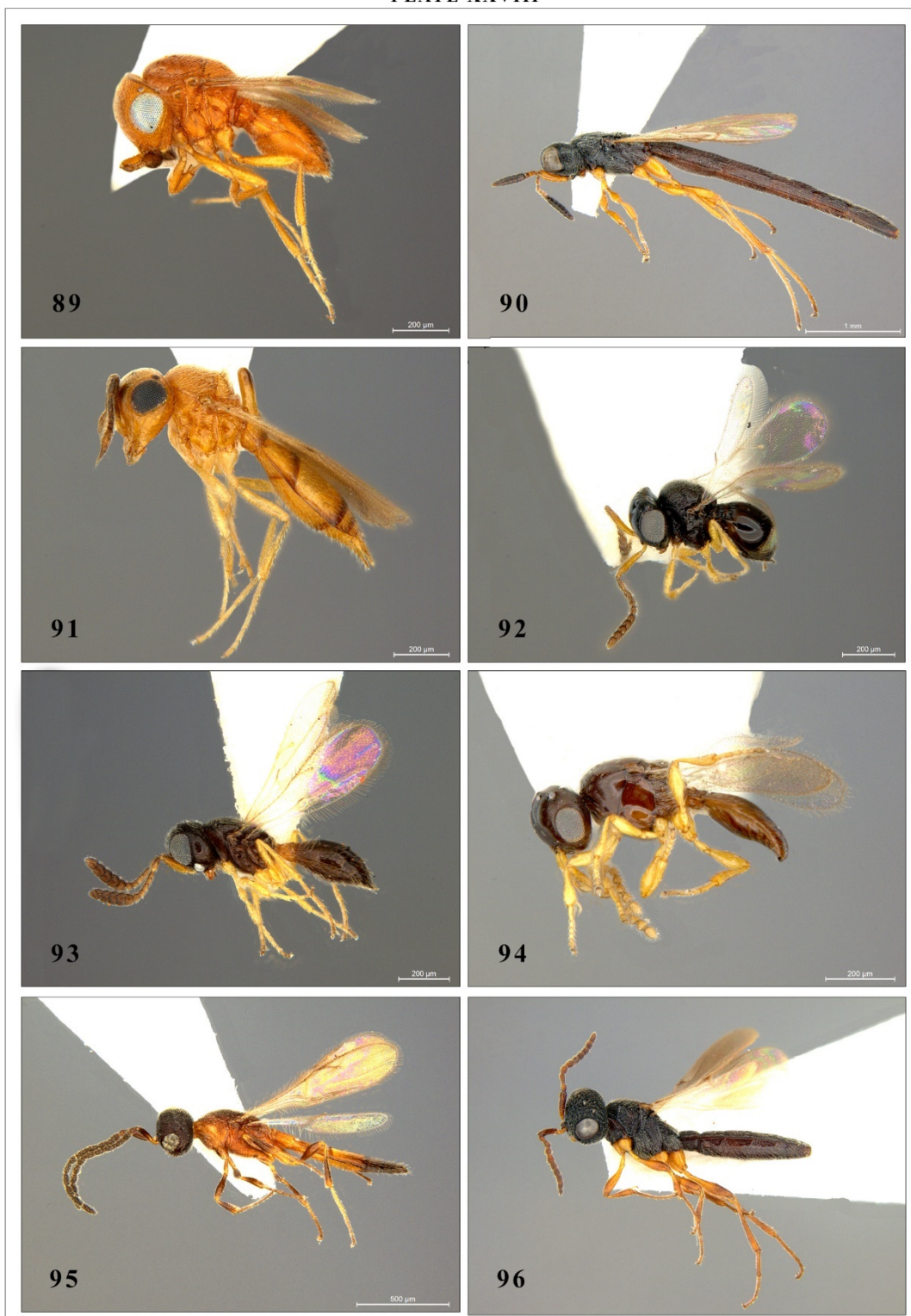
FIGS 73–75.FAM. ICHNEUMONIDAE. 73. *Trathala* sp.; 74. *Xanthopimpla flavolineata* Cameron; 75. *Xanthopimpla punctata*; FIGS 76–80.FAM.MYMARIDAE. 76. *Anagrus* sp.; 77. *Gonatocerus aegyptiacus* Soyka; 78. *Gonatocerus longicornis* Nees; 79. *Gonatocerus meghalayensis* Nees; 80. *Gonatocerus shamimi* Subba Rao & Hayat

PLATE XXVII



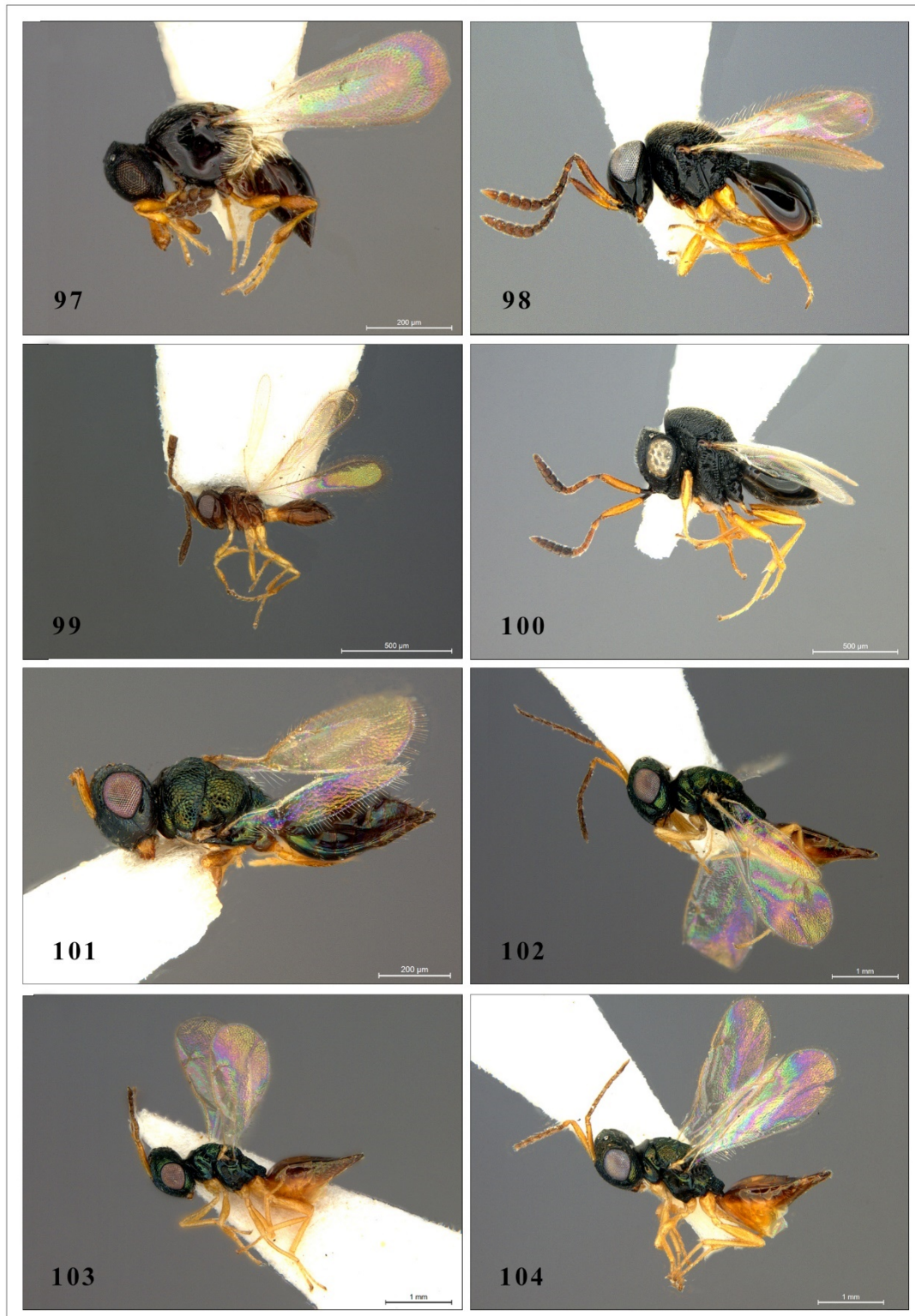
FIGS 81–84.FAM. MYMARIDAE. 81. *Lymaenon aureus* Girault.; 82. *Lymaenon munnarus* Walker; 83. *Mymar schwanni* Girault; 84. *Mymar taprobanicum* Ward; FIGS 85–88. FAM. PLATYGASTRIDAE. 85. *Baryconus* sp.; 86. *Calliscelio* sp.; 87. *Gryon* sp.; 88. *Habroteleia* sp.

PLATE XXVIII



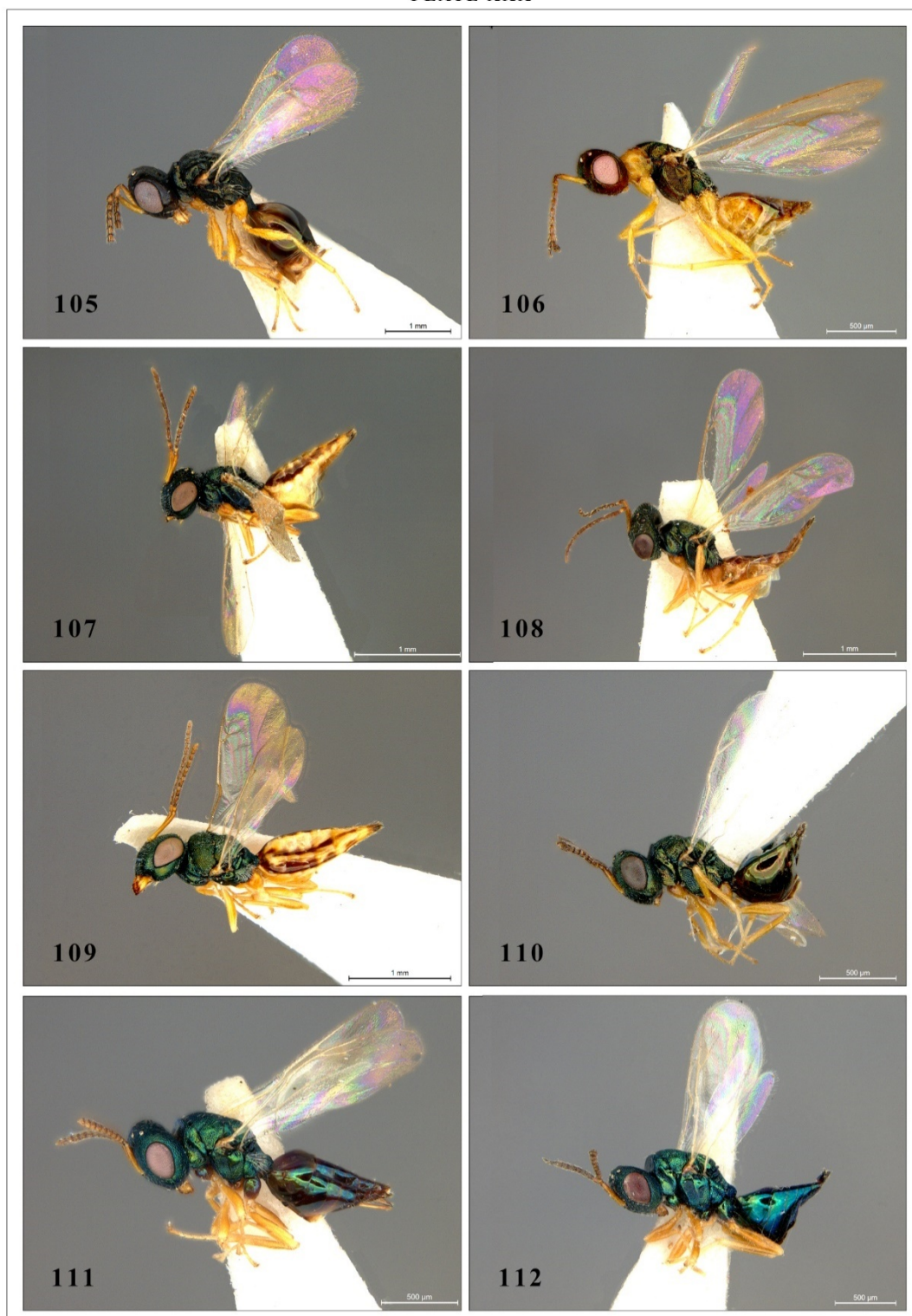
FIGS 89-96. FAM. PLATYGASTRIDAE. 89. *Idris* sp.; 90. *Macroteleia* sp.; 91. *Odontocolus* sp.; 92. *Opisthacantha* sp.; 93. *Palpoteleia* sp.; 94. *Platygaster* sp.; 95. *Probaryconus* sp.; 96. *Scelio* sp.

PLATE XXIX



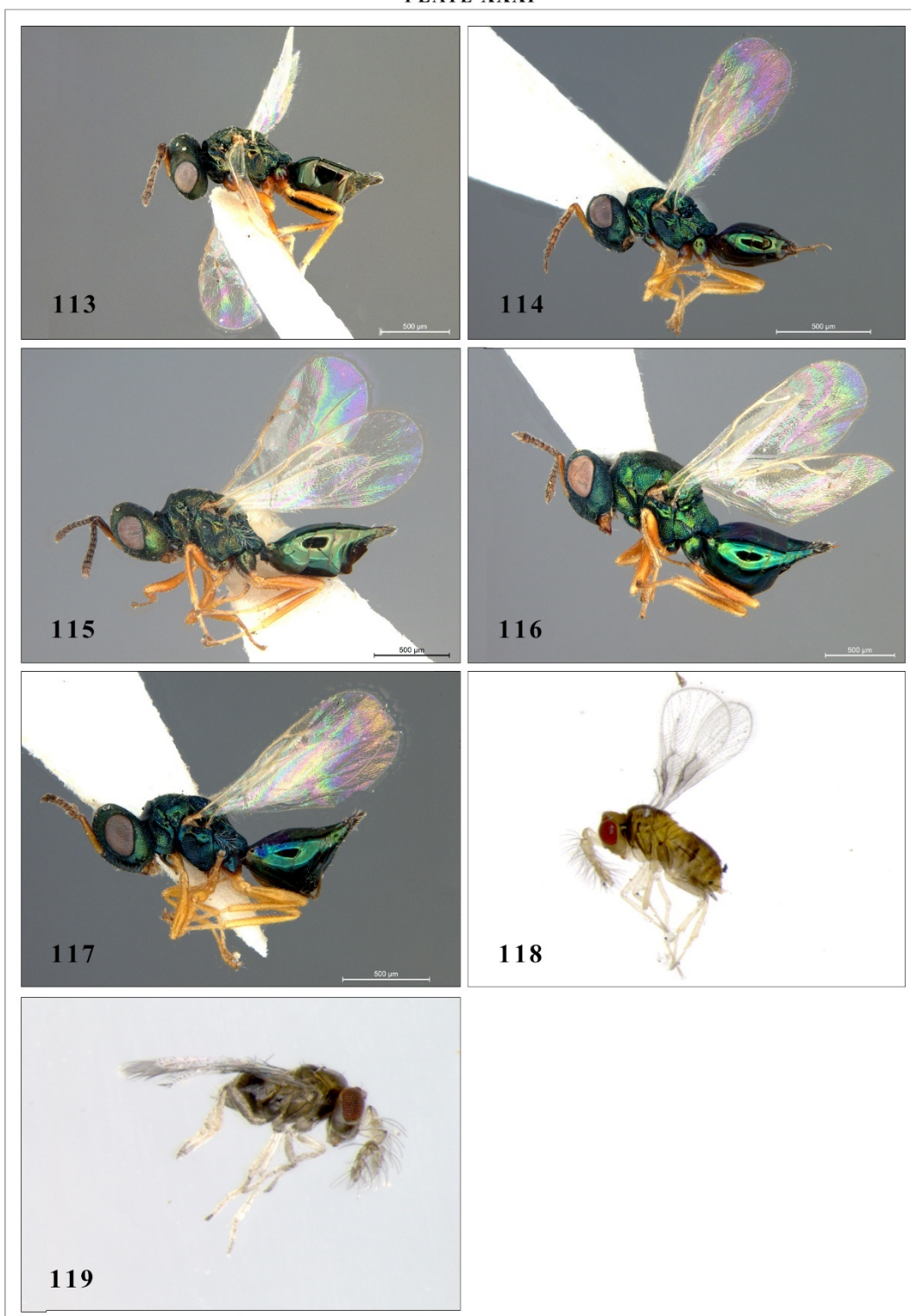
FIGS 97–100. FAM. PLATYGASTRIDAE. 97. *Synopeas* sp.; 98. *Telenomus* sp.; 99. *Trimorus* sp.; 100. *Trissolcus* sp.; FIGS 101– 104. FAM. PTEROMALIDAE. 101. *Callitula anguloclypea* Sureshan; 102. *Callitula peethapada* Narendran & Mohana; 103. *Callitula* sp.; 104. *Callitula travancorensis* Sureshan

PLATE XXX



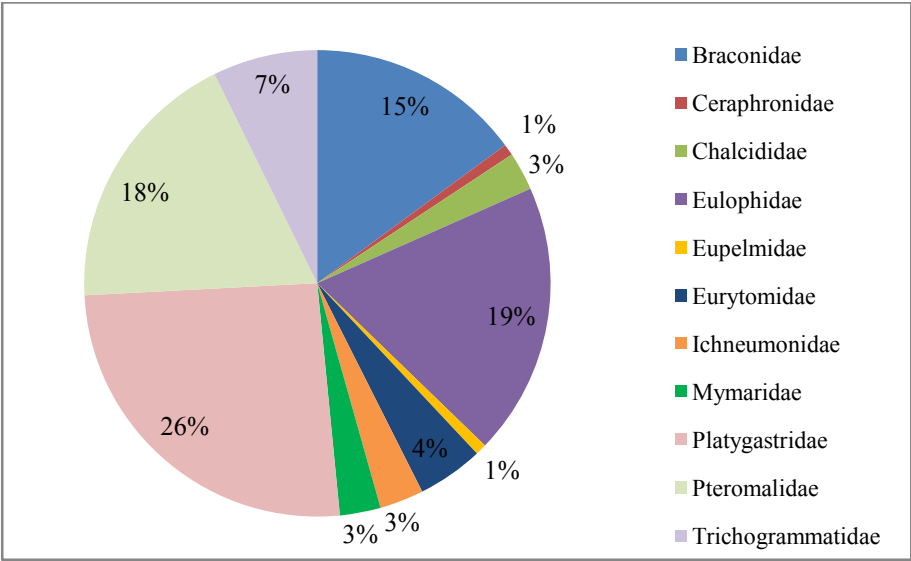
FIGS 105–112.FAM. PTEROMALIDAE. 105. *Notoglyptus scutellaris* (Dodd & Girault); 106. *Panstenon* sp.; 107. *Propicroscyptus mirificus* (Girault); 108. *Propicroscyptus oryza* (Subba Rao); 109. *Propicroscyptus* sp.; 110. *Trichomalopsis acarinata* Sureshan & Narendran; 111. *Trichomalopsis apanteloctena* (Crawford); 112. *Trichomalopsis neelagastra* Sureshan & Narendran

PLATE XXXI



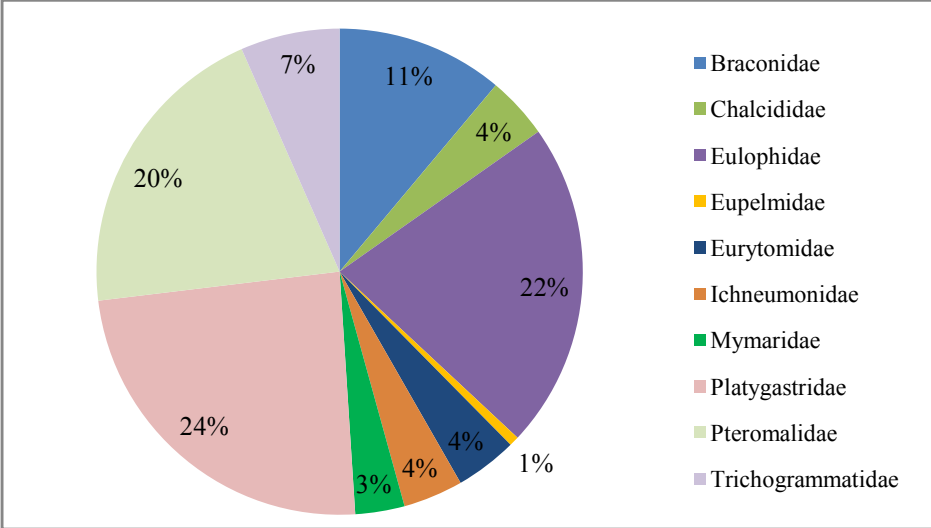
FIGS 113–117.FAM. PTEROMALIDAE. 113. *Trichomalopsis nigra* Sureshan & Narendran; 114.. *Trichomalopsis ovigastrea* Sureshan & Narendran; 115. *Trichomalopsis* sp.; 116.*Trichomalopsis thekkadiensis* Sureshan & Narendran; 117. *Trichomalopsis travanco-rensis* Sureshan & Narendran;FIGS 118 & 119.FAM.TRICHOGRAMMATIDAE.118. *Tricho-gramma achaeae* Nagaraja & Nagarkatti; 119. *Trichogrammatoidea bactrae* Nagaraja

Fig. 3.1: The parasitic hymenopteran families in Conventional rice fields during 2015.



Platygastridae (24%) was the most dominant family recorded from Conventional rice fields during 2016, followed by Eulophidae (22%) Pteromalidae (20%), and Braconidae (11%). The least dominant families were Ceraphronidae, Bethylidae and Eupelmidae (Fig. 3.2).

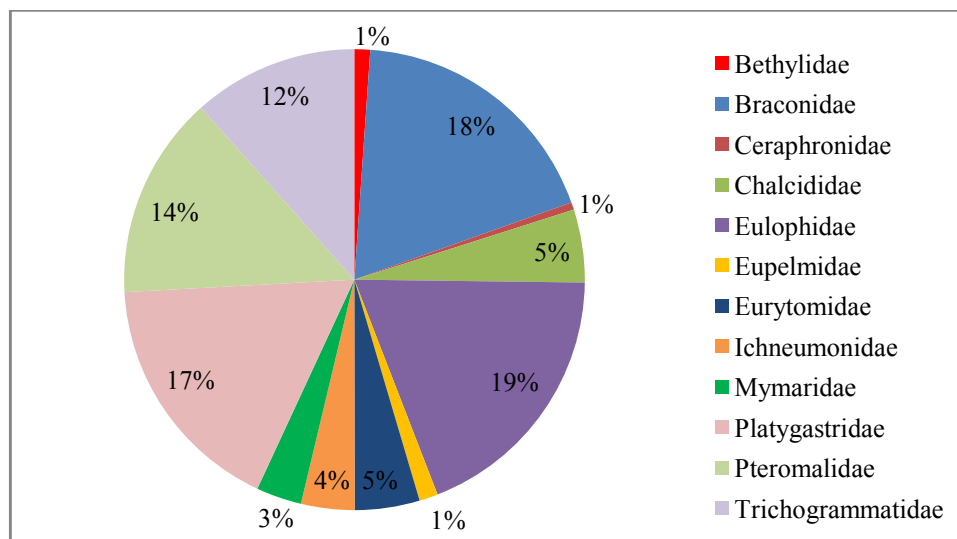
Fig. 3.2: The parasitic hymenopteran families in Conventional rice fields during 2016.



During 2017, Eulophidae (19%) was the most abundant family in Conventional rice fields, and followed by Braconidae (18%), Platygastridae (17%)

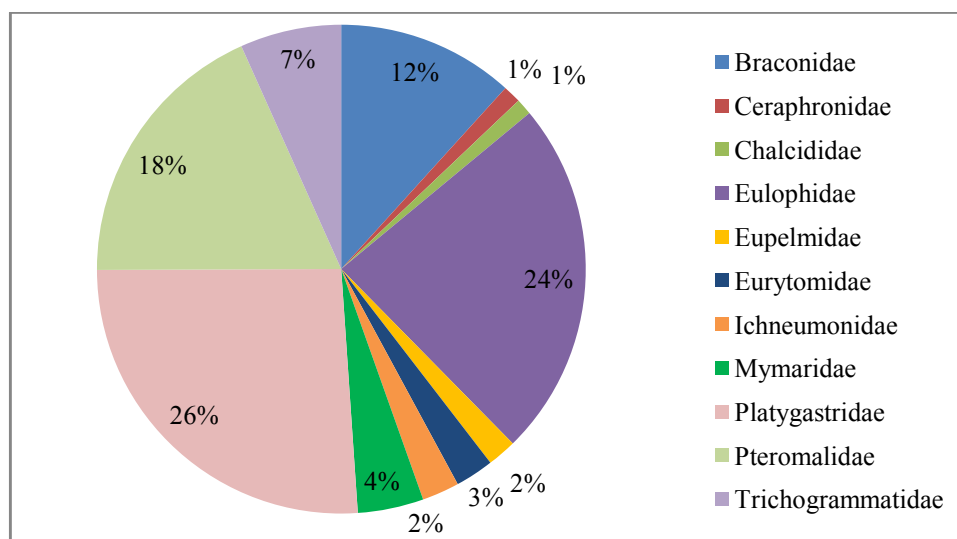
and Pteromalidae (14%). The least abundant families were Ceraphronidae (1%), Bethylidae (1%) and Eupelmidae (1%)(Fig.3.3).

Fig. 3.3: The parasitic hymenopteran families in Conventional rice fields during 2017.



In Kaipad rice fields, Platygastridae (26%) was the most dominant family during 2015, followed by Eulophidae (24%), Pteromalidae (18%) and Braconidae (12%)(Fig. 3.4).

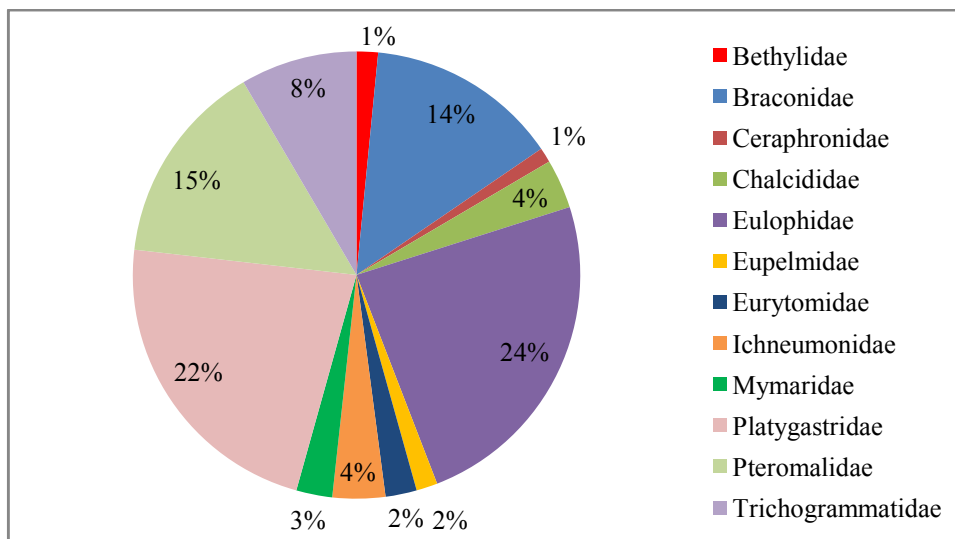
Fig. 3.4: The parasitic hymenopteran families in Kaipad rice fields during 2015.



The predominant families in Kaipad rice fields during 2016 were Eulophidae (24%), followed by Platygastridae (22%), Pteromalidae (15%) and Braconidae

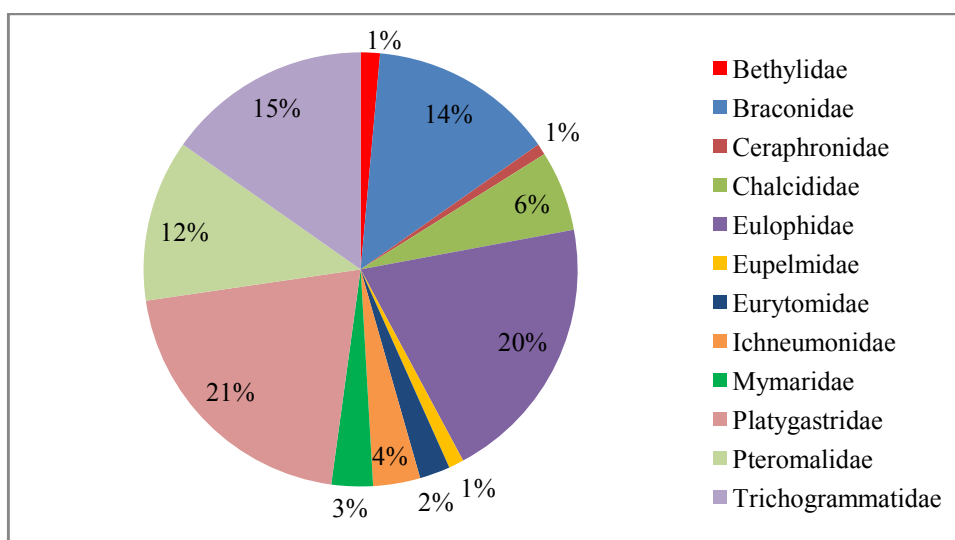
(14%). The less dominant parasitoid families were Ceraphronidae (1%) and Bethylidae (1%) (Fig. 3.5).

Fig. 3.5: The parasitic hymenopteran families in Kaipad rice fields during 2016.



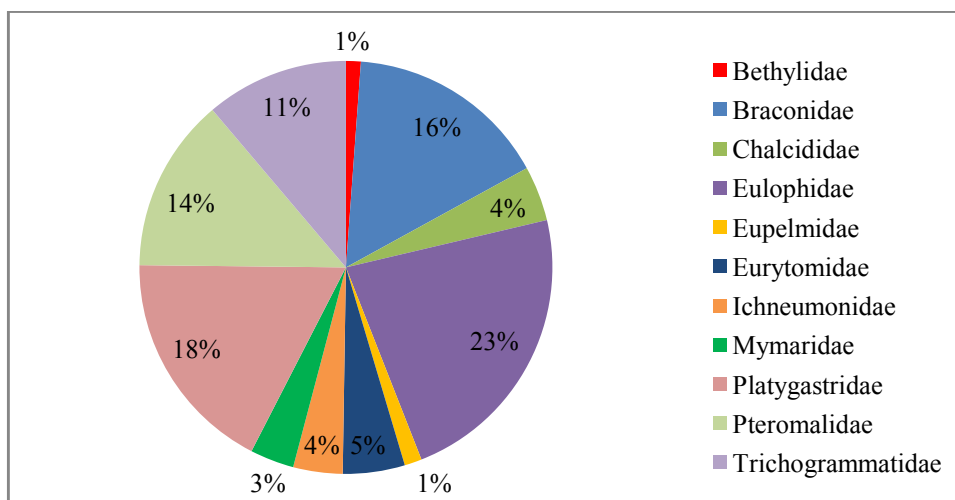
During 2017 in Kaipad rice fields, the most abundant parasitic hymenopteran family was Platygastridae (21%), followed by Eulophidae (20%), Trichogrammatidae (15%) and Braconidae (14%). The less abundant families were Ceraphronidae (1%), Eupelmidae (1%) and Bethylidae (1%) (Fig. 3.6).

Fig. 3.6: The parasitic hymenopteran families in Kaipad rice fields during 2017.



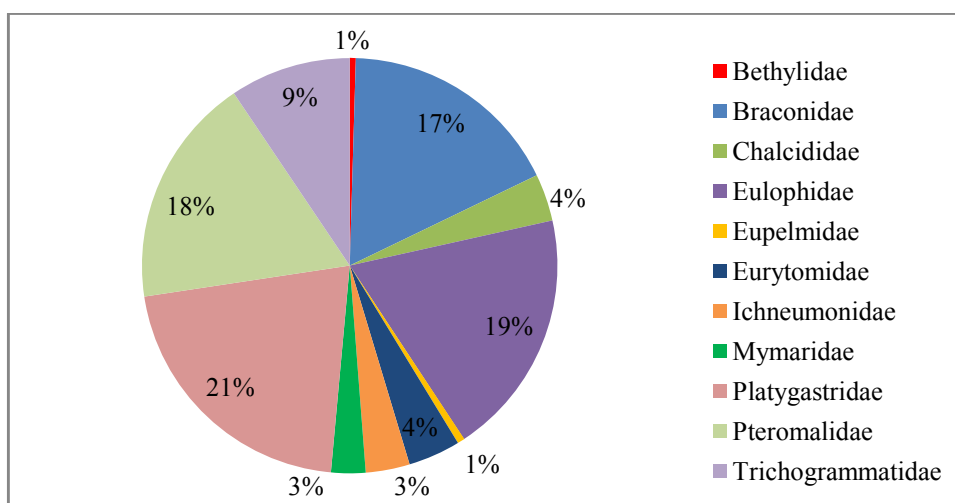
During June in Conventional rice fields, the most dominated parasitoid family was Eulophidae (23%), followed by Platygasteridae (18%), Braconidae (16%) and Pteromalidae (14%), and the least dominant were Bethyidae (1%) and Eupelmidae (1%) (Fig.3.7).

Fig. 3.7: The parasitic hymenoptera families in Conventional rice fields during June.



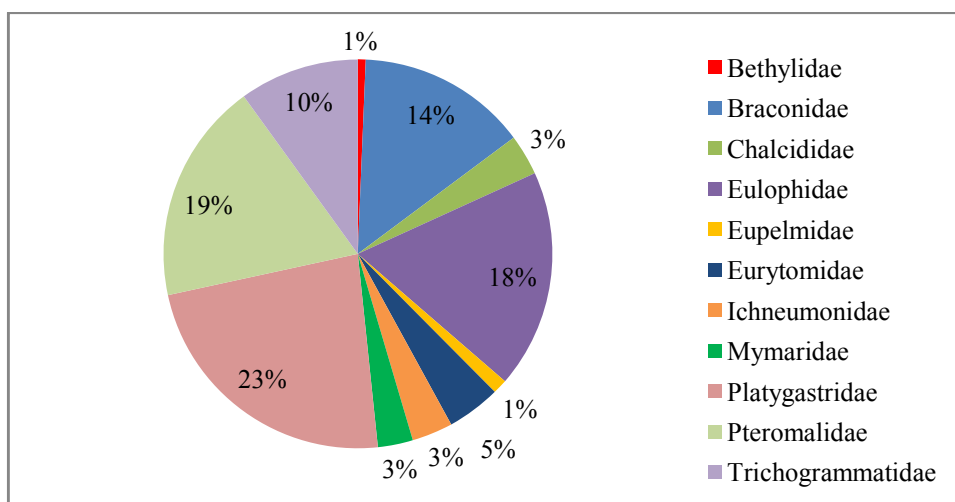
During July in Conventional rice fields, the most abundant family was Platygasteridae (21%), followed by Eulophidae (19%), Pteromalidae (18%) and Braconidae (17%). The abundance of Bethyidae and Eupelmidae were very less (Fig.3.8).

Fig. 3.8: The parasitic hymenopteran families in Conventional rice fields during July.



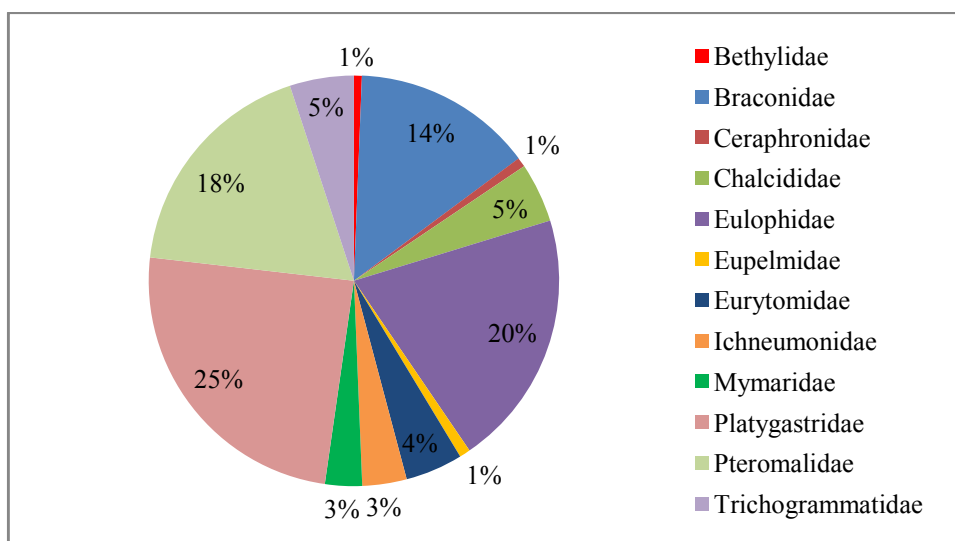
The most dominated parasitoid family in August was Platygasteridae (23%), and followed by Pteromalidae (19%), Eulophidae (18%) and Braconidae (14%). Bethylidae and Eupelmidae were the least recorded ones (Fig.3.9).

Fig. 3.9: The parasitic Hymenoptera families in Conventional rice fields during August.



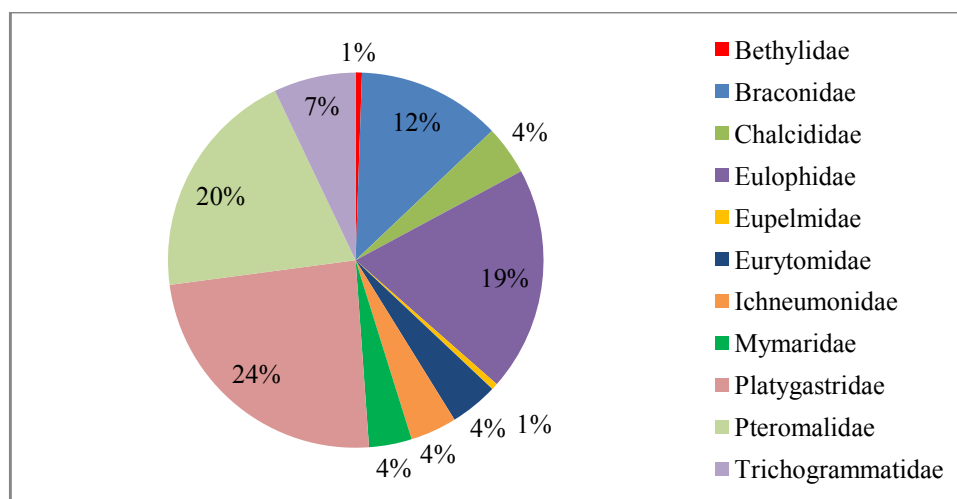
In September, in Conventional rice fields Platygasteridae (25%) was the most abundant family followed by Eulophidae (20%), Pteromalidae (18%) and Braconidae (14%). The families Bethylidae (1%), Ceraphronidae (1%) and Eupelmidae (1%) were the least abundant ones (Fig.3.10).

Fig. 3.10: The parasitic hymenopteran families in Conventional rice fields during September.



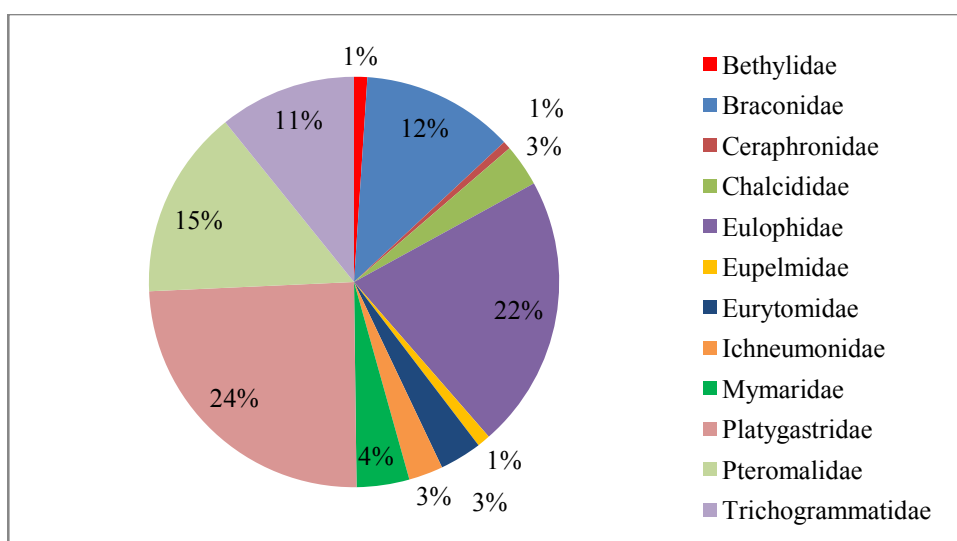
During October in Conventional rice fields, Platygasteridae (24%), Pteromalidae (20%), Eulophidae (19%) and Braconidae (12%) were the most abundant parasitoid groups. Bethyidae and Eupelmidae were the least abundant families (Fig.3.11).

Fig. 3.11: The parasitic hymenopteran families in Conventional rice fields during October.



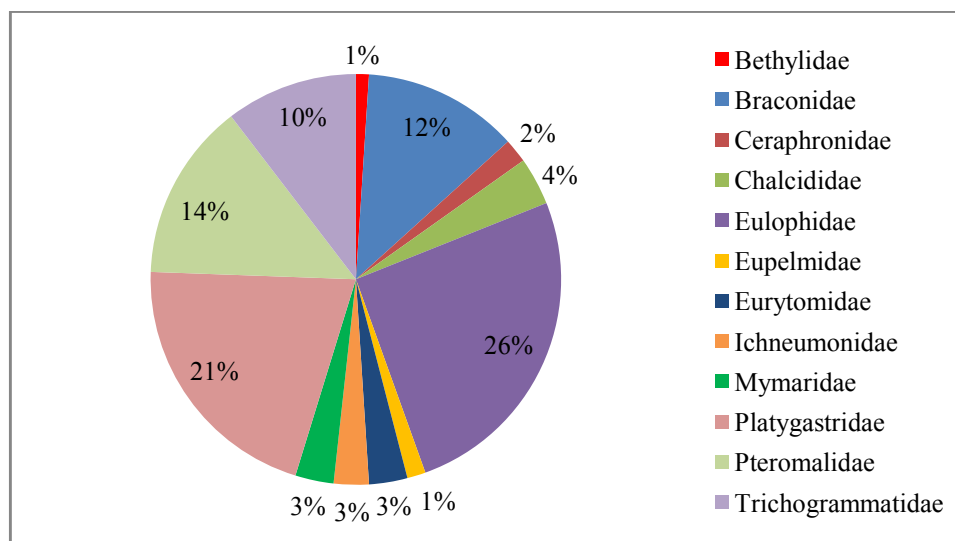
In the Kaipad rice fields, the most abundant parasitoid families in June were Platygasteridae (24%), Eulophidae (25%), Pteromalidae (15%) Braconidae (12%) and Trichogrammatidae (11%); and the least abundant groups were Ceraphronidae, Bethyidae and Eupelmidae (Fig.3.12).

Fig. 3.12: The parasitic hymenopteran families in Kaipad rice fields during June.



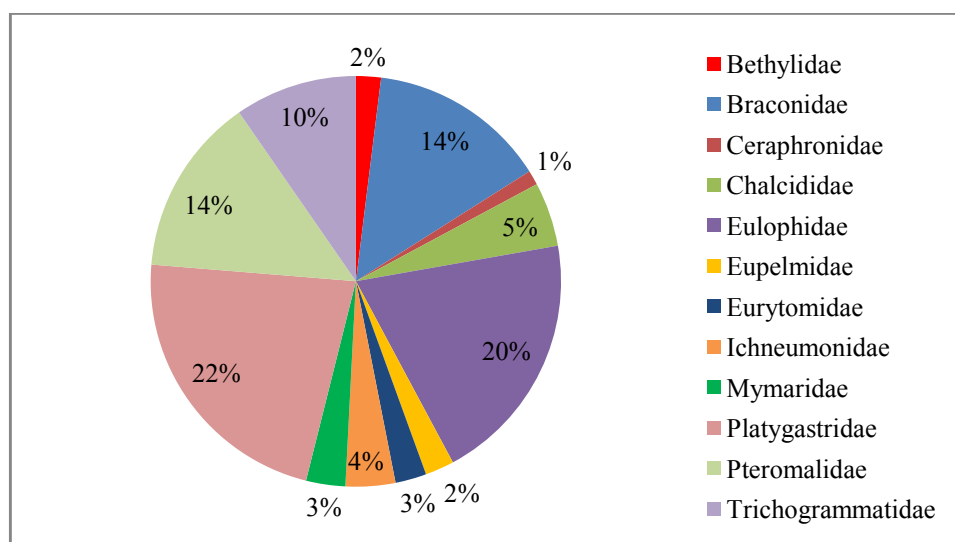
The abundant parasitoid families recorded from Kaipad rice fields during July were Eulophidae (26%), followed by Platygasteridae (21%), Pteromalidae (14%) and Braconidae (12%). The families Bethylidae (1%), Eupelmidae (1%) and Ceraphronidae (2%) were the minor families recorded (Fig.3.13).

Fig. 3.13: The parasitic hymenopteran families in Kaipad rice fields during July.



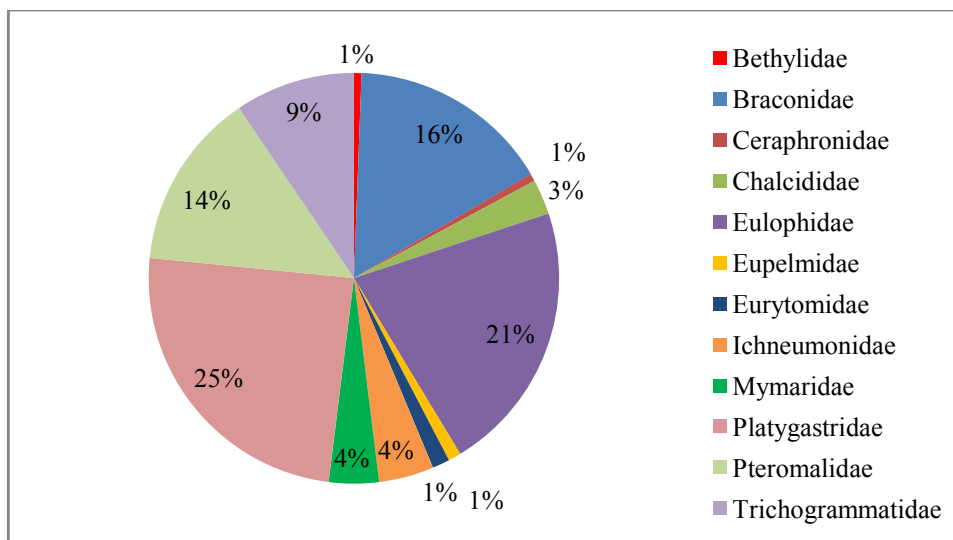
During August, Platygasteridae (22%) was the most dominant family followed by Eulophidae (20%). Braconidae (14%) and Pteromalidae (14%) showed similar percentage of abundance. Ceraphronidae (1%), Bethylidae (2%) and Eupelmidae were the minor ones (Fig. 3.14).

Fig. 3.14: The parasitic hymenopteran families in Kaipad rice fields during August.



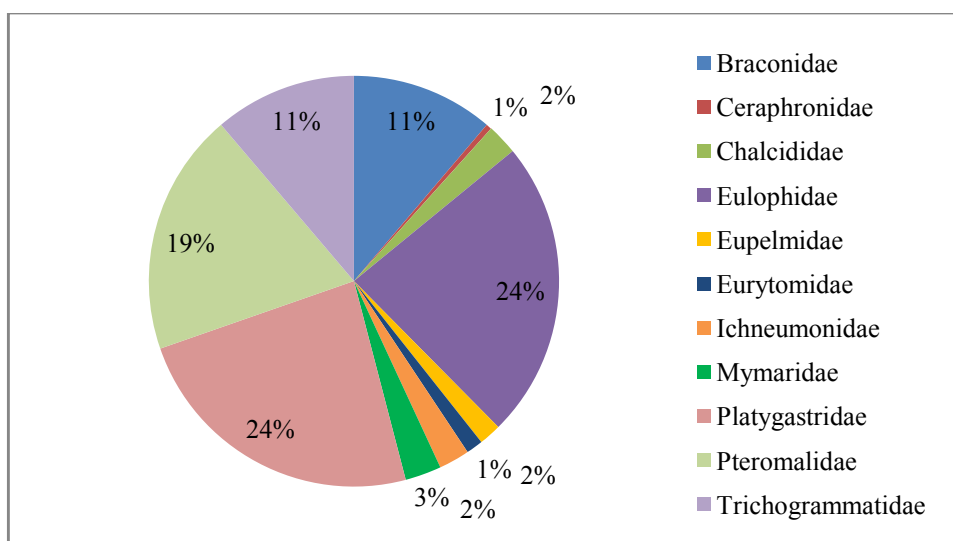
25% of the parasitoids collected from Kaipad rice fields in September belonged to Platygasteridae, followed by Eulophidae (21%), Braconidae (16%) and Pteromalidae (14%). The families Bethyidae, Ceraphronidae, Eupelmidae and Eurytomidae comprised only 1% each (Fig 3.15).

Fig. 3.15: The parasitic hymenopteran families in Kaipad rice fields during September.



During October, the parasitoid families Platygasteridae and Eulophidae showed similar abundance (24%) in Kaipad rice fields, followed by Pteromalidae (19%); and the least abundant ones was Ceraphronidae (1%), Eurytomidae (1%), Chalcididae (2%) and Ichneumonidae (2%)(Fig. 3.16).

Fig. 3.16: The parasitic hymenopteran families in Kaipad rice fields during October.



The hymenopteran parasitoids collected from Conventional and Kaipad rice fields during the present study are showing diverse host specificity, i.e. Egg parasitoids, Larval parasitoids, Larval-Pupal parasitoids, Pupal parasitoids. Their host specificity is given in Tab. 3.2.

The Host Parasitoid association in rice fields

The parasitic hymenoptera recorded during the present study from Conventional and Kaipad rice fields and their host stage and host insect pests noted during previous studies are listed out in the Tab. 3.2. In future, we can utilize those host specific parasitoids to minimize the attack of insect pests in Kaipad and Conventional rice fields.

Tab. 3.2: The list of reported parasitoids and their host specificity

Sl.No	Parasitoid species	Host stage	Host	References
1	<i>Goniozus</i> sp.	Larva	<i>Marasmia patnalis</i>	Rani et al., (2007)
2	<i>Aleiodes</i> sp.	Larva	Host unknown	Achterberg et al., 2020
3	<i>Amyosoma chinensis</i> (Szépligeti, 1902)	Egg Egg	<i>Scirpophaga excerptalis</i> <i>Sesamia inferens</i>	Quicke, 1987 Quicke, 1987
4	<i>Apanteles</i> sp.	Larva Larva Larva	<i>Parnara guttata</i> <i>Marasmia patnalis</i> <i>Scirpophaga incertulas</i>	Jamalahmad&Zaki, 2008 Randhawa et al., (2006) Hendawy et al., 2016
5	<i>Apanteles</i> sp.1	Larva	<i>Marasmia patnalis</i>	Randhawa et al., (2006)
6	<i>Apanteles</i> sp.2	Larva	<i>Marasmia patnalis</i>	Randhawa et al., (2006)
7	<i>Aspidobracon noyesi</i> van Achterberg, 1984	Pupa Pupa Pupa	<i>Pelopidas mathias</i> <i>Melantis leda ismene</i> Cramer <i>Marasmia patnalis</i>	He et al., (1990) You et al., (1994) You et al., (1994)
8	<i>Aspidobracon</i> sp.	Pupa	Host unknown	Wang et al., 2007
9	<i>Bracon brevicornis</i> Wesmael, 1838	Larva Larva Larva	Crambidae <i>Spodoptera litura</i> (Fabricius) <i>S. frugiperda</i> (J.E. Smith)	Khan and Murthy, 1954 Ghosh et al., 2020. Ghosh et al., 2020
10	<i>Bracon</i> sp.	Larva Larva	<i>Marasmia patnalis</i> <i>Scirpophaga incertulas</i>	Rao et al., 1970 Moolman et al., (2013)
11	<i>Bracon</i> sp.1	Larva	<i>Marasmia patnalis</i>	Rao et al., 1970
12	<i>Bracon</i> sp.2	Larva	<i>Marasmia patnalis</i>	Rao et al., 1970
13	<i>Cardiochiles</i> sp.	Larva Larva	Pyralidae and Noctuidae <i>Marasmia patnalis</i>	Huddleston and Walker, 1998 Randhawa et al., (2006)
14	<i>Chelonus</i> sp.	Larva Larva	<i>Spodoptera</i> sp. <i>Marasmia patnalis</i>	Ananathanarayanan and Ayyar, 1937 Randhawa et al., (2006)

15	<i>Cotesia</i> sp.	Larva Larva	<i>Marasmia patnalis</i> <i>Sirpophaga incertulas</i>	Ali and Prasad, 1958 Battacharyya et al., 2006
16	<i>Cotesia</i> sp.1	Larva Larva	<i>Marasmia patnalis</i> <i>Sirpophaga incertulas</i>	Ali and Prasad, 1958 Battacharyya et al., 2006
17	<i>Dacnusine</i> sp.	Unknown	Host unknown	NA
18	<i>Dolichogenidea</i> sp.	Larva	Host unknown	Yazdani et al., 2014
19	<i>Dolichogenidea</i> sp. 1	Larva	Host unknown	Yazdani et al., 2014
20	<i>Exoryza schoenobii</i> Wilkinson, 1932	Larva Larva	<i>Marasmia patnalis</i> <i>Scirpophaga incertulas</i>	Lam and Thanh (1989) Triana et al., 2016
21	<i>Exoryza</i> sp.	Larva	Pyralidae	Triana et al., 2016
22	<i>Glyptapanteles</i> sp.	Larva	Host unknown	Gosh, 2012
23	<i>Gnamtodon</i> sp.	Unknown	Host unknown	NA
24	<i>Macrocentrus philippinensis</i> Ashmead	Larva	<i>Marasmia patnalis</i>	Talgeri and Dalaya, 1971
25	<i>Macrocentrus</i> sp.	Larva	<i>Marasmia patnalis</i>	NPPS and ZAU (1991)
26	<i>Microplitis</i> sp.	Larva Larva	<i>Marasmia patnalis</i> <i>Psalis pennatulae</i>	NPPS and ZAU (1991) Ranjith et al., 2015
27	<i>Myosoma</i> sp.	Larva	<i>Sirpophaga incertulas</i>	Battacharyya et al., 2006
28	Opiine sp.	Unknown	Host unknown	NA
29	Opiine sp.1	Unknown	Host unknown	NA
30	Opiine sp.2	Unknown	Host unknown	NA
31	Opiine sp.3	Unknown	Host unknown	NA
32	<i>Orgilonia ashmeadi</i> (Viereck, 1911)	Pupa	Host unknown	Vargas et al., 1993
33	<i>Parapanteles</i> sp.	Unknown	Host unknown	NA
34	<i>Scutibracon</i> sp.	Larva	<i>Diadraspa armigera</i>	Battacharyya et al., 2006
35	<i>Rhaconotus</i> sp.	Larva Larva	Host unknown <i>Scirpophaga</i> sp.	Sallam, 2006 Heinrichs and Barrion, 2004
36	<i>Tropobracon luteus</i> Cameron, 1905	Larva	<i>S. incertulas</i> , <i>Sesamia inferens</i> , <i>Chilo suppressalis</i>	Ayyar and Ananthanarayanan, 1937 Battacharyya et al., 2006

37	<i>Ceraphron</i> sp.	Larva	<i>Marasmia patnalis</i>	NPPS & ZAU (1991)
38	<i>Aphanogamus</i> sp.	Larva	<i>Pelopidas mathias</i>	Battacharyya et al., 2006
39	<i>Antrocephalus phaeospilus</i> Waterston, 1922	Pupa	Host unknown	Narendran and Achterberg, 2016
40	<i>Antrocephalus</i> sp.	Pupa	Host unknown	Pereira et al., 2013
41	<i>Brachymeria excarinata</i> Gahan, 1925	Pupa Larva	<i>Marasmia patnalis</i> <i>Marasmia patnalis</i>	Randhawa et al., 2006 Battacharyya et al., 2006
42	<i>Brachymeria jambolana</i> Gahan, 1942	Pupa	Host unknown	Narendran and Achterberg, 2016
43	<i>Brachymeria lasus</i> (Walker, 1841)	Pupa	<i>Marasmia patnalis</i>	Randhawa et al., 2006
44	<i>Brachymeria nepantidis</i> Gahan, 1930	Pupa	Host unknown	Raghawani et al., 1997
45	<i>Brachymeria</i> sp.	Pupa Pupa Pupa	<i>Parnara guttata</i> <i>Marasmia patnalis</i> <i>Pelopidas mathias</i>	Jamalahmad and Zaki, 2008 Rani et al., 2007 Heinrichs and Barrion, 2004
46	<i>Dirhinus anthracia</i> Walker, 1846	Pupa	<i>Marasmia patnalis</i>	NPPS and ZAU (1991)
47	<i>Hockeria aligharensis</i> Roy & Farooqi, 1984	Unknown	Host unknown	NA
48	<i>Hockeria</i> sp.	Unknown	Host unknown	NA
49	<i>Kriechbaumerella pulvinata</i> (Masi, 1932)	Larva	<i>Marasmia patnalis</i>	Pati and Mathur (1982)
50	<i>Aprostocetus uthonia</i> , Narendran 2007	Unknown	Host unknown	NA
51	<i>Aprostocetus</i> sp.	Larva Pupa Pupa	Cecidomyiidae <i>Orseolia oryzae</i> <i>Orseolia oryzae</i>	Hendawye et al., 2016 Fry, 1987 Ogah et al., 2009
52	<i>Asecodes</i> sp.	Larva	Host unknown	Fors, 2015
53	<i>Chrysonotomyia</i> sp.	Larva	<i>Dicladispa armigera</i>	Battacharyya et al., 2006
54	<i>Derostenoides</i> sp.	Unknown	Host unknown	NA
55	<i>Elasmus</i> sp.	Larva	<i>Marasmia patnalis</i>	NPPS and ZAU (1991) Battacharyya et al., 2006
56	<i>Elasmus hyblaeae</i> Ferriere, 1929	Larva	<i>Marasmia patnalis</i>	Lam, 2000

57	<i>Elasmus viridiscutellatus</i> Verma and Hayat, 2002	Larva	<i>Marasmia patnalis</i>	Verma et al., 2002
58	<i>Elasmus zatonus</i> Narendran and Sheeba, 2008	Unknown	Host unknown	NA
59	<i>Entedon</i> sp	Egg/Larva	Host unknown	Gumovsky, 2007
60	<i>Euplectrus</i> sp.	Larva	Lepidoptera	Hansson and Schmidt, 2018
61	<i>Hemitarseus</i> sp	Unknown	Host unknown	NA
62	<i>Minotetrastichus</i> sp.	Larva	Leaf mining Lepidoptera	Japoshvili and Kostjukov, 2017
63	<i>Neotrichoporoides</i> sp.	Larva	Muscidae and Diopsidae (Diptera)	Japoshvili et al., 2017
64	<i>Omphale</i> sp.	Larva	Cecidomyiidae	Hansson and Ekaterina, 2012
65	<i>Pediobius</i> sp.	Larva Pupa Larva Larva Unknown	<i>Marasmia patnalis</i> <i>Marasmia patnalis</i> <i>Borbo cinnara</i> <i>Pelopidas mathias</i> <i>Orseolia oryzyvora</i>	Manisegaran et al., 1997 Manisegaran et al., 1997 Gupta and Kalesh, 2012 Gupta and Kalesh, 2012 Heinrichs and Barrion, 2004
66	<i>Quadrastichus dicleus</i> Narendran , 2007	Unknown	Host unknown	NA
67	<i>Stenomesus</i> sp.	Larva	<i>Marasmia patnalis</i>	Barrion et al. (1991)
68	<i>Tetrastichus parapyxi</i> Santhosh, 2016	Pupa	<i>Parapyx stagnalis</i>	Santhosh and Karthikeyan, 2016
69	<i>Tetrastichus schoenobii</i>	Larva Egg Egg Egg	<i>Marasmia patnalis</i> <i>Marasmia patnalis</i> <i>Spodoptera mauritia</i> <i>Scirpophaga incertulas</i>	Barrion et al., (1991) Battacharyya et al., 2006 Baltazar, 1966 Ahangama and Gilstrap, 1987
70	<i>Tetrastichus sissoo</i> Khan, Agnihotri & Sushil, 2005	Unknown	Host unknown	NA

71	<i>Tetrastichus</i> sp.	Larva Larva Larva Larva Larva Pupa Larva/Pupa	<i>Marasmia patnalis</i> <i>Scirpophaga incertulas</i> <i>Orseolia oryzae</i> <i>Nilaparvata lugens</i> <i>Sogatella frucifera</i> <i>Marasmia patnalis</i> <i>Orseolia oryzae</i>	de Kraker (1999a) Hendawy et al., 2016 Hummelen and Soenarjo, 1977 Pathak and Khan, 1994 Gurr et al., 2011 Korat and Pathak, 1996 Ogah et al., 2009
72	<i>Anastatus</i> sp.	Egg	Pentatomidae Acrididae	Stahl et al., (2019) Ramachandra Rao (1921)
73	<i>Eupelmus</i> sp.	Larva/Pupa	Host unknown	Cortesero and Monge, 1994
74	<i>Neanastatus</i> sp.	Pupa	Cecidomyiidae <i>Orseolia oryzae</i>	Kobayashi et al. (1990) Das et al., 1987
75	<i>Eurytoma</i> sp.	Larva Larva Larva	Hesperiidae <i>Marasmia patnalis</i> <i>Orseolia oryzae</i>	Narendran (2001) NPPS and ZAU (1991) Barrión and Litsinger, 1983
76	<i>Anomalon</i> sp.	Larva	Host unknown	Gauld and Bolton, 1988
77	<i>Atropha</i> sp.	Unknown	Host unknown	NA
78	<i>Atropha</i> sp1.	Unknown	Host unknown	NA
79	<i>Caenopimpla</i> sp.	Larva	Host unknown	Borah and Sarma, 2004
80	<i>Caenopimpla</i> sp1.	Larva	Host unknown	Borah and Sarma, 2004
81	<i>Casinarina pedunculata</i> (Szepligeti, 1908)	Larva	Host unknown	Nhi and Long, 2016
82	<i>Casinarina</i> sp.	Larva	Host unknown	Nhi and Long, 2016
83	<i>Charops bicolor</i> (Szepligeti, 1906)	Larva Larva Larva Larva	<i>Marasmia patnalis</i> <i>Scirpophaga incertulas</i> <i>Spodoptera mauritia</i> <i>Pelopidas mathias</i>	He et al. (1996) Lakshman et al., 2013 Lakshman et al., 2013 Nasser et al., 2018
84	<i>Charops</i> sp.	Larva	<i>Pelopidas mathias</i>	Yadav et al., 2018
85	<i>Diadegma</i> sp.	Larva	<i>Marasmia patnalis</i>	Subharani et al., 2010
86	<i>Goryphus</i> sp.	Pupa	<i>Marasmia patnalis</i>	Viet, 2017
87	<i>Gotra</i> sp.	Pupa	Host unknown	Nhi and Long, 2016

88	<i>Ishnojoppa</i> sp.	Larva/Pupa Larva	<i>Marasmia patnalis</i> <i>Sirpophaga incertulas</i>	Randhawa et al. (2006) Battacharyya et al., 2006
89	<i>Isotima</i> sp.	Larva	<i>Sirpophaga incertulas</i>	Battacharyya et al., 2006
90	<i>Javra</i> sp.	Pupa	Host unknown	Nhi and Long, 2016
91	<i>Leptobatopsis indica</i> (Cameron, 1897)	Larva	<i>Marasmia patnalis</i>	Randhawa et al. (2006)
92	<i>Leptobatopsis</i> sp.	Larva	Host unknown	Nhi and Long, 2016
93	<i>Lusius</i> sp.	Unknown	Host unknown	NA
94	<i>Menaforia</i> sp.	Unknown	Host unknown	NA
95	<i>Pristomerus</i> sp.	Larva	Host unknown	Rao et al., 1968
96	<i>Scenocharops</i> sp.	Larva	<i>Marasmia patnalis</i>	Sudheer and Narendran, 2005
97	<i>Sinophorus</i> sp.	Larva	Host unknown	Ling et al., 2015
98	<i>Skeatia</i> sp.	Unknown	Host unknown	NA
99	<i>Temelucha</i> sp.	Larva Larva Larva	<i>Marasmia patnalis</i> <i>Marasmia patnalis</i> <i>Scirpophaga incertulas</i>	Randhawa et al. (2006) Battacharyya et al., 2006 Hendawy et al., 2016
100	<i>Theronia</i> sp.	Unknown	Host unknown	NA
101	<i>Trathala flavoorbitalis</i> (Cameron, 1907)	Larva	<i>Marasmia patnalis</i>	Randhawa et al. (2006)
102	<i>Trathala</i> sp.	Larva	Host unknown	Chhavi et al., 2019
103	<i>Xanthopimpla flavolineata</i> Cameron, 1907	Larva Pupa	<i>Marasmia patnalis</i> <i>Marasmia patnalis</i>	Viet, 2017 Battacharyya et al., 2006 Rani et al., 2007
104	<i>Xanthopimpla punctata</i> (Fabricius, 1781)	Larva Pupa	<i>Marasmia patnalis</i> <i>Marasmia patnalis</i>	He et al. (1996) Yadav et al., 2018
105	<i>Xanthopimpla</i> sp.	Larva Pupa	<i>Marasmia patnalis</i> <i>Marasmia patnalis</i>	Yadav et al., 2018 Vijayakumar and Patel, 2003

106	<i>Anagrus</i> sp.	Egg Egg Egg Egg Egg Egg	<i>Nephotettix cincticeps</i> (Uhler) <i>Laodelphax striatella</i> (Fallén) <i>Nilaparvata lugens</i> (Stål) <i>Sogatella furcifera</i> (Horváth) <i>Recilia dorsalis</i> (Motschulsky) Leaf and Planthopper	Triapitsyn et al., 2020 Triapitsyn et al., 2020 Triapitsyn et al., 2020 Triapitsyn et al., 2020 Triapitsyn et al., 2020 Hendawyet al., 2016
107	<i>Gonatocerus aegyptiacus</i> Soyka, 1950	Egg Egg	<i>Nephotettix cincticeps</i> <i>Recilia dorsalis</i> (Motschulsky)	Triapitsyn et al., 2020 Triapitsyn et al., 2020
108	<i>Gonatocerus longicornis</i> Nees 1834	Egg	Host unknown	Triapitsyn, 2013 Rajesh et al., 2015
109	<i>Gonatocerus meghalayensis</i> Nees von Esenbeck, 1834	Egg	Host unknown	Manickavasagam and Athithya, 2018
110	<i>Gonatocerus shamimi</i> Subba Rao & Hayat, 1986	Egg	Host unknown	Manickavasagam and Athithya, 2018 Rajesh et al., 2015
111	<i>Lymaenon aureus</i> Girault, 1911	Egg	Planthoppers	Gurret al, 2011 Rajesh et al., 2015
112	<i>Lymaenon delhiensis</i> Narayanan & Subba Rao, 1961	Egg	Planthoppers	Gurr et al, 2011
113	<i>Lymaenon munnarus</i> Walker	Egg	Host unknown	Zeya et al., 2017 Rajesh et al., 2015
114	<i>Lymaenon narayani</i> Subba Rao & Kaur, 1959	Egg	Host unknown	Zeya and Hayat, 1995
115	<i>Mymar schwanni</i> Girault, 1912	Egg	Host unknown	Triapitsyn et al., 2020 Rajesh et al., 2015
116	<i>Mymar</i> sp.	Egg	Host unknown	Triapitsyn et al., 2020
117	<i>Mymar taprobanicum</i> Ward, 1875	Egg Egg Egg Egg	<i>Nephotettix cincticeps</i> <i>Recilia dorsalis</i> (Motschulsky) <i>Nilaparvatalugens</i> <i>Sogatella frucifera</i>	Triapitsyn et al., 2020 Triapitsyn et al., 2020 Hayat, 1992 Hayat, 1992 Rajesh et al., 2015

118	<i>Baryconus</i> sp.	Egg	Host unknown	Shweta and Rajmohana, 2016
119	<i>Calliscelio</i> sp.	Egg	Insect and Spiders	Rajmohana et al., 2015
120	<i>Cremastobaeus</i> sp.	Egg	Insect and Spiders	Rajmohana et al., 2015
121	<i>Duta indica</i> Mukerjee, 1994	Egg	Insect and Spiders	Rajmohana et al., 2015
122	<i>Duta</i> sp.	Egg	Insect and Spiders	Rajmohana et al., 2015
123	<i>Fusicornia</i> sp.	Egg	Insect and Spiders	Rajmohana et al., 2015
124	<i>Greyon</i> sp.	Egg Egg	<i>Leptocorisa acuta</i> <i>Nilaparvata lugens</i>	Battacharyya et al., 2006 Gurr et al., 2011
125	<i>Habroteleia</i> sp.	Egg	Orthoptera	Chen et al., 2018
126	<i>Idris</i> sp.	Egg	Spider	Hendawy et al., 2016
127	<i>Macroteleia</i> sp.	Egg	Insect and Spiders	Perrichot et al., 2014
128	<i>Odontacholus</i> sp.	Egg	Insect and Spiders	Rajmohana et al., 2015
129	<i>Opisthacantha</i> sp.	Egg	Insect and spiders	Rajmohana et al., 2015
130	<i>Palpoteleia</i> sp.	Egg	Insect and Spiders	Rajmohana et al., 2015
131	<i>Paratelenomus</i> sp.	Egg	Insect and Spiders	Rajmohana et al., 2015
132	<i>Paridris</i> sp.	Egg	Spider	Shweta and Rajmohan, 2016
133	<i>Platygaster</i> sp.	Egg	<i>Orseolia oryza</i>	Hendawy et al., 2016
134	<i>Probaryconus</i> sp.	Egg	Insect and Spiders	Rajmohana et al., 2015
135	<i>Psillanteris</i> sp.	Egg	Spider	Shweta and Rajmohan, 2016
136	<i>Scelio</i> sp.	Egg	Insect and Spiders	Rajmohana et al., 2015
137	<i>Synopeas</i> sp.	Egg	Cecidomyiidae	Abram et al., 2012
138	<i>Telenomus</i> sp.	Egg	<i>Scirpophagaintertulas</i>	Hendawyet al., 2016
139	<i>Trimorus</i> sp.	Egg	Insects and Spiders	Rajmohanaet al., 2015
140	<i>Trissolcus</i> sp.	Egg	Stink bugs	Chen et al., 2020
141	<i>Callitula anguloclypea</i> Sureshan, 2002	Unknown	Host unknown	NA
142	<i>Callitula peethapada</i> Narendran& Mohana, 2001	Unknown	Host unknown	NA
143	<i>Callitula</i> sp.	Larva	Lepidptera	Hendawyet al., 2016
144	<i>Callitula travancorensis</i> Sureshan 2002	Unknown	Host unknown	NA
145	<i>Notoglyptus scutellaris</i> (Dodd &Girault, 1915)	Unknown	Host unknown	NA

146	<i>Notoglyptus</i> sp.	Unknown	Host unknown	NA
147	<i>Panstenon</i> sp.	Egg	<i>Nilaparvata lugens</i> Planthoppers	Gurret al., 2011 Gurret al., 2011
148	<i>Propicroscytus mirificus</i> (Girault, 1915)	Larva Larva	<i>Orseolia oryzae</i> <i>Scirpophaga incertulas</i>	Barrion and Litsinger, 1983 Farooqi and Subba Rao, 1986
149	<i>Propicroscytus oryza</i> (Subba Rao, 1973)	Larva	<i>Orseolia oryzae</i>	Chengsang and Jeerapong, 2001
150	<i>Propicroscytus</i> sp.	Larva	Host unknown	Chengsang and Jeerapong, 2001
151	<i>Trichomalopsis acarinata</i> Sureshan&Narendran, 2001	Unknown	Host unknown	NA
152	<i>Trichomalopsis apanteloctena</i> (Crawford, 1911)	Larva Larva Larva Pupa	<i>Marasmia patnalis</i> <i>Pelopidas mathias</i> <i>Dicladispa armigera</i> <i>Scirpophaga incertulas</i>	Barrion et al., (1991) Battacharyya et al., 2006 Misra et al., 1983 Rao and Behera, 1988
153	<i>Trichomalopsis neelagastra</i> Sureshan and Narendran, 2001	Unknown	Host unknown	NA
154	<i>Trichomalopsis nigra</i> Sureshan and Narendran, 2001	Unknown	Host unknown	NA
155	<i>Trichomalopsis ovigastra</i> Sureshan and Narendran, 2001	Unknown	Host unknown	NA
156	<i>Trichomalopsis</i> sp.	Pupa	Host unknown	Kamijo and Grissell, 1982
157	<i>Trichomalopsis thekkadiensis</i> Sureshan and Narendran, 2001	Unknown	Host unknown	NA
158	<i>Trichomalopsis travancorensis</i> Sureshan and Narendran, 2001	Unknown	Host unknown	NA
159	<i>Trichomalus kannurensis</i> Sureshan and Narendran, 2001	Unknown	Host unknown	NA
160	<i>Trichomalus</i> sp.	Unknown	Host unknown	NA
161	<i>Chaetostricha</i> sp.	Egg	Pyralidae	Martinek, 1963
162	<i>Lathromeroidea</i> sp.	Egg	Dytiscidae	Ikram and Yousuf, 2016

163	<i>Oligosita</i> sp.	Egg Egg Egg Egg Egg Egg Egg	<i>Nilaparvata lugens</i> <i>Nephotettix cincticeps</i> <i>Nephotettix nigropictus</i> <i>Sogatella furcifera</i> <i>Nilaparvata lugens</i> <i>Nephotettix virescens</i> <i>Leaf and Planthoppers</i>	Sann et al., 2018 a & b Gurr et al., 2011 Hayat and Viggiani, 1984 Gurr et al., 2011 Atmaja and Laba, 2000 Gurr et al., 2011 Hendawy et al., 2016
164	<i>Trichogramma achaeae</i> Nagaraja & Nagarkatti, 1970	Egg	<i>Spodoptera litura</i>	Yousuf et al., 2015
165	<i>Trichogramma chilonis</i> Ishii, 1941	Egg Egg	<i>Marasmia patnalis</i> <i>Scirpophaga incertulas</i>	Hemachandra and Perera, 2016 Srivastava et al., 2015
166	<i>Trichogramma hebbalensis</i>	Egg	<i>Corcyra cephalonica</i>	Yousuf et al., 2015
167	<i>Trichogramma japonicum</i> Ashmead, 1904	Egg Egg	<i>Marasmia patnalis</i> <i>Scirpophaga incertulas</i>	Hemachandra and Perera, 2016 Hendawy et al., 2016
168	<i>Trichogramma</i> sp.	Egg Egg Egg	<i>Marasmia patnalis</i> <i>Scirpophaga incertulas</i> <i>Scirpophaga innotata</i>	Pasalu et al., 2004 Battacharyya et al., 2006 Joshi et al., 1991
169	<i>Trichogrammatoidea bactrae</i> Nagaraja 1979	Egg	<i>Marasmia patnalis</i>	Hemachandra and Perera, 2016
170	<i>Trichogrammatoidea</i> sp.	Egg	<i>Marasmia patnalis</i>	Hemachandra and Perera, 2016
171	<i>Tumidiclava</i> sp.	Egg Egg	Noctuidae Pyralidae	Scheibelreiter, G.K. 1980 Scheibelreiter, G.K. 1976

In Conventional rice fields, 47 % of the collected parasitoids were egg parasitoids, followed by larval parasitoids (31%), and pupal parasitoids (10%) (Fig.3.17). Host stages of 12% of the parasitoids were not known. 57 % of the collected parasitoids from Kaipad rice fields were egg parasitoids, followed by larval parasitoids (25%), and pupal parasitoids (8%)(Fig. 3.18).The hosts of 10% of the parasitoids were host unknown.

Fig. 3.17: The parasitoid guild in Conventional rice fields.

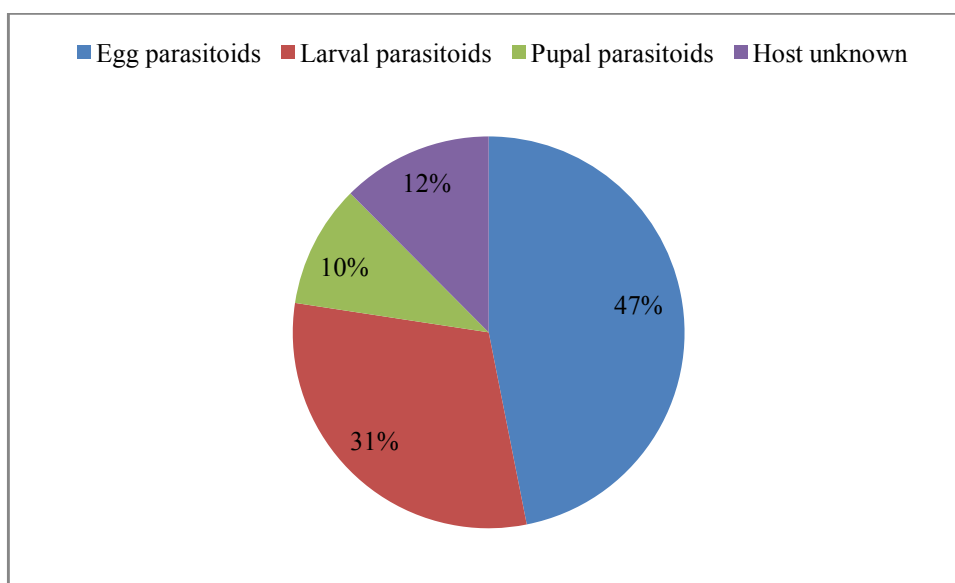
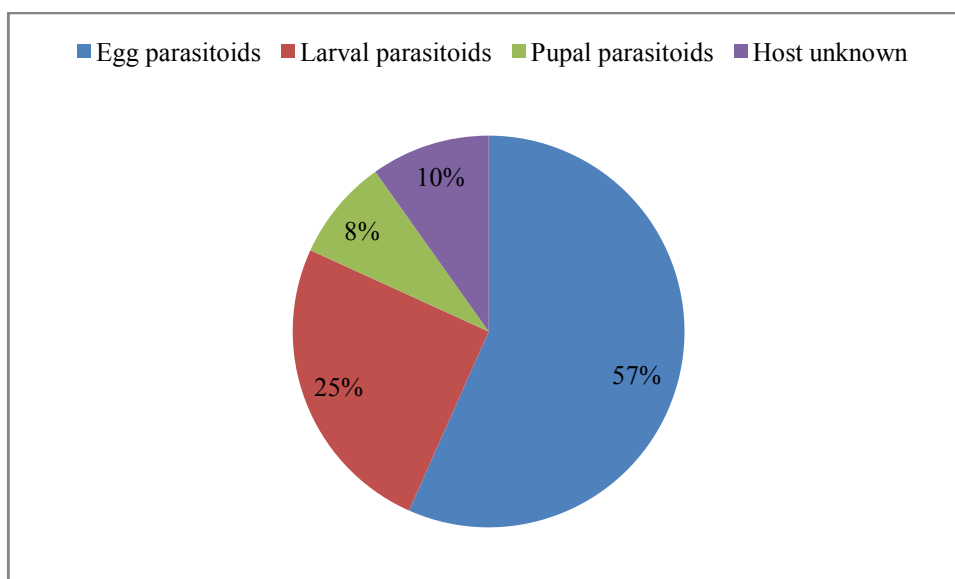


Fig. 3.18: The parasitoid guild specificity in Kaipad rice fields.



Abundance of species of Braconidae in Conventional and Kaipad rice fields

In Braconidae, the most abundant species recorded from Conventional rice field was *Aspidobracon* sp., followed by *Apanteles* sp. and *Cotesia* sp. and the least abundant was *Bracon* sp.2 and *Bracon* sp1. (Fig.3.19). In Kaipad rice fields, the most recorded species was *Apanteles* sp. followed by *Aspidobracon* sp. and *Glyptapanteles* sp. and the least observed was *Aleiodes* sp., *Exoryza* sp. and *Parapanteles* sp. (Fig.3.20).

Fig. 3.19: Species abundance of Braconidae in Conventional rice fields.

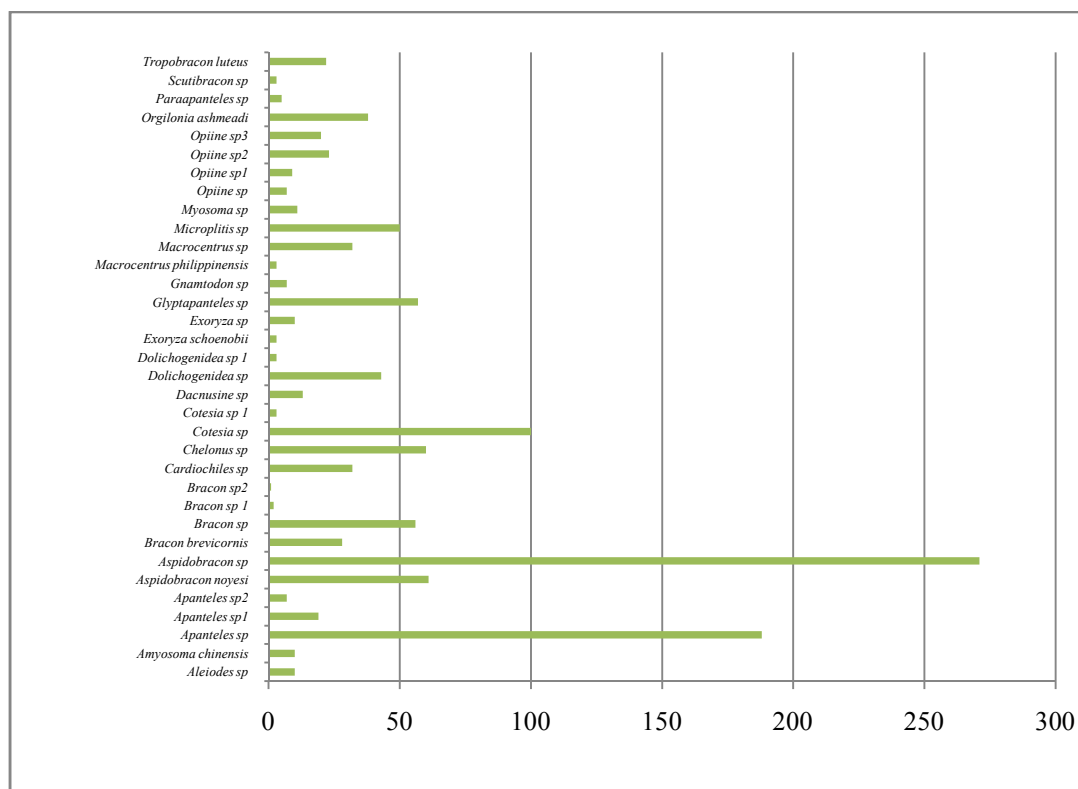
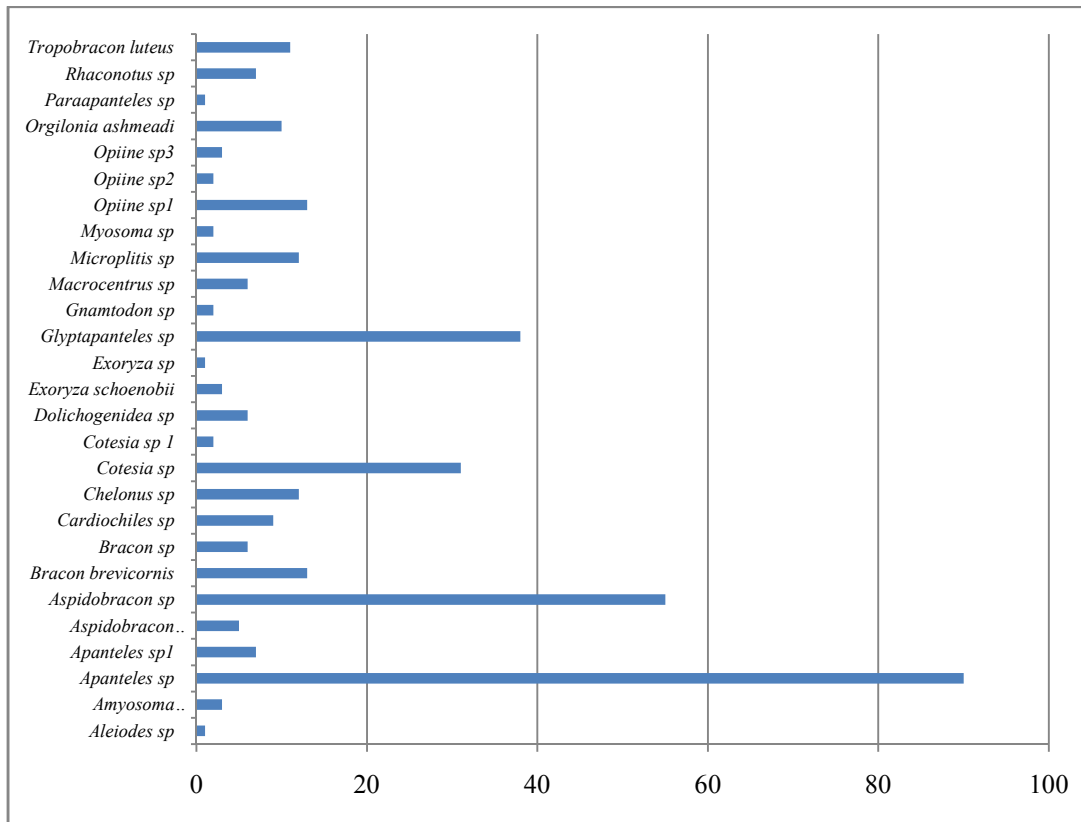


Fig. 3.20: Species abundance of Braconidae in Kaipad rice fields.



Abundance of species of Chalcididae in Conventional and Kaipad rice fields

The most abundant species in Family Chalcididae reported from Conventional rice fields was *Brachymeria lasus*, followed by *Brachymeria* sp., *Antrocephalus* sp., *Antrocephalus phaeospilus*, *B. excarinata*, *B. nephantidis*, *B. jambolana*, *Hockeria aligharensis*, *Kriechbaumerella pulvinata*, *Dirhinus anthracia* and *Hockeria* sp. (Fig.3.21). In Kaipad rice fields also, the most abundant species was *B.lasus*, and followed by *Brachymeria* sp., *A.phaeospilus*, *B. excarinata*, *B. nephantidis*, *Antrocephalus* sp., *B. jambolana* and *H.aligharensis* (Fig.3.22).

Fig. 3.21: Species abundance of Chalcididae in Conventional rice fields.

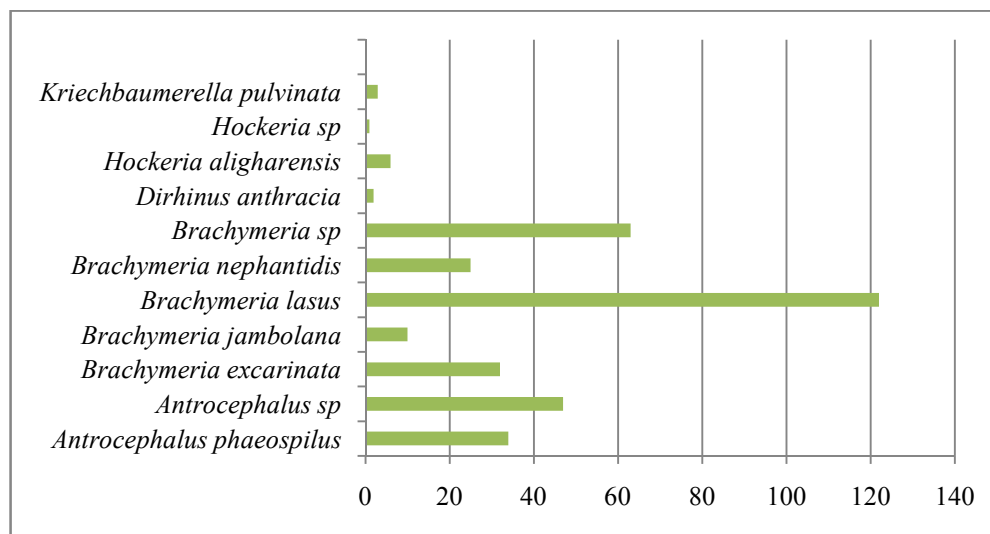
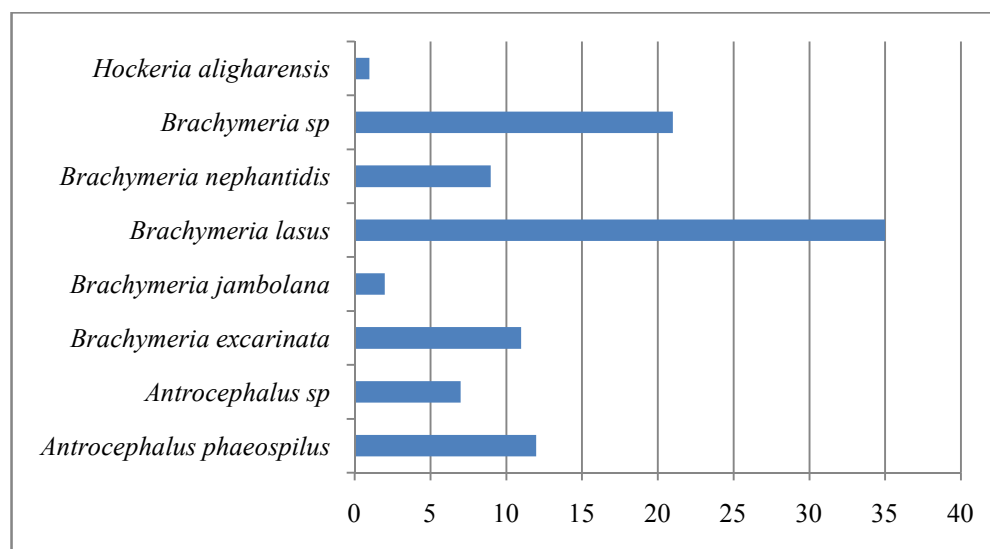


Fig. 3.22: Species abundance of Chalcididae in Kaipad rice fields.



Abundance of species of Eulophidae in Conventional and Kaipad rice fields.

The most abundant Eulophidae species recorded from Conventional rice field was *Tetrastichus schoenobii*, followed by *Elasmus* sp., *Tetrastichus* sp., *Aprostocetus* sp., *Pediobius* sp., *Chrysonotomyia* sp. and *Euplectrus* sp., etc (Fig.3.23). In Kaipad rice fields also the most dominant species was *T.schoenobii*, followed by *Tetrastichus* sp., *Elasmus* sp., *Pediobius* sp., *Aprostocetus* sp., *Chrysonotomyia* sp. and *Euplectrus* sp., *T. parapyxi* and *Omphale* sp. (Fig.3.24).

Fig. 3.23: Species abundance of Eulophidae in Conventional rice fields.

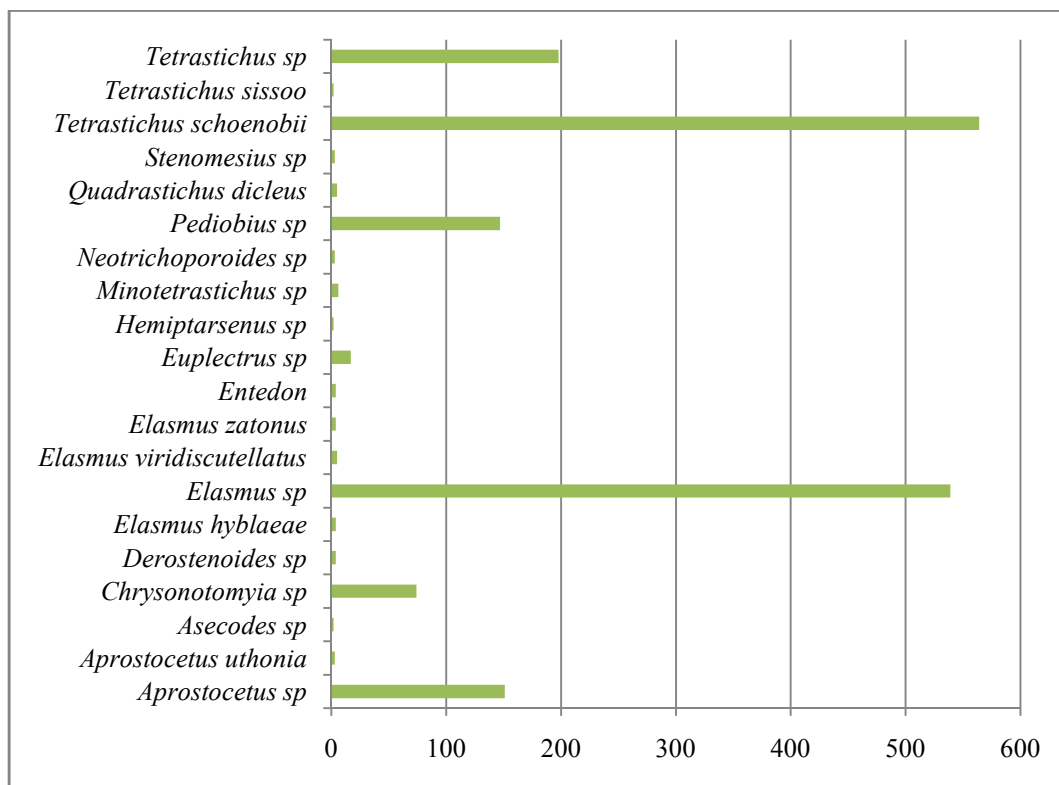
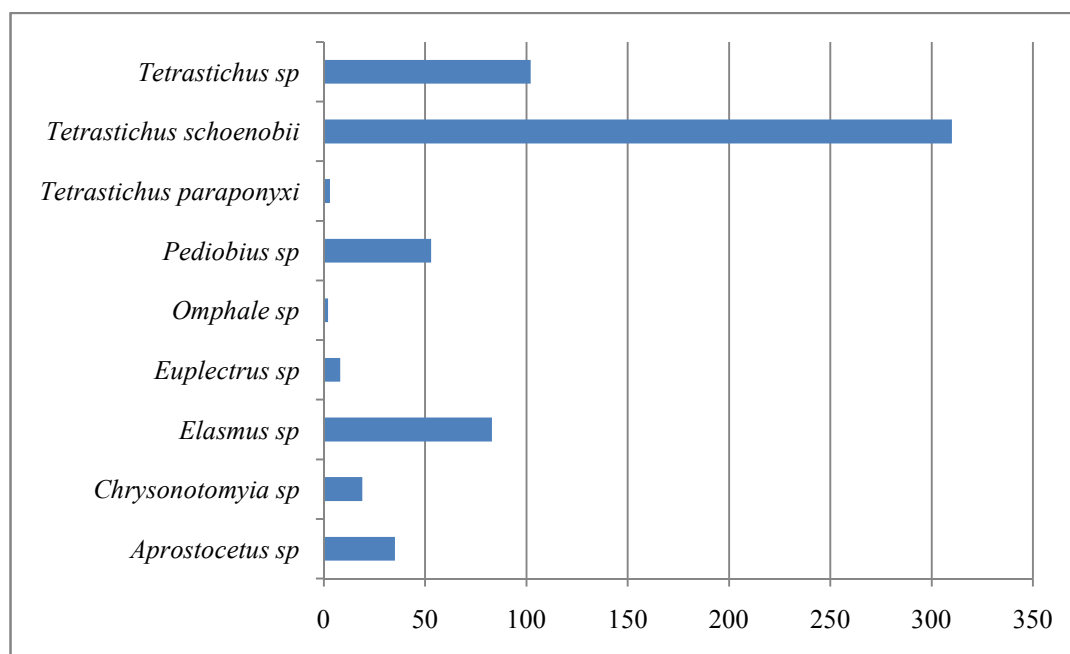


Fig. 3.24: Species abundance of Eulophidae in Kaipad rice fields.



Abundance of species of Eupelmidae in Conventional and Kaipad rice fields

During the present study, three species from Eupelmidae family were collected from Conventional rice fields and among them *Neanastatus* sp. was the most dominant one and followed by *Anastatus* sp. and *Eupelmus* sp. (Fig.3.25). In Kaipad rice fields also, *Neanastatus* sp. was the most dominant species, followed by *Anastatus* sp. (Fig.3.26).

Fig. 3.25: Species abundance of Eupelmidae in Conventional rice fields.

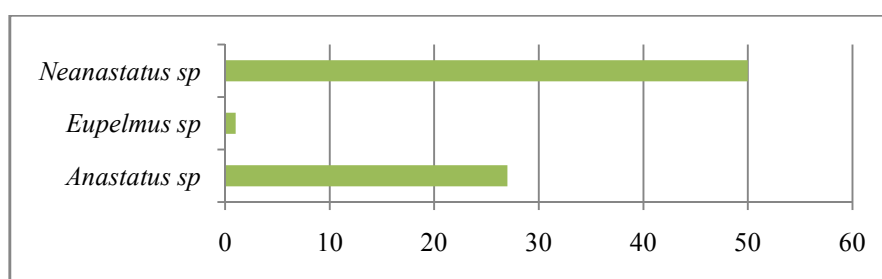
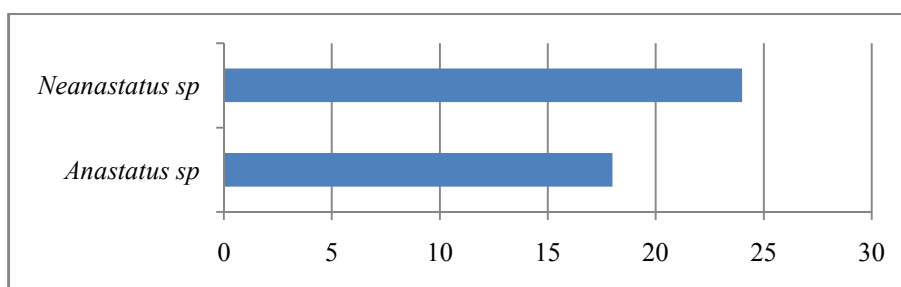


Fig. 3.26: Species abundance of Eupelmidae in Kaipad rice fields.



Abundance of species of Ichneumonidae in Conventional and Kaipad rice fields

In the case of Ichneumonidae, the most abundant species observed during present study in Conventional rice fields was *Charops bicolor*, followed by *Javra* sp., *Xanthopimpla flavolineata*, *Theronia* sp. and *Anomalon* sp. and the least noted ones were *Casinaraia* sp., *Trathala* sp. and *Diadegma* sp. (Fig.3.27). In Kaipad rice fields also *C.bicolor* was the most abundant, followed by *X.flavolineata*, *Theronia* sp. and *Anomalon* sp. in second, third and fourth position respectively (Fig.3.28).

Fig. 3.27: Species abundance of Ichneumonidae in Conventional rice fields.

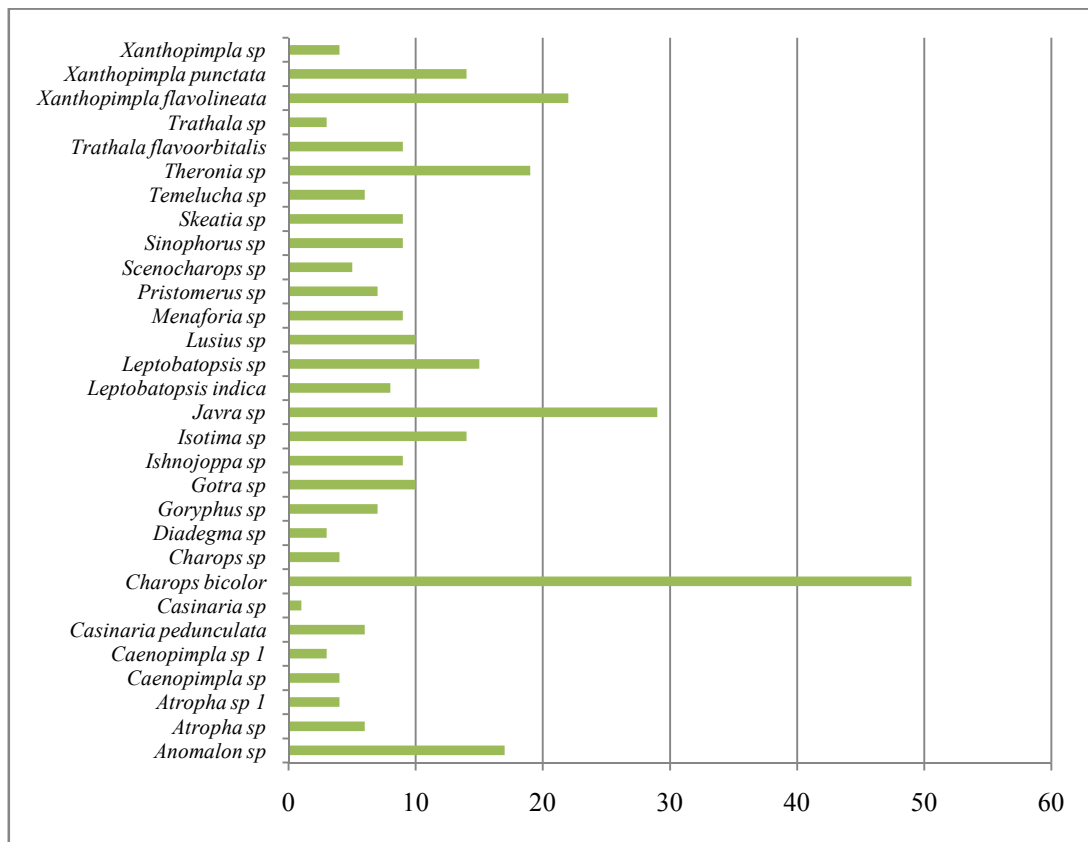
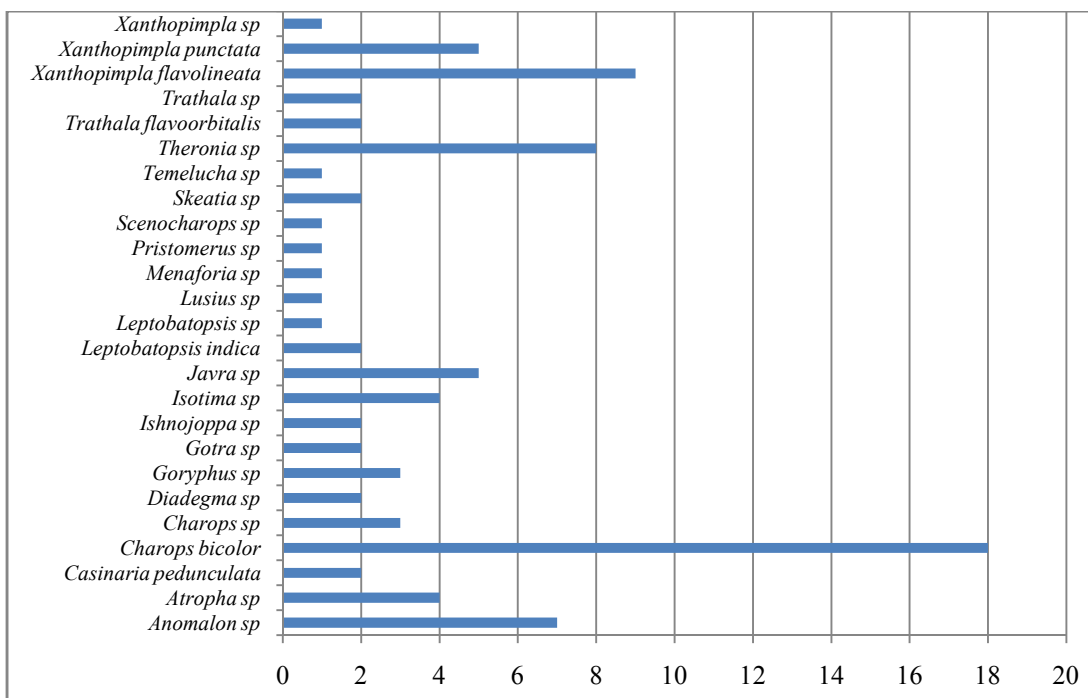


Fig. 3.28: Species abundance of Ichneumonidae in Kaipad rice fields.



Abundance of species of Mymaridae in Conventional and Kaipad rice fields

The most abundant mymarid species recorded from Conventional rice field was *Gonatocerus aegyptiacus*, followed by *Lymaenon munnarus*, *G.longicornis*, *G.shamimi*, *Anagrus* sp. and *L.aureus* (Fig.3.29). In the case of Kaipad rice fields also, the species *G.aegyptiacus* showed higher abundance, followed by *L. munnarus*, *G.longicornis*, *Mymar taprobanicum*, *L.aureus*, *G.shamimi* and *Anagrus* sp. *Myma* rsp., *Mymar schwanni*, *L.delhiensis*, *L.narayani* and *G.meghalayensis* were only reported from Conventional rice fields (Fig.3.30).

Fig. 3.29: Species abundance of Mymaridae in Conventional rice fields.

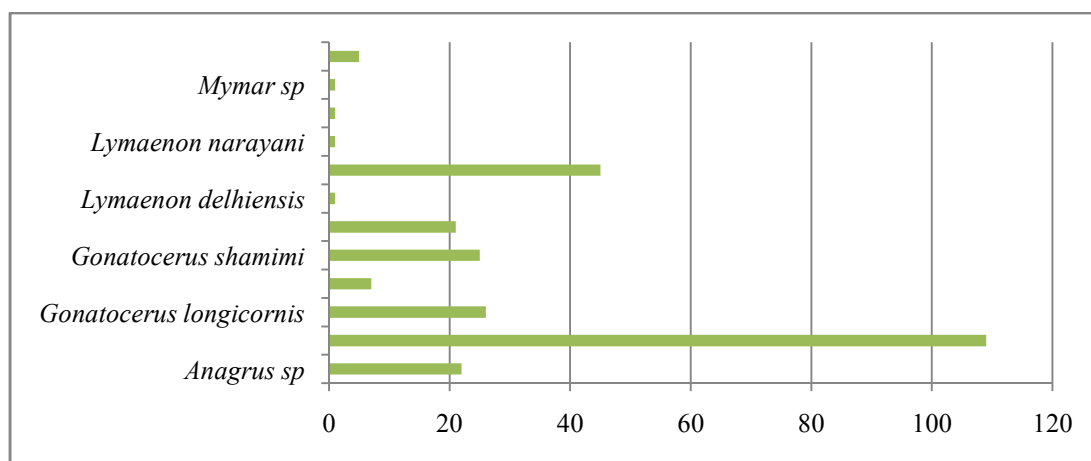
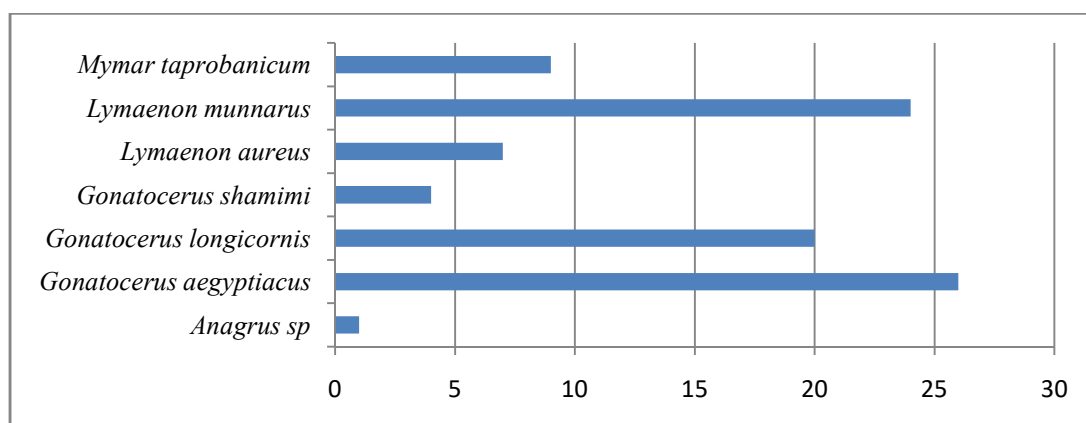


Fig. 3.30: Species abundance of Mymaridae in Kaipad rice fields.



Abundance of species of Platygasteridae in Conventional and Kaipad rice fields

In Platygasteridae, Twenty two species from Twenty one genus were collected from Conventional rice fields, and the most dominant species was *Telenomus* sp., followed by *Greyon* sp., *Trissolcus* sp., *Trimorus* sp., *Macroteleia* sp. and *Palpoteleia* sp.. The least noted species were *Habroteleia* sp., *Odontocolus* sp., and *Paratelenomus* sp. (Fig.3.31). *Telenomus* sp. also showed higher abundance in Kaipad rice fields among the 18 species collected (Fig.3.32).

Fig. 3.31: Species abundance of Platygasteridae in Conventional rice fields.

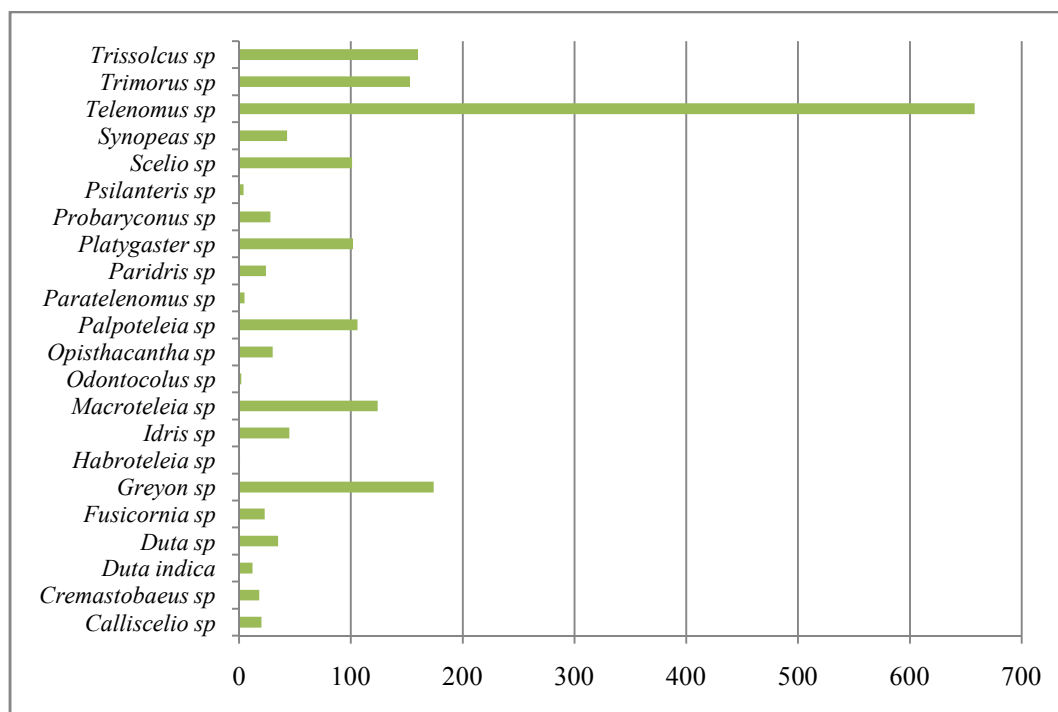
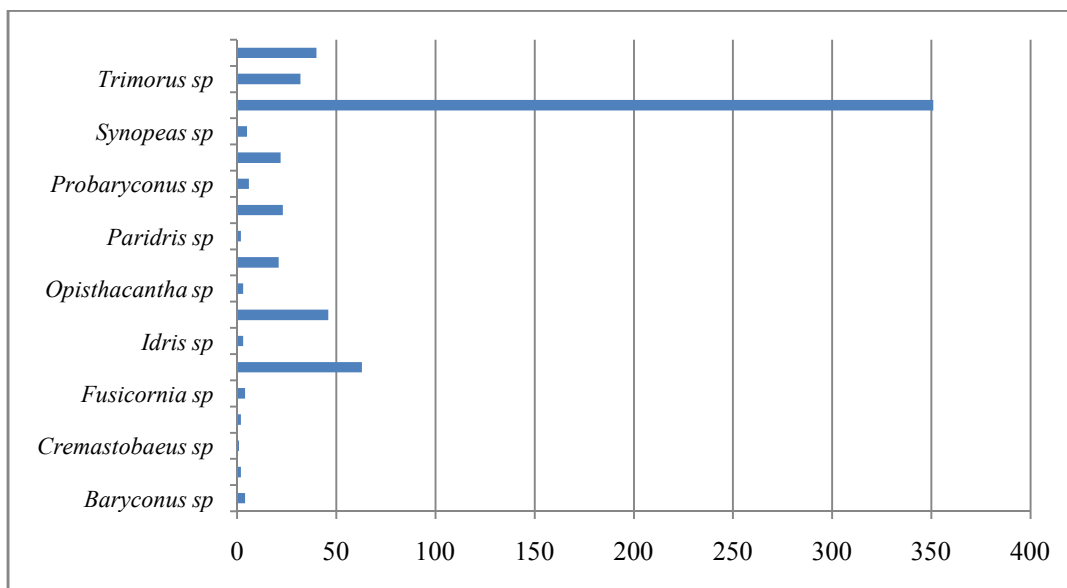


Fig. 3.32: Species abundance of Platygasteridae in Kaipad rice fields.



Abundance of species of Pteromalidae in Conventional and Kaipad rice fields

20 species coming under 6 Genus of Pteromalidae parasitoids were recorded from Conventional rice fields, and among them the most dominant species was *Trichomalopsis apanteloctena* (Fig.3.33). From Kaipad rice fields, 14 species in 6 genus were recorded, and among them *T. thekkadiensis* was the most dominant one (Fig.3.34).

Fig. 3.33: Species abundance of Pteromalidae in Conventional rice fields.

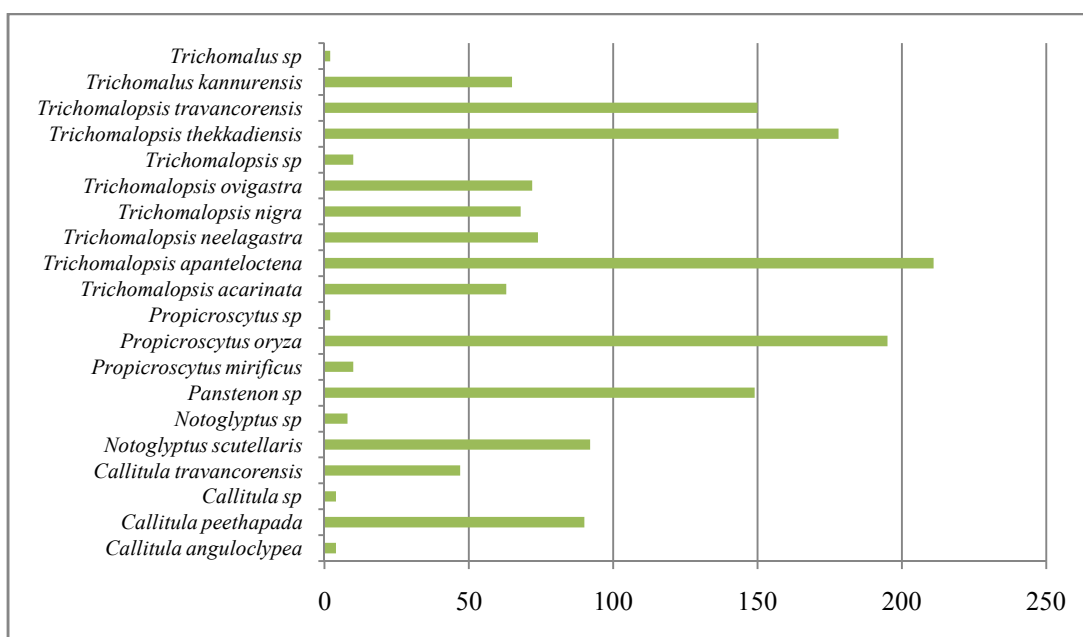
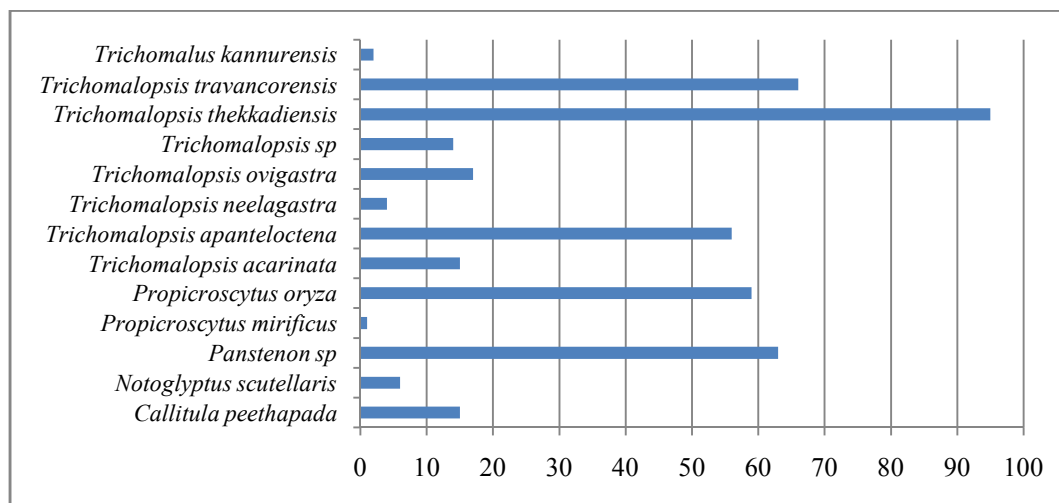


Fig. 3.34: Species abundance of Pteromalidae in Kaipad rice fields.



Abundance of species of Trichogrammatidae in Conventional and Kaipad rice fields

10 species under 6 Genus in Trichogrammatidae are recorded from Conventional rice fields. *Trichogramma chilonis* was the most abundant species followed by *Trichogramma sp.* and *T. japonicum*. The species *Chaetostricha sp.* and *Trichogrammatoidea bactrae* were the least dominant in Conventional rice fields (Fig.3.35). In Kaipad rice fields, 10 specie under 5 genus were recorded, and the most abundant species was *Trichogramma sp.* and followed by *Trichogramma chilonis* and *T. japonicum*. *Trichogrammatoidea bactrae*, *T.achaeae* and *Chaetostricha sp.* showed lower dominance in Kaipad rice fields (Fig.3.36).

Fig. 3.35: Species abundance of Trichogrammatidae in Conventional rice fields.

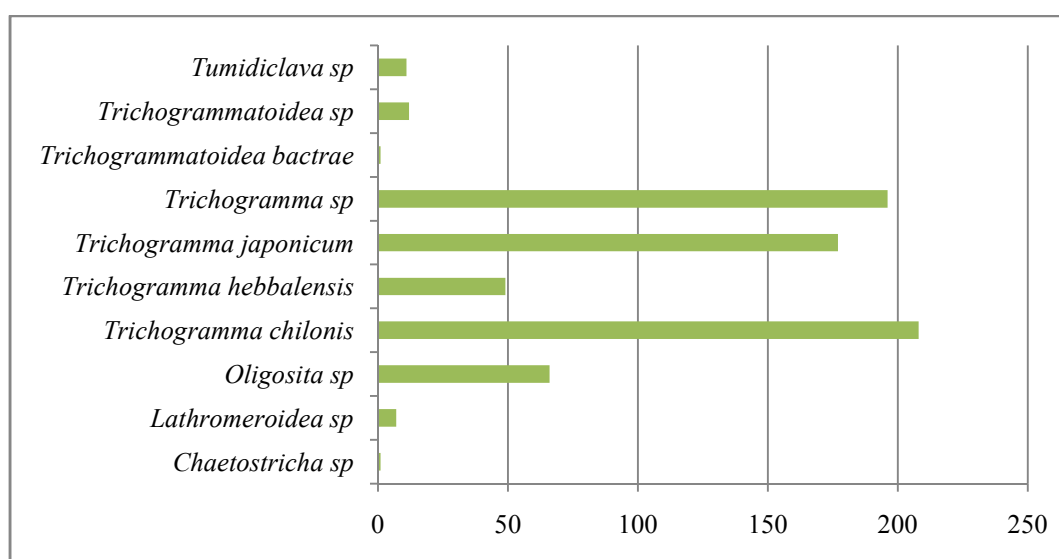
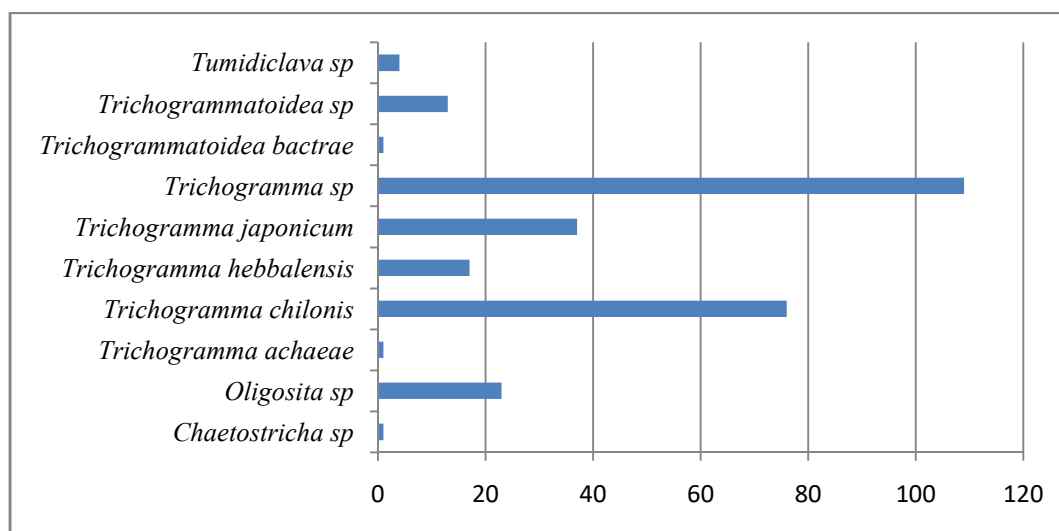


Fig. 3.36: Species abundance of Trichogrammatidae in Kaipad rice fields.

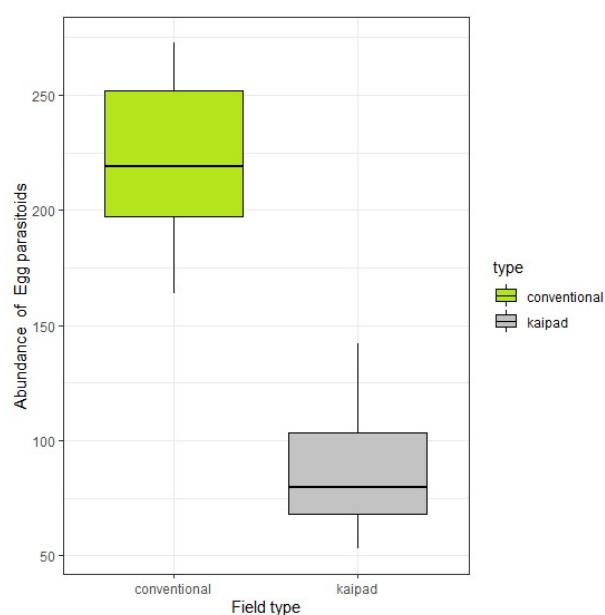


Abundance of parasitoid guilds in conventional and Kaipad rice fields

Egg parasitoids

The abundance of egg parasitoids was significantly different in Conventional and Kaipad rice fields ($p=2.014e-15$ ***) (Tab. 3.3). The range of observation in Conventional rice fields and Kaipad rice fields are given in Fig.3.37.

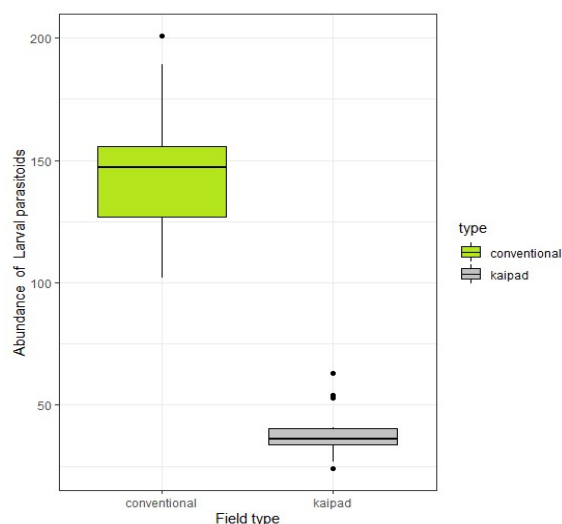
Fig. 3.37: Abundance of egg parasitoids in Conventional and Kaipad rice fields.



Larval parasitoids

The abundance of larval parasitoids in Conventional and Kaipad rice fields are significantly different ($p < 2.2e-16$ ***) (Tab. 3.3). The range of observation in Conventional rice fields and Kaipad rice fields are given in Fig.3.38.

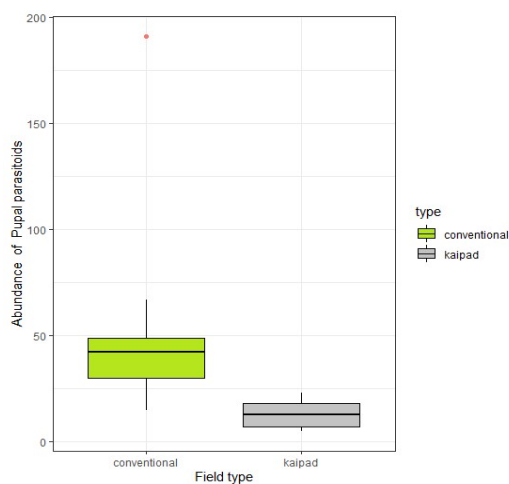
Fig. 3.38: Abundance of larval parasitoids in Conventional and Kaipad rice fields.



Pupal parasitoids

The abundance of pupal parasitoids in Conventional and Kaipad rice fields are significantly different ($2.863e-05$ ***) (Tab 3.3). The range of observation in Conventional rice fields and Kaipad rice fields are given in Fig. 33.9.

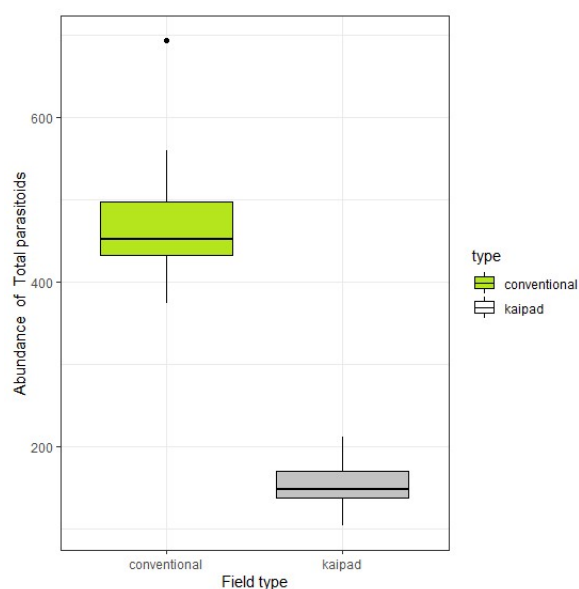
Fig. 3.39: Abundance of pupal parasitoids in Conventional and Kaipad rice fields.



Overall parasitoids

The total abundance of parasitoids in Conventional and Kaipad rice fields are also significantly different ($p < 2.2e-16$ ***) (Tab. 3.3). The range of observation in Conventional rice fields and Kaipad rice fields are given in Fig 3.40.

Fig. 3.40: Abundance of Overall parasitoids in Conventional and Kaipad rice fields.



Tab. 3.3: The abundance of parasitoid guilds in Conventional and Kaipad rice fields.

SI.No	Analysis	Sum sq	Df	F Value	Pr (>)
1	Egg Parasitoids	1110.4	1	188.3	2.014e-15 ***
2	Larval Parasitoids	1182.56	1	321.84	< 2.2e-16 ***
3	Pupal Parasitoids	391.38	1	23.314	2.863e-05 ***
4	OverallParsitoids	3109.74	1	355.9	< 2.2e-16 ***

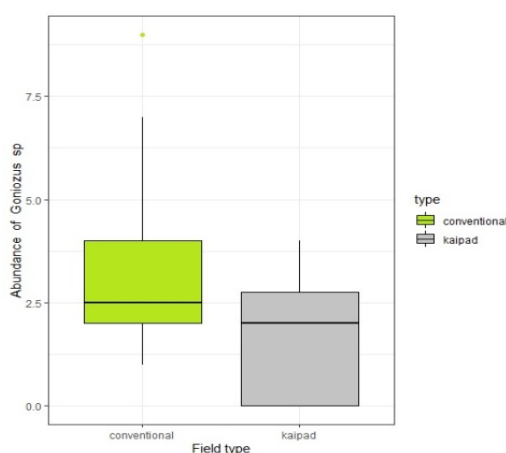
Abundance of parasitoid species in Conventional and Kaipad rice fields

Bethylidae

Goniozuz sp.

The abundance of *Goniozus* sp. (Plate XVII.1) in Conventional and Kaipad rice fields was significantly different ($p = 0.008022$ **)(Tab 3.4). More number of *Goniozus* sp. is recorded from Conventional rice fields (Fig.3.41).

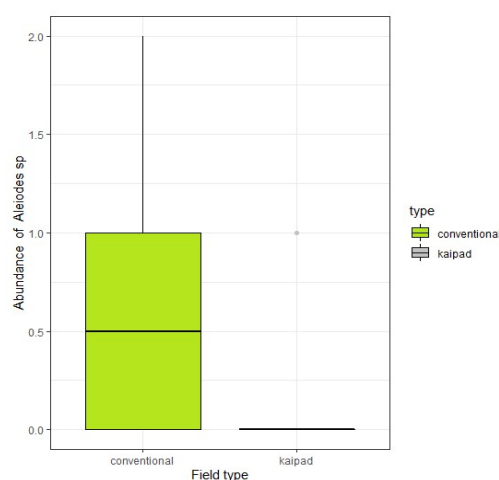
Fig. 3.41: Abundance of *Goniozus* sp. in Conventional and Kaipad rice fields.



Braconidae

35 species of Braconidae have been recorded during the study. Among them, the abundance of *Aleiodes* sp., *Apanteles* sp.(Plate XVII.2), *Aspidobracon noyesi* (Plate XVII.5), *Aspidobracon* sp.(Plate XVII.6), *Bracon brevicornis*, *Bracon* sp. (Plate.XVII.7), *Cardiochiles* sp. (Plate XVIII.10), *Chelonus* sp. (Plate XVIII.11), *Cotesia* sp.(Plate XVIII.12), *Dolichogenidea* sp.(Plate XVIII.15), *Exoryza* sp., *Macrocentrus* sp. (Plate XIX.21), *Microplitis* sp., *Myosoma* sp., *Opiine* sp.2 (Plate XIX.24) and *Orgilonia ashmeadi* (Plate XX.25) are significantly different between the Conventional and Kaipad rice fields (Tab. 3.4). *Aleiodes* sp. is more abundant in Conventional rice fields than Kaipad ($p=0.003073$ **)(Tab. 3.4) (Fig.3.42).

Fig. 3.42: Abundance of *Aleiodes* sp. in Conventional and Kaipad rice fields.



The abundance of *Amyosoma chinensis* is higher in Conventional rice fields than in Kaipad rice fields but the difference is not significantly different ($p=0.2741$) (Tab. 3.4). The abundance of *Apanteles* sp. in Conventional and Kaipad rice fields is significantly different ($p=0.0005511$ ***)(Tab3.4)(Fig.3.43 and Fig.3.44).The *Apanteles* sp.2 (XVII.4) is only recorded from Conventional rice fields.

Fig. 3.43: Abundance of *Apanteles* sp. in Conventional and Kaipad rice fields.

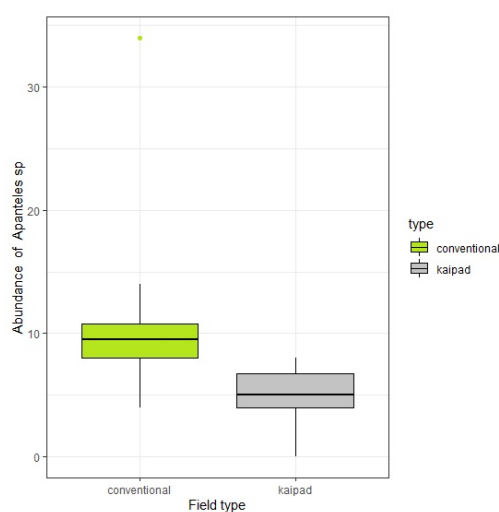
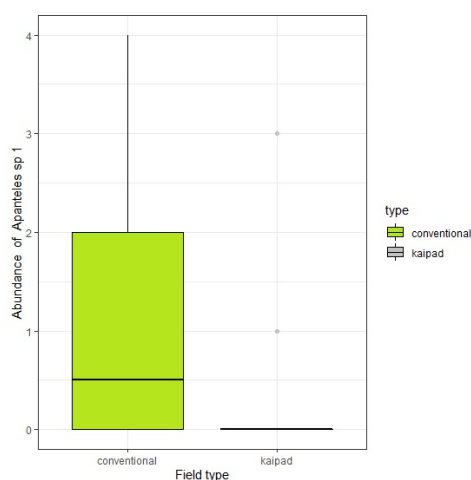


Fig. 3.44: Abundance of *Apanteles* sp.1 in Conventional and Kaipad rice fields.



Aspidobracon noyesi, and *Aspidobracon* sp. are recorded from Conventional rice fields. The abundance of *A.noyesi*, and *Aspidobracon* sp. in Conventional and Kaipad are significantly different ($p=0.01777$ *, and $p= 0.01057$ * respectively)

(Tab. 3.4). The range of *A. noyesi* and *Aspidobracon* sp. in Conventional and Kaipad rice fields are given in the Figs. 3.45 and 3.46.

Fig. 3.45: Abundance of *Aspidobracon noyesi* in Conventional and Kaipad rice fields.

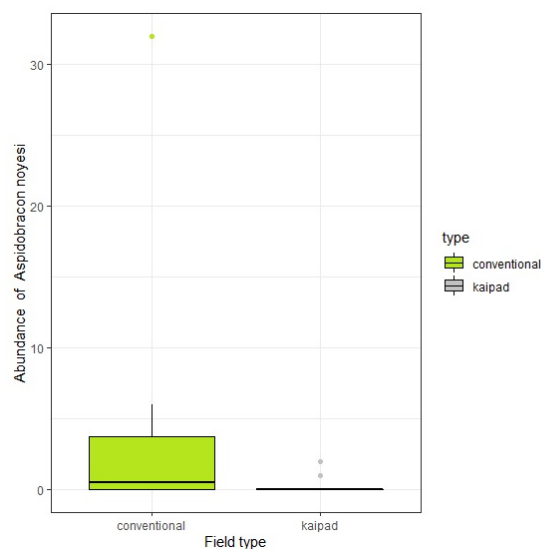
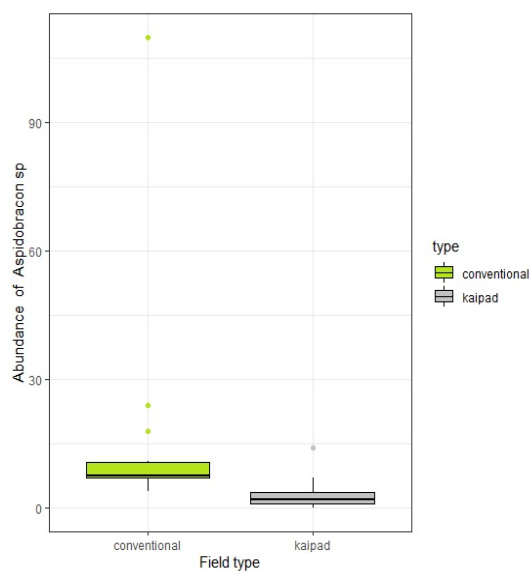


Fig. 3.46: Abundance of *Aspidobracon* sp. in Conventional and Kaipad rice fields.



Bracon brevicornis, *Bracon* sp., *Bracon* sp.1 (Plate XVII.8) and *Bracon* sp.2 (Plate XVIII.9) are reported from Conventional rice fields (Tab. 3.4), but the presence of *Bracon* sp.1 and *Bracon* sp.2 are not reported in Kaipad rice fields. The

four species showed higher abundance in Conventional rice fields than in Kaipad rice fields (Figs. 3.47 and 3.48).

Fig. 3.47: Abundance of *Bracon brevicornis* between Conventional and Kaipad rice fields.

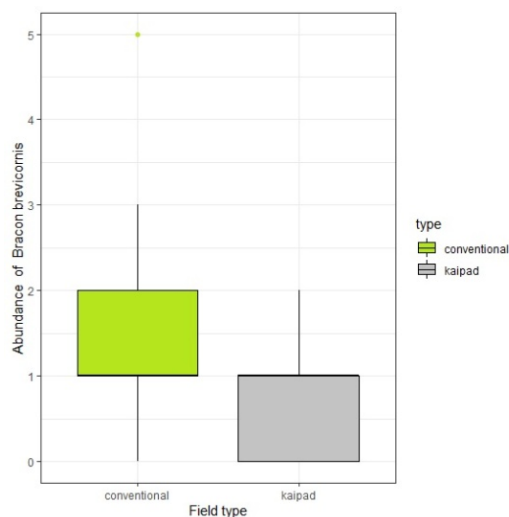
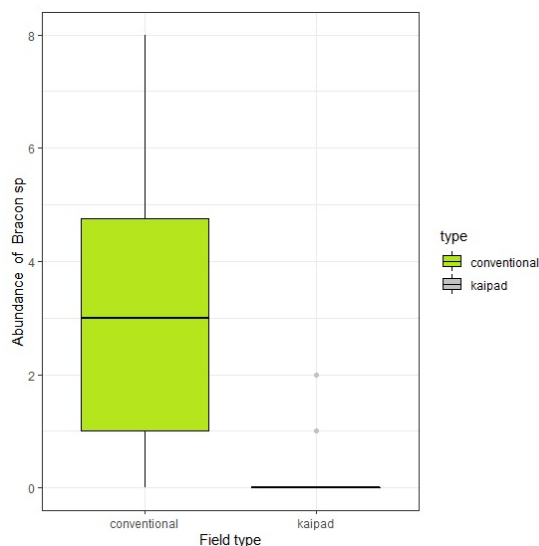
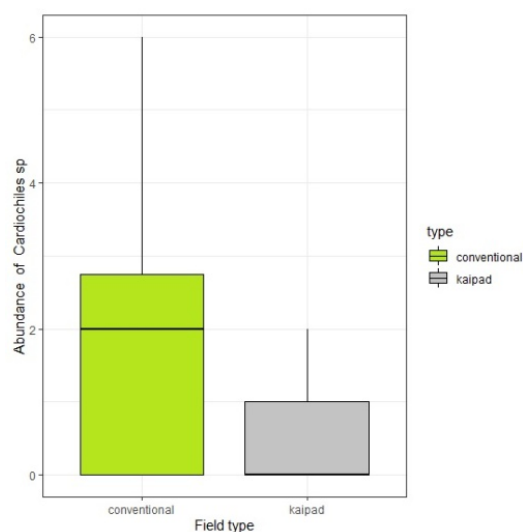


Fig. 3.48: Abundance of *Bracon* sp.in Conventional and Kaipad rice fields.



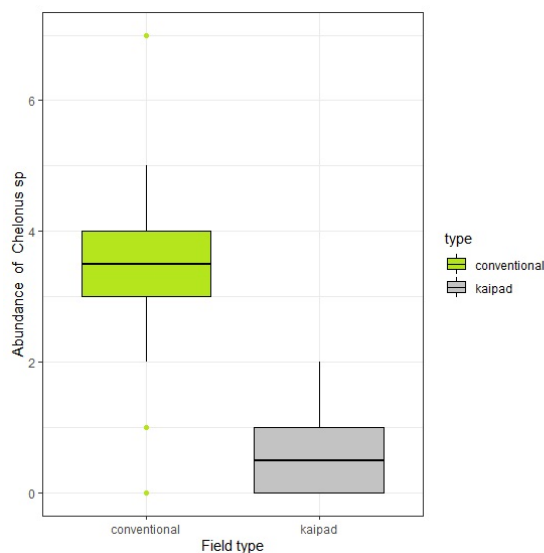
The abundance of *Cardiochiles* sp. in the Conventional and Kaipad rice fields are significantly different ($p=0.002054$ **) (Tab. 3.4) (Fig.3.49).

Fig. 3.49: Abundance of *Cardiochiles* sp. in Conventional and Kaipad rice fields.



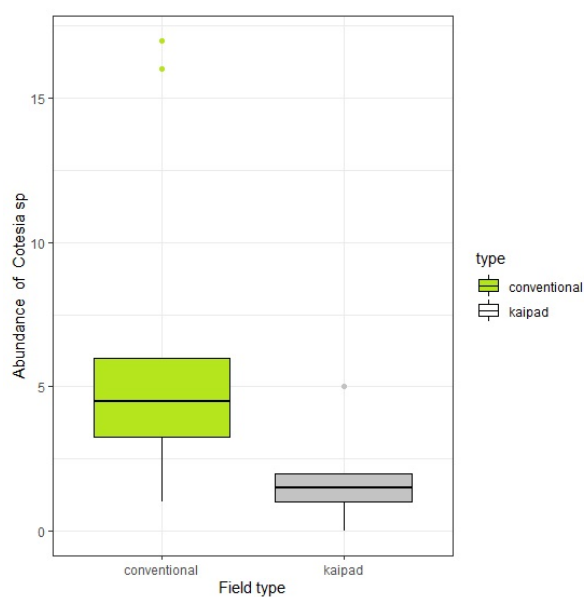
Chelonus sp. is more abundant in Conventional rice fields than in Kaipad rice fields ($p=2.453\text{e-}07$ ***) (Tab.3.4) (Fig.3.50).

Fig. 3.50: Abundance of *Chelonus* sp. in Conventional and Kaipad rice fields.



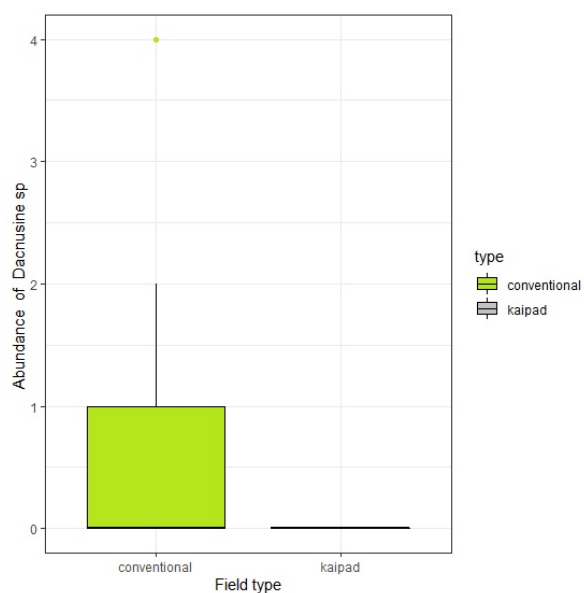
Two species of *Cotesia* are recorded from both Conventional and Kaipad rice fields and the abundance of *Cotesia* sp. in the two types of fields is significantly different ($p=0.0001736$ ***) (Fig.3.51).

Fig. 3.51: Abundance of *Cotesia* sp. in Conventional and Kaipad rice fields.



The Genus *Dacnusine* is only reported from Conventional rice fields, and range of *Dacnusine* sp. in Conventional and Kaipad rice fields is given in the Fig. 3.52.

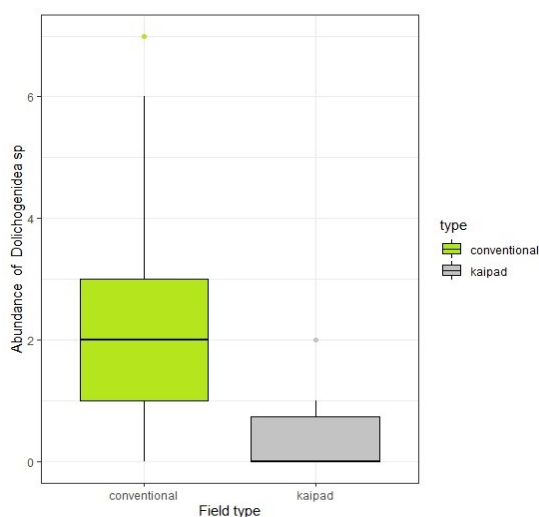
Fig. 3.52: Abundance of *Dacnusine* sp. in Conventional and Kaipad rice fields.



The abundance of *Diadegma* sp. is higher in Conventional than in Kaipad rice fields ($p=0.6414$) (Tab. 3.4). Two species of genus *Dolichogenidea* viz.

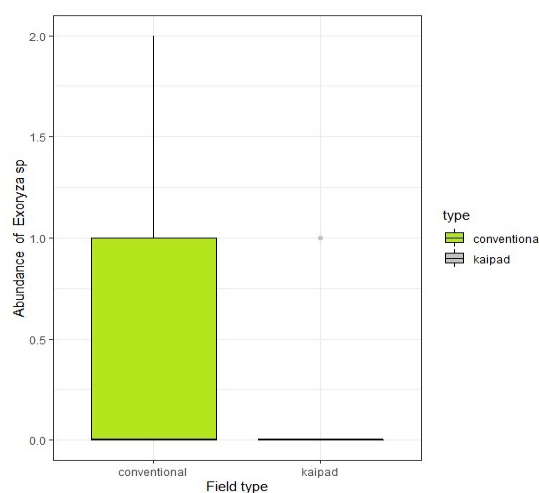
Dolichogenidea sp. and *Dolichogenidea* sp.1 are found in Conventional rice fields and one species (*Dolichogenidea* sp.) in Kaipad rice fields. The abundance of *Dolichogenidea* sp. in Conventional and Kaipad rice fields are significantly different ($p=2.781e-05$ ***) (Tab. 3.4) (Fig.3.53).

Fig. 3.53: Abundance of *Dolichogenidea* sp. in Conventional and Kaipad rice fields.



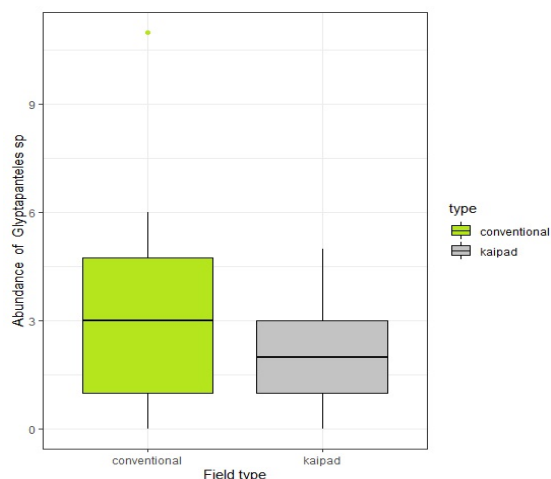
Two species of the genus *Exoryza*, viz. *Exoryza schoenobii* and *Exoryza* sp. are recorded from the conventional and Kaipad rice fields (Tab. 3.4), with *Exoryza* sp. showing higher abundance in conventional rice fields ($p=0.004971$ **) (Tab. 3.4) (Fig.3.54 & 3.55).

Fig. 3.54: Abundance of *Exoryza* sp. in Conventional and Kaipad rice fields.



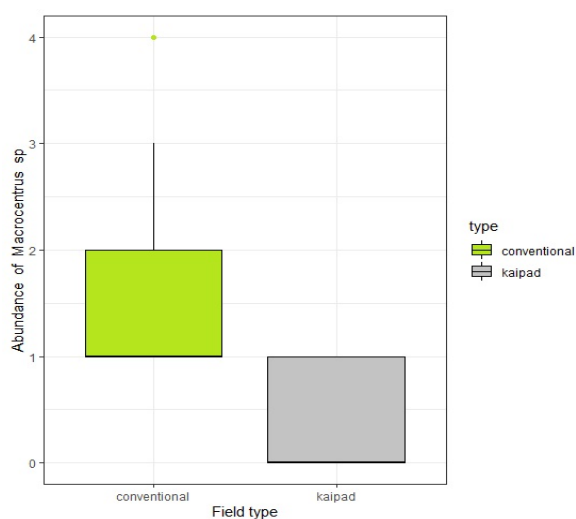
The abundance of *Glyptapanteles* sp. (Plate XIX.18)(Fig.3.55) and *Gnamptodon* sp. are higher in Conventional rice fields, but the difference is not significantly different (($p=0.144$ and $p=0.2069$ respectively) (Tab. 3.4).

Fig. 3.55: Abundance of *Glyptapanteles* sp. in Conventional and Kaipad rice fields.



Two species under the Genus *Macrocentrus* are recorded during present study. The reported species from Conventional rice fields are *Macrocentrus philippinensis* (Plate XIX.20) and *Macrocentrus* sp.(Plate XIX.21) and only *Macrocentrus* sp. is recorded from Kaipad rice fields. The abundance of *Macrocentrus* sp. in Conventional and Kaipad rice fields is significantly different ($p=5.15e-06$ ***) (Tab. 3.4). The range of *Macrocentrus* sp. is higher in Conventional type of rice fields (Fig.3.56).

Fig. 3.56: Abundance of *Macrocentrus* sp. in Conventional and Kaipad rice fields.



The abundance of the species *Microplitis* sp. and *Myosoma* sp. are significantly different in Conventional and Kaipad rice fields ($p=1.246e-06$ *** and $p=0.008167$ ** respectively) (Tab. 3.4) (Fig.3.57 and Fig.3.58).

Fig. 3.57: Abundance of *Microplitis* sp. in Conventional and Kaipad rice fields.

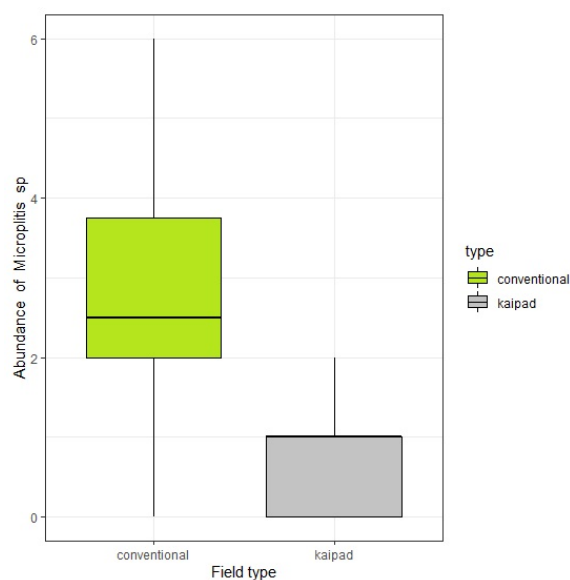
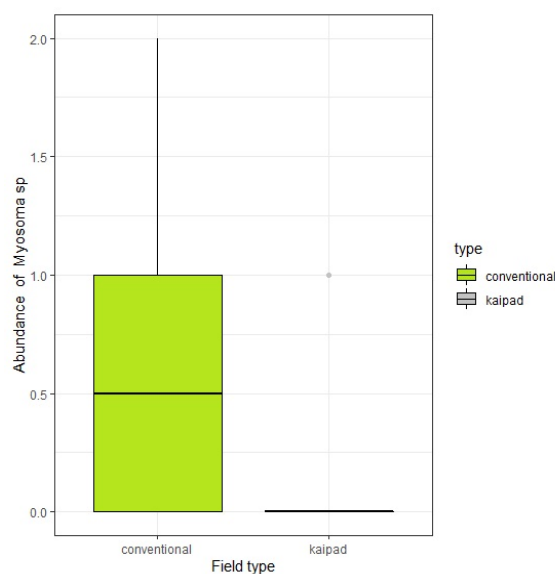


Fig. 3.58: Abundance of *Myosoma* sp. in Conventional and Kaipad rice fields.



Under the genus *Opiine* in Braconidae family, four species are reported during present study, viz: *Opiine* sp., *Opiine* sp1., *Opiine* sp2. And *Opiine* sp3. All of them are recorded from Conventional rice fields, but *Opiine* sp. is not reported

from Kaipad rice fields. These four species showed higher abundance in Conventional rice fields than Kaipad rice fields, and significant difference is noted in the abundance of *Opiine* sp2. And *Opiine* sp3 in Conventional and Kaipad rice fields ($p=0.0002568$ *** and $p=0.0017$ **)(Tab. 3.4), but *Opiine* sp.1 is not showing any significant difference ($p=0.5159$)(Tab. 3.4)(Figs. 3.59, 3.60, 3.61 and 3.62).

Fig. 3.59: Abundance of *Opiine* sp. in Conventional and Kaipad rice fields.

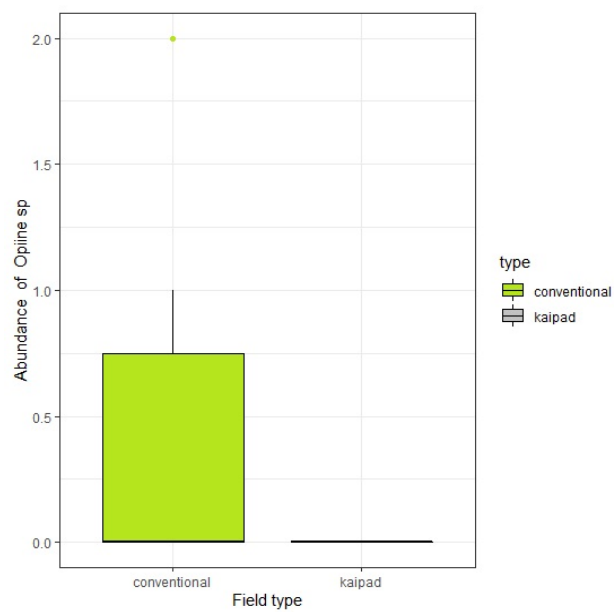


Fig. 3.60: Abundance of *Opiine* sp.1 in Conventional and Kaipad rice fields.

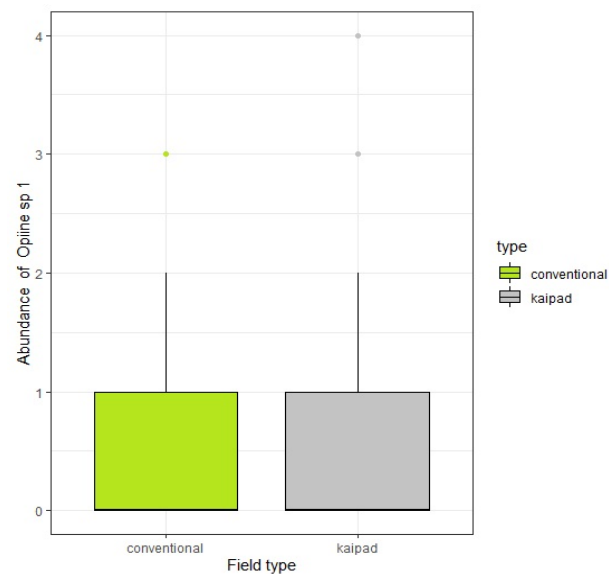


Fig. 3.61: Abundance of *Opiine* sp.2 in Conventional and Kaipad rice fields.

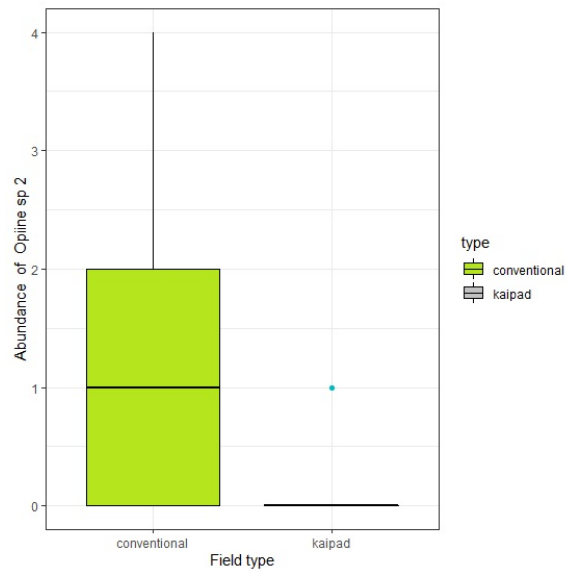
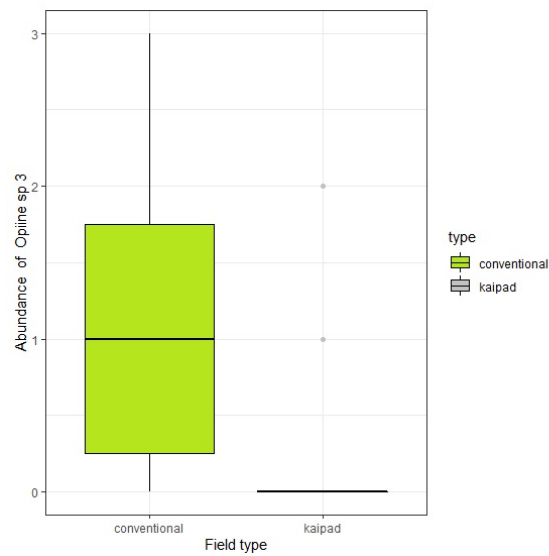
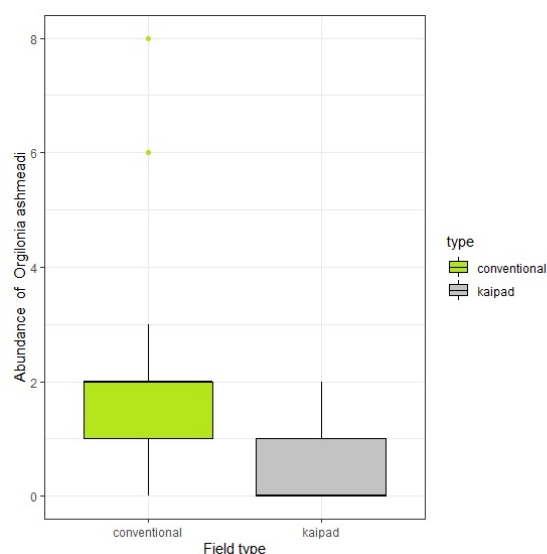


Fig. 3.62: Abundance of *Opiine* sp.3 in Conventional and Kaipad rice fields.



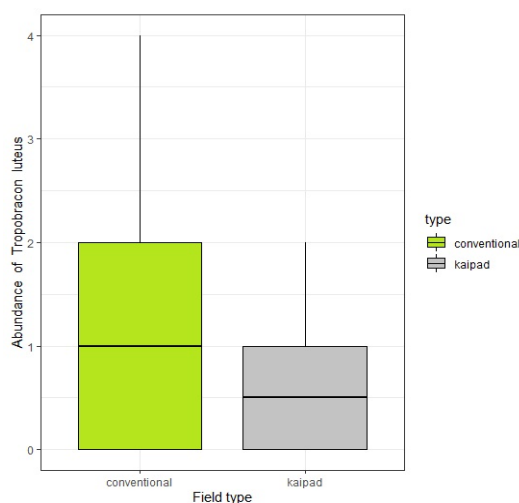
The abundance of *Orgilonia ashmeadi* in Conventional and Kaipad rice fields are significantly different ($p=0.001837$ **) (Tab. 3.4)(Fig.3.63).

Fig. 3.63: Abundance of *Orgilonia ashmeadi* in Conventional and Kaipad rice fields.



Parapanteles sp. (Plate XX.26), *Rhaconotus* sp. (Plate XX.27) and *Scutibracon* sp. (Plate XX.28) are minor Braconidae species recorded during the present study. The abundance of *Parapanteles* sp. in Conventional and Kaipad rice fields is not significantly different ($p=0.1121$) (Tab. 3.4). The species *Rhaconotus* is only reported in Kaipad rice fields and the *Scutibracon* sp. is only seen in Conventional rice fields. There is no significant difference between the abundance of *Tropobracon luteus* (Plate XX.29) in Conventional and Kaipad rice fields ($p=0.06189$) (Tab. 3.4)(Fig.3.64).

Fig. 3.64: Abundance of *Tropobracon luteus* in Conventional and Kaipad rice fields.



Ceraphronidae

Aphanogamus sp. and *Ceraphron* sp. are the species under Ceraphronidae recorded during present study. *Aphanogamus* sp. ($p=0.003267^{**}$)(Fig.65) showed significant difference in their abundance between both categories of fields, while *Ceraphron* sp. did not show any significant difference ($p=0.3298$) (Tab. 3.4)(Fig.3.66).

Fig. 3.65: Abundance of *Aphanogamus* sp. in Conventional and Kaipad rice fields.

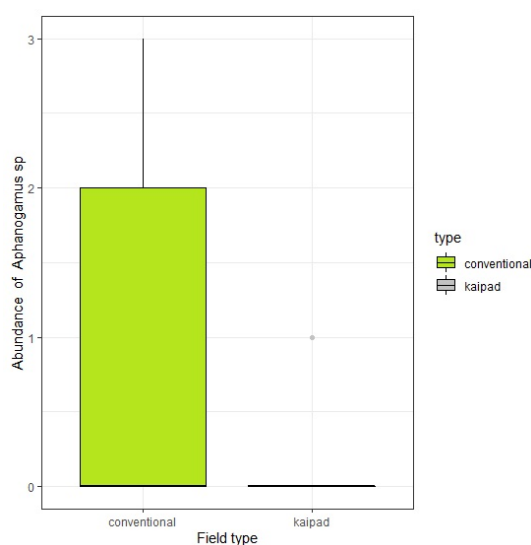
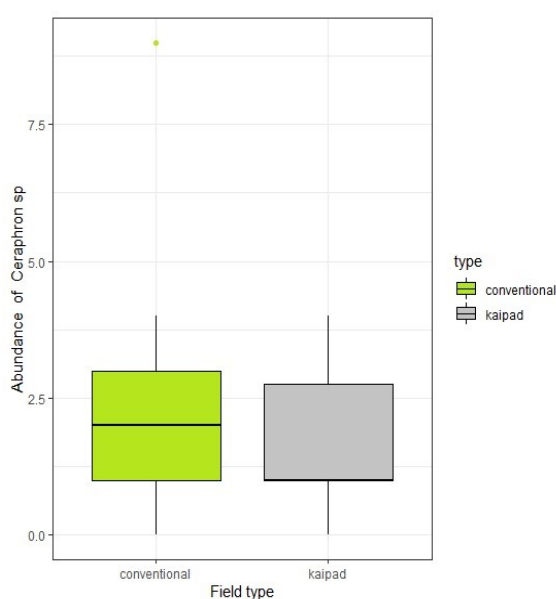


Fig. 3.66: Abundance of *Ceraphron* sp. in Conventional and Kaipad rice fields.



Chalcididae

Antrocephalus phaeospilus ($p=0.001175$ **)(Fig.3.67)(Plate XX.30), *Antrocephalus* sp. ($p=8.706e-05$ ***)(Fig.3.68)(Plate XX.31), *Brachymeria excarinata* ($p=0.007699$ **)(Fig.3.69)(Plate XX.32), *Brachymeria jambolana* ($p=0.01132$ *)(Fig.3.70), *Brachymeria lasus* ($p=2.443e-05$ ***)(Fig.3.71)(Plate XXI.33), *Brachymeria nephandidis* ($p=0.02362$ *)(Fig.3.72)(Plate XXI.34), *Brachymeria* sp. ($p=0.002187$ **)(Fig.3.73) and *Hockeria aligharensis* ($p=0.0383$ *)(Fig.3.74)(Plate XXI.36) are showing significant difference in their abundance in Conventional and Kaipad rice fields (Tab. 3.4). *Dirhinus anthracia* (Plate XXI.35), *Hockeria* sp. (Plate XXI.37) and *Kriechbaumerella pulvinata* (Plate XXI.38) are only reported from Conventional rice fields.

Fig. 3.67: Abundance of *Antrocephalus phaeospilus* in Conventional and Kaipad rice fields.

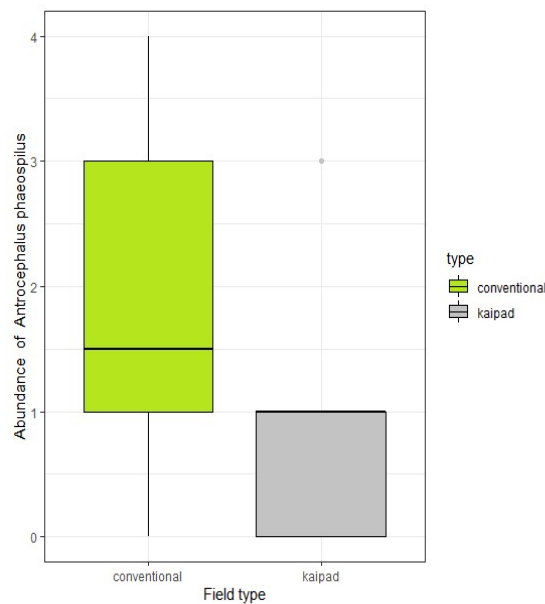


Fig. 3.68: Abundance of *Antrocephalus* sp. in Conventional and Kaipad rice fields.

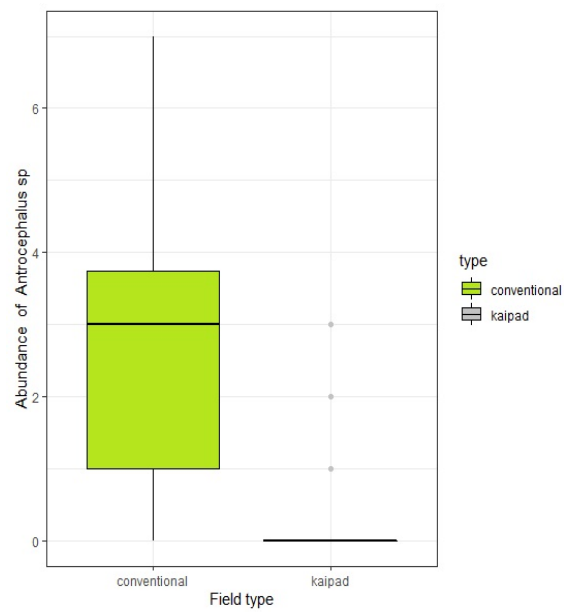


Fig. 3.69: Abundance of *Brachymeria excarinata* in Conventional and Kaipad rice fields.

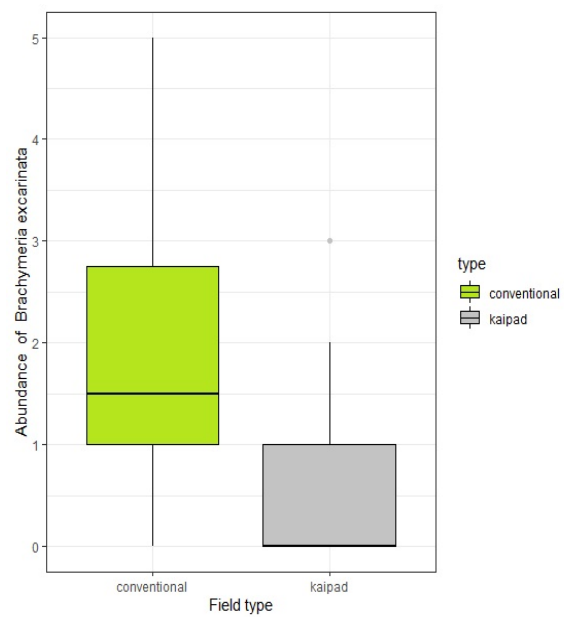


Fig. 3.70: Abundance of *Brachymeria jambolana* in Conventional and Kaipad rice fields.

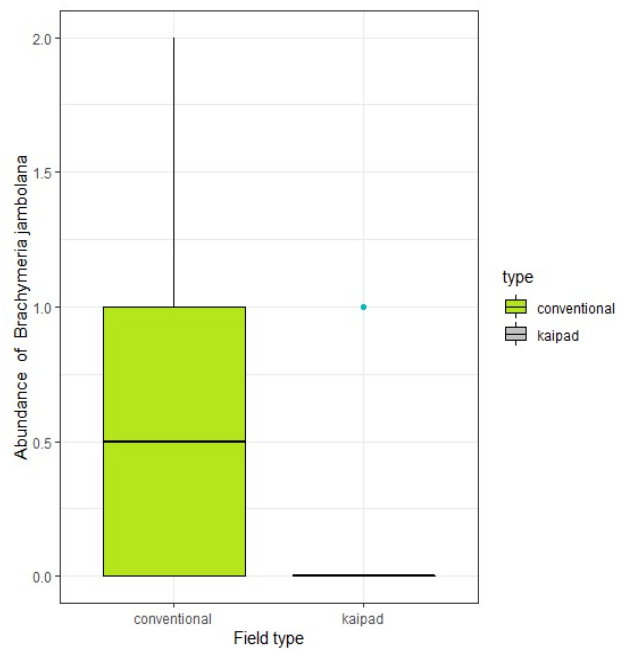


Fig. 3.71: Abundance of *Brachymeria lasus* in Conventional and Kaipad rice fields.

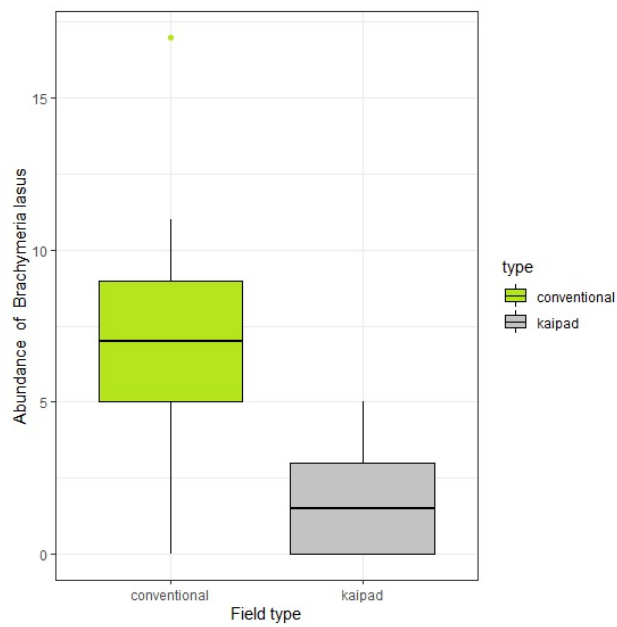


Fig. 3.72: Abundance of *Brachymeria nephtidis* in Conventional and Kaipad rice fields.

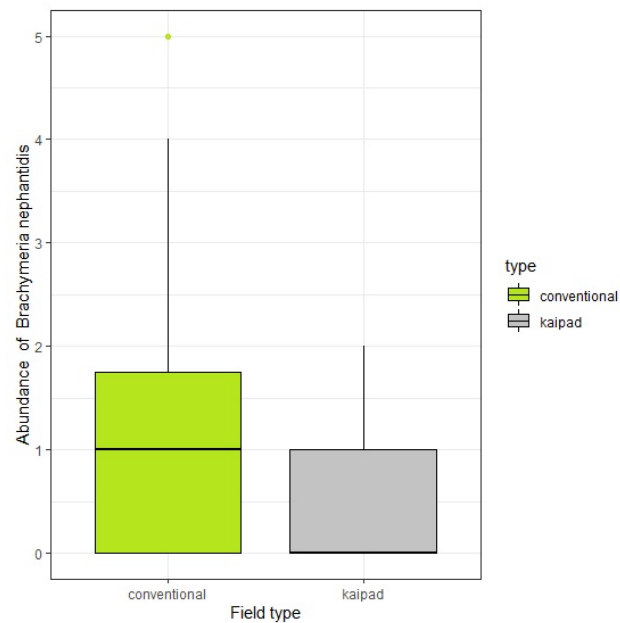


Fig. 3.73: Abundance of *Brachymeria* sp. in Conventional and Kaipad rice fields.

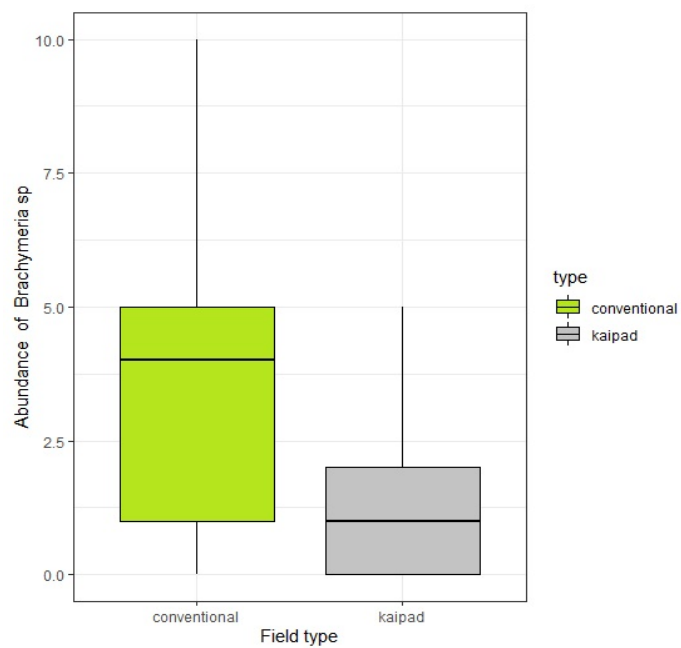
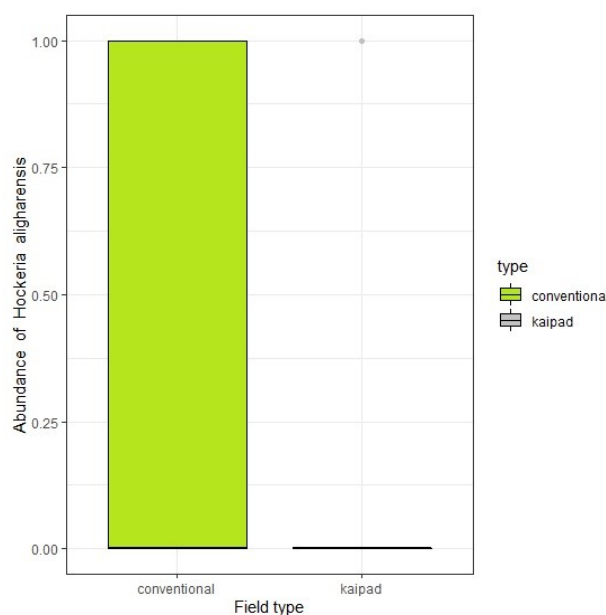


Fig. 3.74: Abundance of *Hockeria aligharensis* in Conventional and Kaipad rice fields.



Eulophidae

The species of Eulophidae family recorded during present study are *Aprostocetus* sp., *Aprostocetus uthonia* Narendran, *Asecodes* sp., *Chrysonotomyia* sp., *Derostenoides* sp., *Elasmus hyblaeae* Ferriere (Plate XXI.40), *Elasmus* sp. (Plate XXI.39), *Elasmus viridiscutellatus* Verma et Hayat (Plate XXII.41), *Elasmus zatonus* Narendran&Sheeba (Plate XXII.42), *Entedon* sp. (Plate XXII.47), *Euplectrus* sp. (Plate XXII.48), *Hemiptarsenus* sp. (Plate XXIII.49), *Minotetrastichus* sp.(Plate XXIII.50), *Neotrichoporoides* sp. (Plate XXIII.51), *Omphale* sp.(Plate XXIII.52), *Pediobius* sp.(Plate XXIII.53), *Quadrastichus dicleus* Narendran (Plate XXIII.54), *Stenomesus* sp.(Plate XXIII.55), *Tetrastichus parapyxi* Santhosh (Plate XXIII.56), *Tetrastichus schoenobii*, *Tetrastichus sissoo* Khan, Agnihotri & Sushil (Plate XXIV.57), and *Tetrastichus* sp. (Plate XXIV.58) Among them *Aprostocetus* sp. (Plate XXII.44), *Chrysonotomyia* sp., *Elasmus* sp.(Plate XXI.39), *Euplectrus* sp., *Pediobius* sp., *Tetrastichus schoenobii* and *Tetrastichus* sp. are recorded from both categories of rice fields, and *Omphale* sp. and *Tetrastichus parapyxi* is only noted in Kaipad.

The abundance of *Aprostocetus* sp. ($p=1.112e-07$ ***)(Fig.3.75), *Chrysonotomyia* sp. ($p=0.0006612$ ***)(Fig.3.76), *Elasmus* sp. ($p=2.57e-09$ ***)(Fig.3.77), *Pediobius* sp. ($p=1.148e-05$ ***)(Fig.3.78), *Tetrastichus schoenobii* (0.0001255 ***)(Fig.3.79), *Tetrastichus* sp. (0.0001318 ***)(Fig.3.80) showed significant difference in their abundance in Conventional and Kaipad rice fields (Tab. 3.4). The *Euplectrus* sp. is the only species which is not showing any significant difference in their abundance in Conventional and Kaipad rice fields ($p=0.2116$)(Fig.3.77) (Tab. 3.4).

Fig. 3.75: Abundance of *Aprostocetus* sp. in Conventional and Kaipad rice fields.

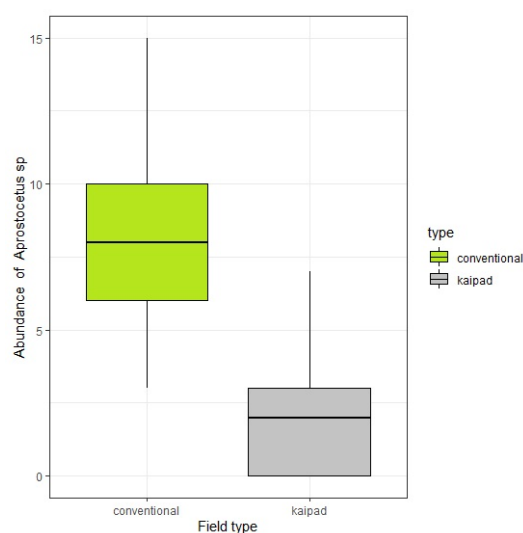


Fig. 3.76: Abundance of *Chrysonotomyia* sp. in Conventional and Kaipad rice fields.

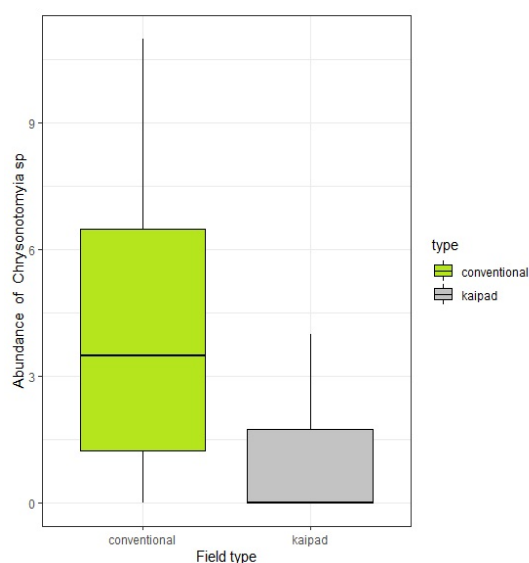


Fig. 3.77: Abundance of *Elasmus* sp. in Conventional and Kaipad rice fields.

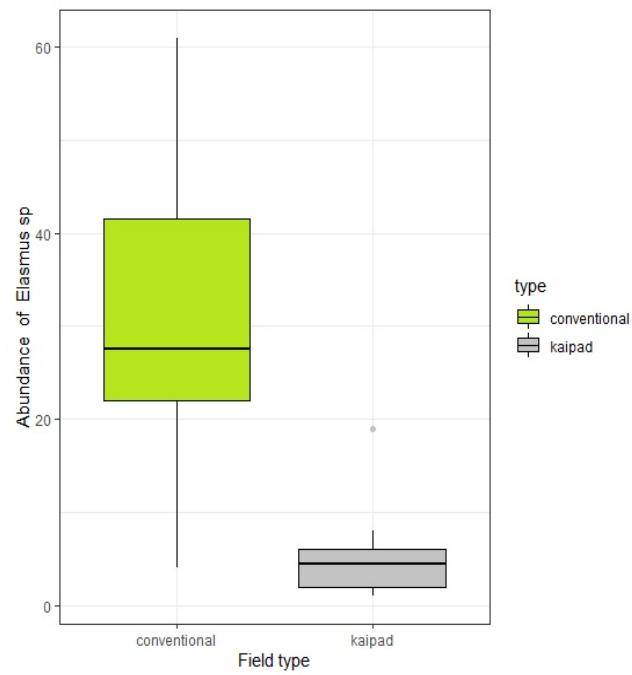


Fig. 3.78: Abundance of *Euplectrus* sp. in Conventional and Kaipad rice fields.

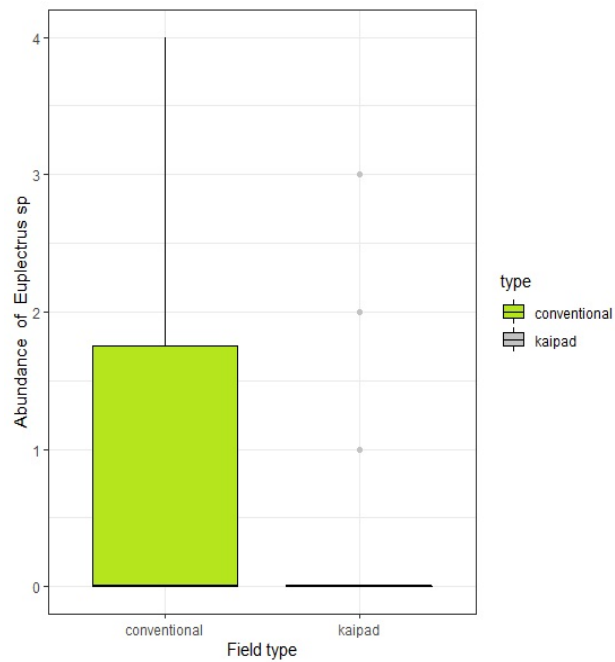


Fig. 3.79: Abundance of *Pediobius* sp. in Conventional and Kaipad rice fields.

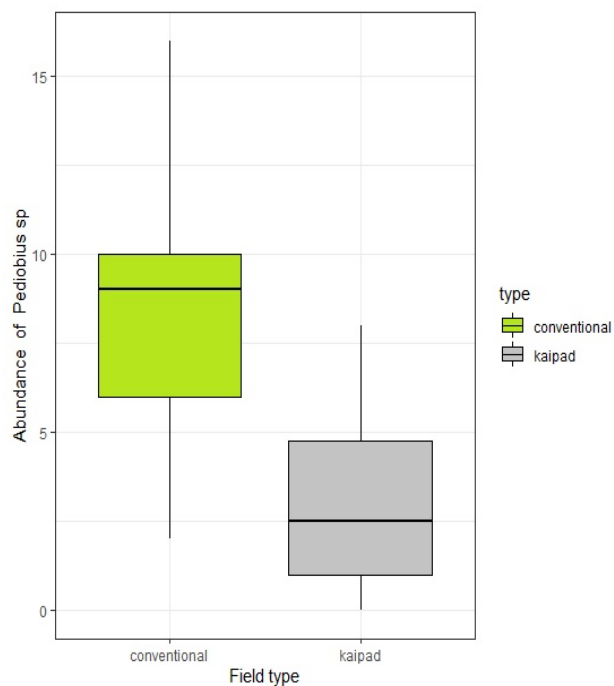


Fig. 3.80: Abundance of *Tetrastichus schoenobii* in Conventional and Kaipad rice fields.

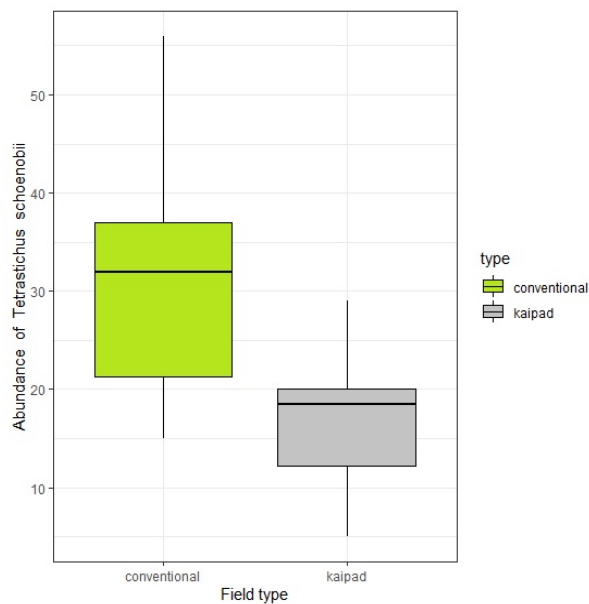
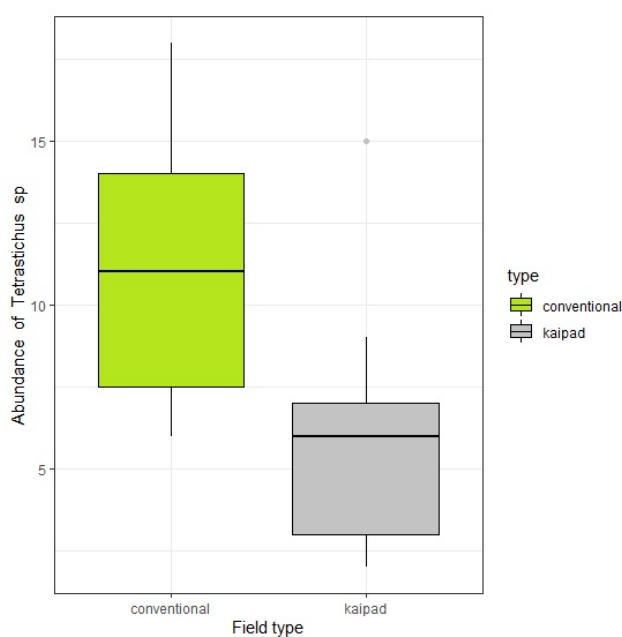


Fig. 3.81: Abundance of *Tetrastichus* sp. in Conventional and Kaipad rice fields.



Eupelmidae

The species reported during present study under Eupelmidae are *Anastatus* sp., *Eupelmus* sp. and *Neanastatus* sp. Among them *Anastatus* sp. ($p=0.1402$)(Fig.3.82) is not showing any significant difference in their abundance between Conventional and Kaipad rice fields, and only *Neanastatus* sp. showed significant difference in their abundance ($p=0.0264$ *) (Fig.3.83) (Tab. 3.4). *Anastatus* sp. and *Neanastatus* sp. showed higher abundance in Conventional rice fields than in Kaipad rice fields, and *Eupelmus* sp is only reported from Conventional rice fields.

Fig. 3.82: Abundance of *Anastatus* sp. in Conventional and Kaipad rice fields.

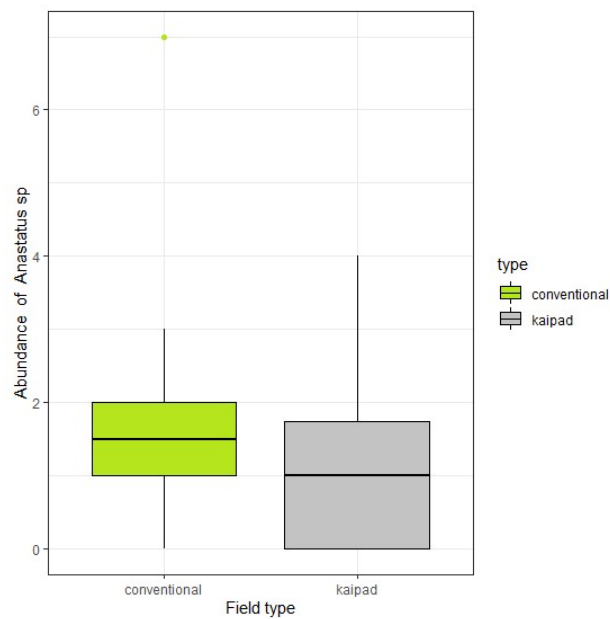
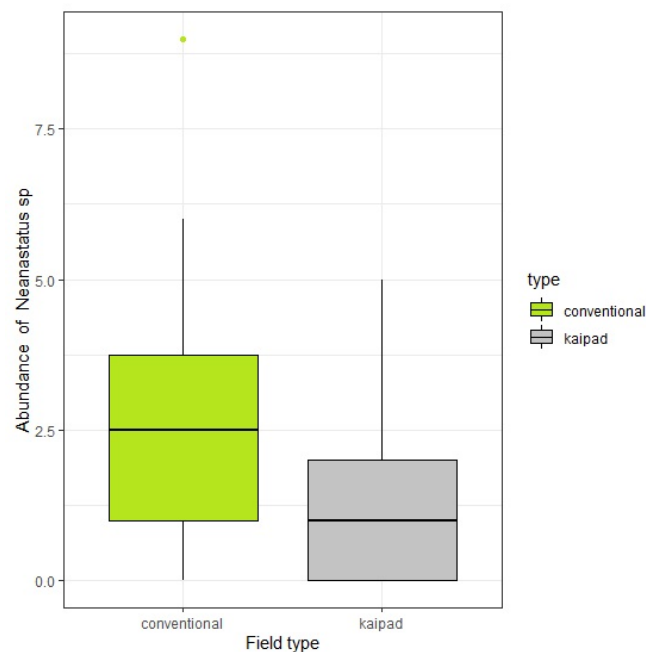


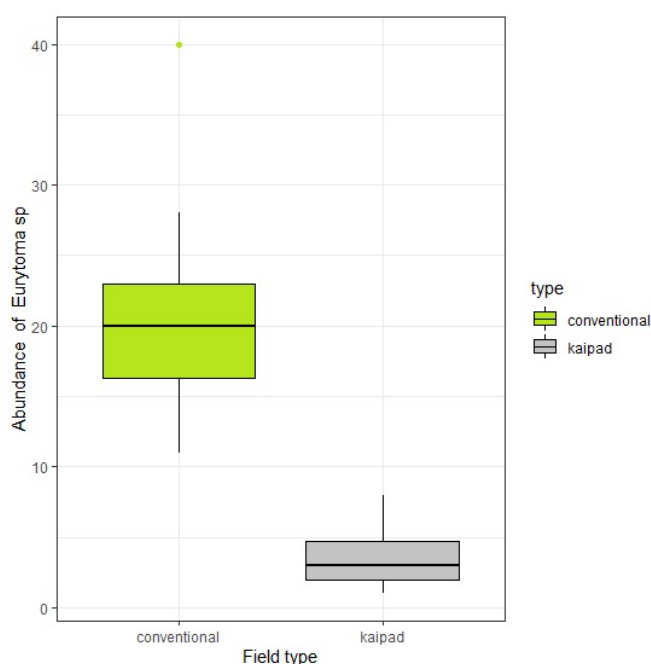
Fig. 3.83: Abundance of *Neanastatus* sp. in Conventional and Kaipad rice fields.



Eurytomidae

The abundance of *Eurytoma* sp., the only species reported under this family in Conventional and Kaipad rice fields are significantly different ($p=1.425e-14$ ***) (Tab. 3.4), with higher range in Conventional rice fields (Fig.3.84).

Fig. 3.84: Abundance of *Eurytoma* sp. in Conventional and Kaipad rice fields.



Ichneumonidae

30 species of parasitoids belonging to Ichneumonidae are recorded during the present study and among them 16 species are showing significant difference in their abundance between Conventional and Kaipad rice fields, the remaining ones are not showing any significant difference.

The following species show significant difference in their abundance between Conventional and Kaipad rice fields, viz: *Anomalon* sp. ($p=0.01571$ *), *Charops bicolor* ($p=0.0006264$ ***) (Plate XXIV..64), *Ishnojoppa* sp. ($p=0.009803$ **), *Isotima* sp. ($p=0.008594$ **)(Plate XXV.65), *Javra* sp. ($p=8.107e-05$ ***) (Plate XXV.66), *Leptobatopsis indica* ($p=0.03137$ *) (Plate XXV.67), *Leptobatopsis* sp. ($p=0.00145$ **)(Plate XXV.68), *Lusius* sp. ($p=0.007392$ **)(Plate XXV.69), *Menaforia* sp. ($p=0.003846$ **)(Plate XXV.70), *Pristomerus* sp. ($p=0.02908$ *), *Skeatia* sp. ($p=0.01509$ *), *Temelucha* sp. ($p=0.0383$ *), *Theronia* sp. ($p=0.00889$ **), *Trathala flavoorbitalis* ($p=0.02324$ *) (Plate XXV.72), *Xanthopimpla flavolineata* ($p=0.03916$ *) (Plate XXVI.74) and *Xanthopimpla punctate* ($p=0.03115$ *) (Plate XXVI.75) (Tab. 3.4).

The range of *Anomalon* sp. (Fig.3.85), *Charops bicolor* (Fig.83.8), *Isotima* sp. (Fig.3.92), *Javra* sp. (Fig.3.93), *Leptobatopsis* sp. (Fig.3.95), *Lusius* sp.(Fig.3.96), *Pristomerus* sp. (Fig.3.98), *Theronia* sp. (Fig.3.103), *Trathala flavoorbitalis* (Fig.3.104), *Xanthopimpla flavoorbitalis* (Fig.3.105) and *Xanthopimpla punctuate* (Fig.3.106) are higher in Conventional rice fields than that of Kaipad rice fields. The *Caenopimpla* sp. (Plate XXIV.61), *Casinaria* sp. and *Sinophorus* sp. (Plate XXV.71) are only recorded in Conventional rice fields.

The *Atropha* sp. ($p=0.5671$)(Fig.3.86), *Casinaria pedunculata* ($p=0.1201$) (Plate XXIV.63)(Fig.3.87), *Charops* sp. ($p=0.7225$), *Diadegma* sp. ($p=0.6414$), *Goryphus* sp. ($p=0.189$)(Fig.3.89), *Gotra* sp. ($p=0.05288$)(Fig.3.90), *Scenocharops* sp. ($p=0.07814$)(Fig.3.99), *Trathala* sp. ($p=0.6414$)(Plate XXVI.73) and *Xanthopimpla* sp. ($p=0.2092$) are not showing any significant difference in their abundance in Conventional and Kaipad rice fields (Tab. 3.4).

Fig. 3.85: Abundance of *Anomalon* sp. in Conventional and Kaipad rice fields.

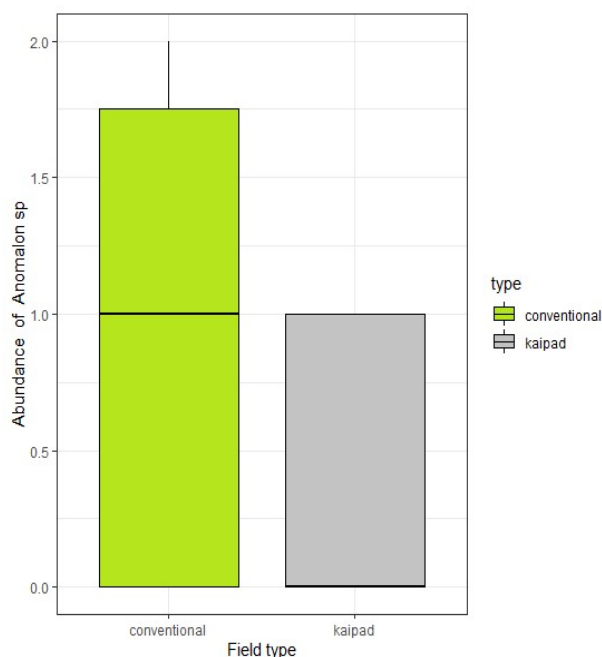


Fig. 3.86: Abundance of *Atropa* sp. in Conventional and Kaipad rice fields.

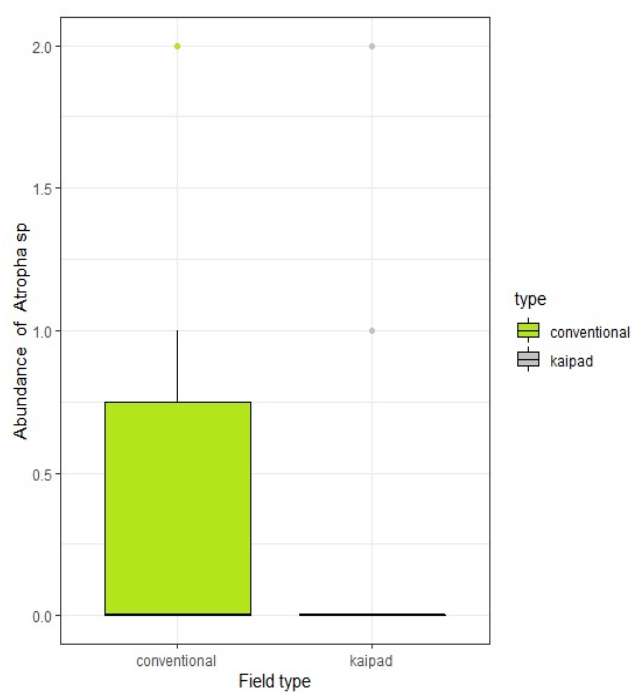


Fig. 3.87: Abundance of *Casuarina pedunculata* in Conventional and Kaipad rice fields.

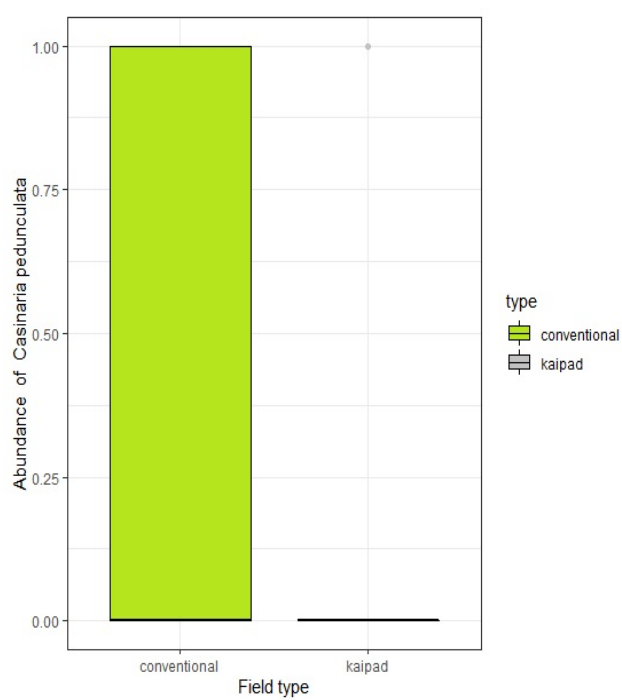


Fig. 3.88: Abundance of *Charops bicolor* in Conventional and Kaipad rice fields.

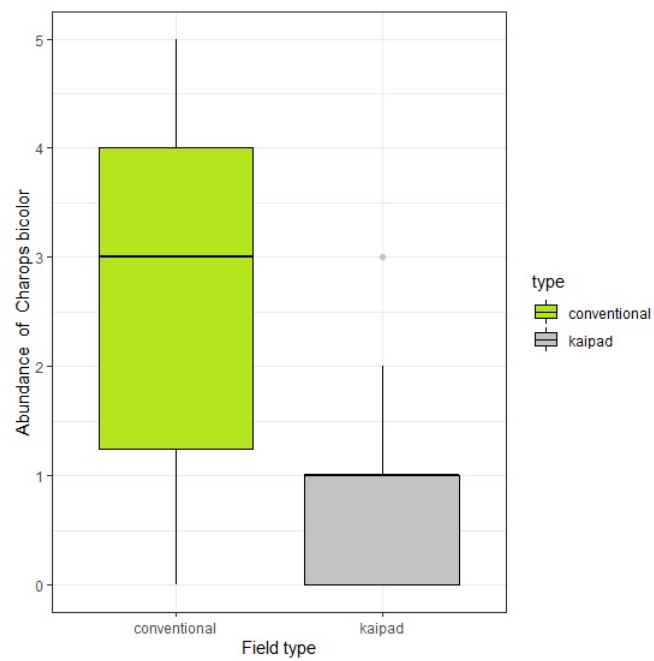


Fig. 3.89: Abundance of *Goryphus* sp. in Conventional and Kaipad rice fields.

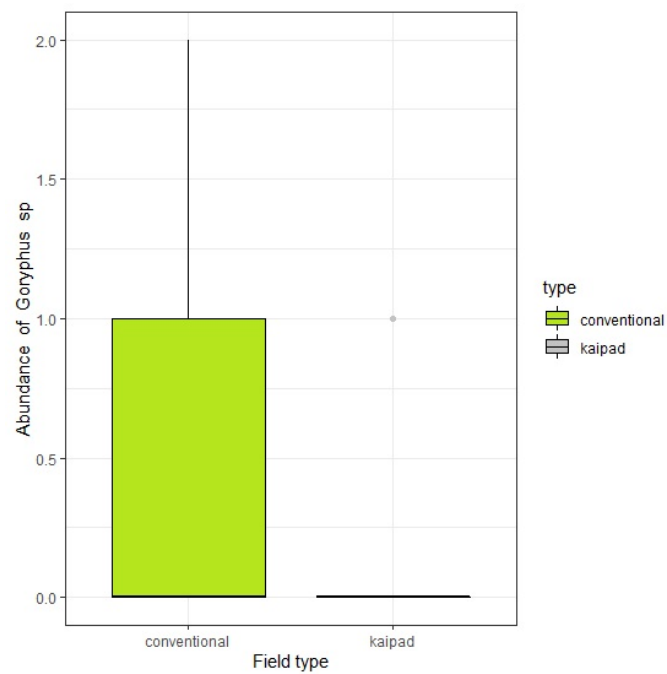


Fig. 3.90: Abundance of *Gotra* sp. in Conventional and Kaipad rice fields.

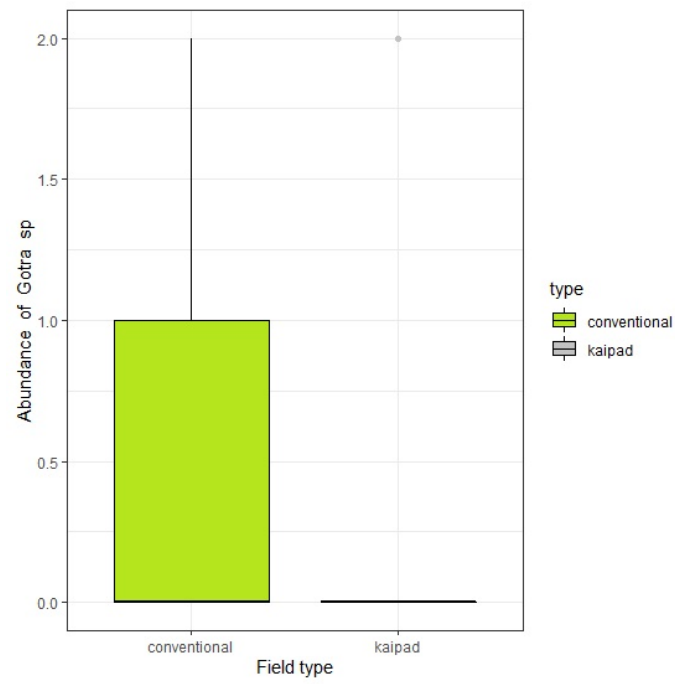


Fig. 3.91: Abundance of *Ishnojoppa* sp. in Conventional and Kaipad rice fields.

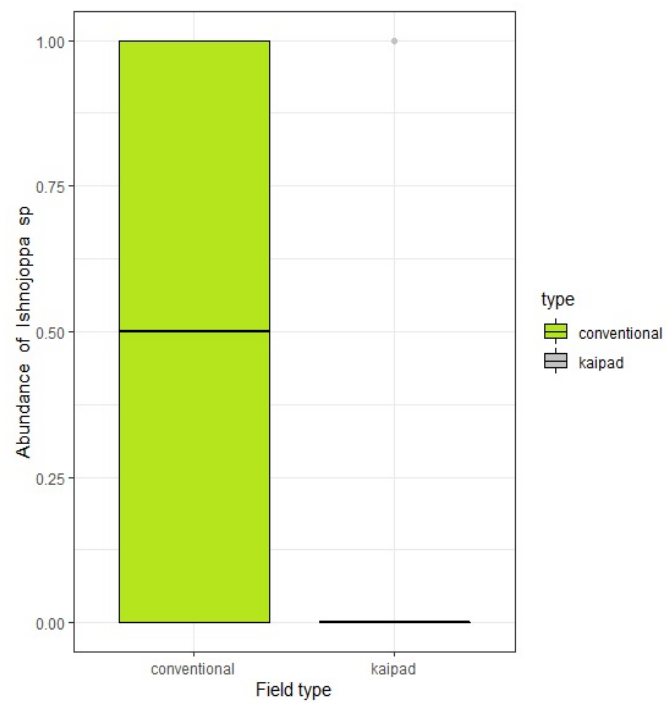


Fig. 3.92: Abundance of *Isotima* sp. in Conventional and Kaipad rice fields.

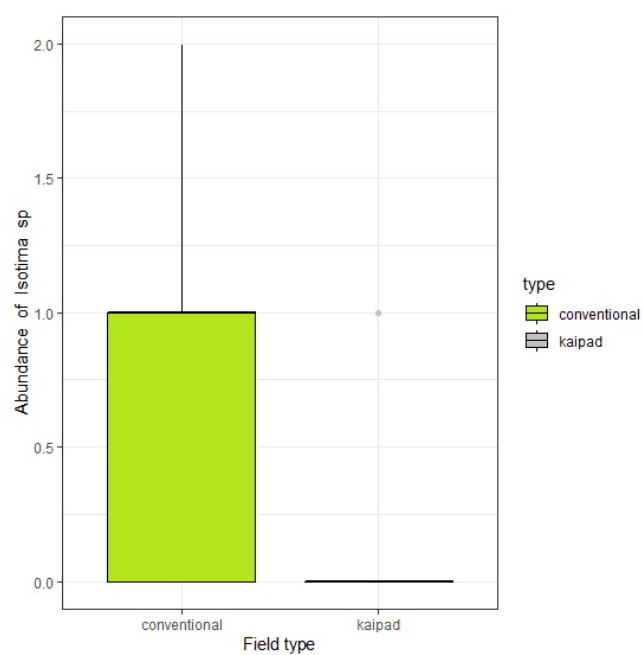


Fig. 3.93: Abundance of *Javra* sp. in Conventional and Kaipad rice fields.

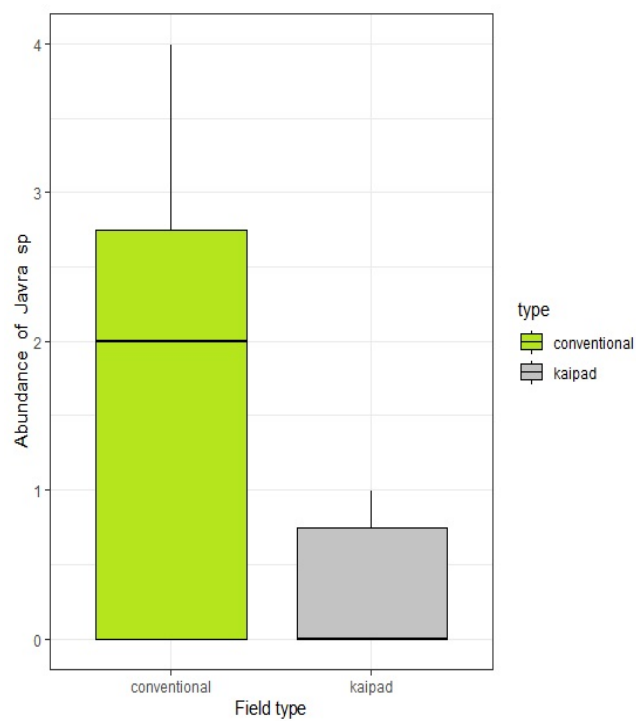


Fig. 3.94: Abundance of *Leptobatopsis indica* in Conventional and Kaipad rice fields.

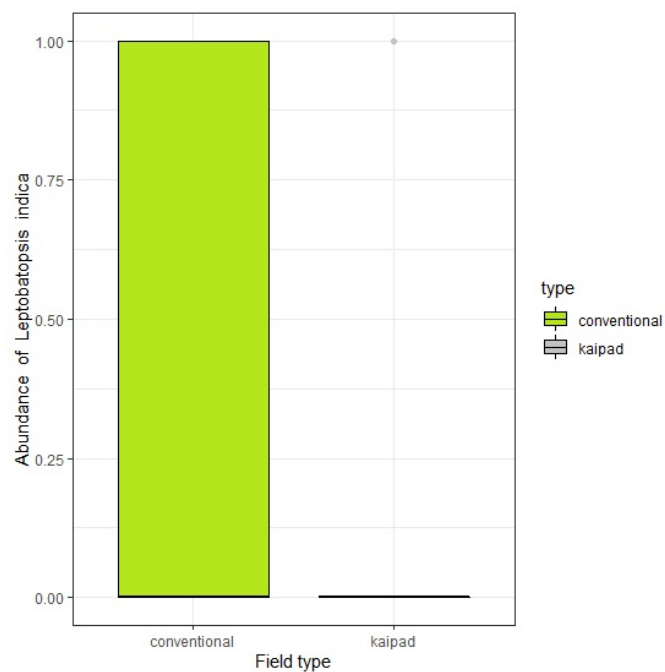


Fig. 3.95: Abundance of *Leptobatopsis* sp. in Conventional and Kaipad rice fields.

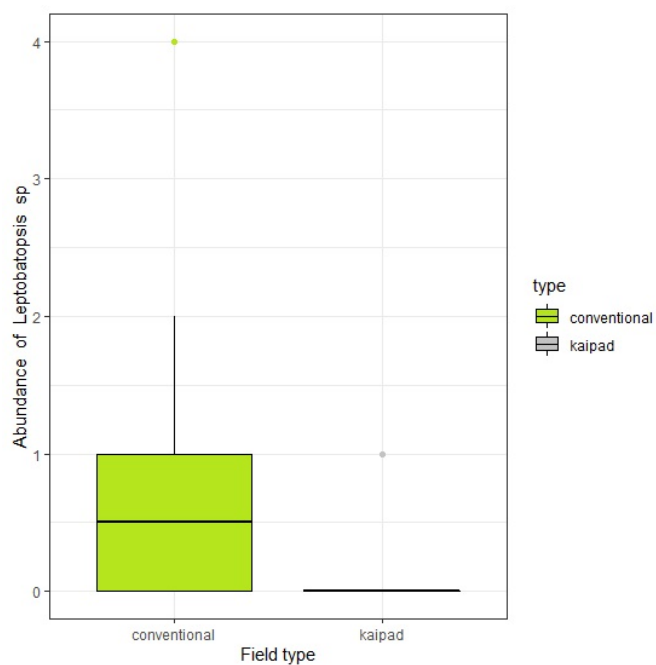


Fig. 3.96: Abundance of *Lusius* sp. in Conventional and Kaipad rice fields.

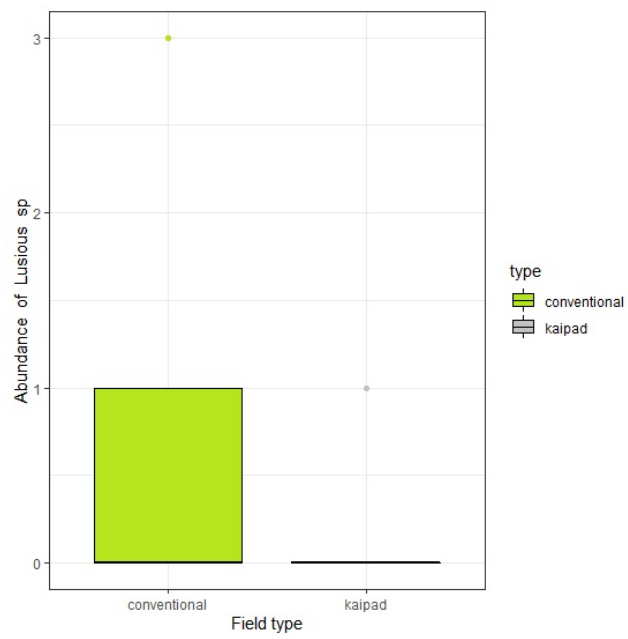


Fig. 3.97: Abundance of *Menaforia* sp. in Conventional and Kaipad rice fields.

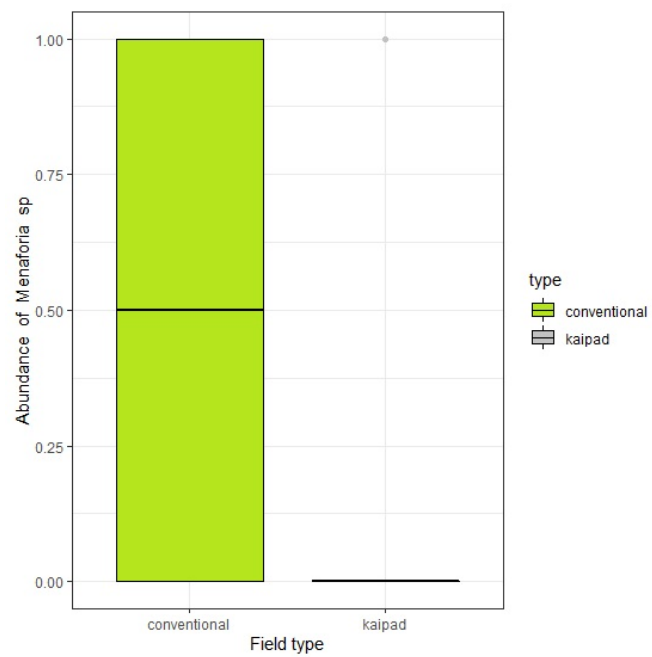


Fig. 3.98: Abundance of *Pristomerus* sp. in Conventional and Kaipad rice fields.

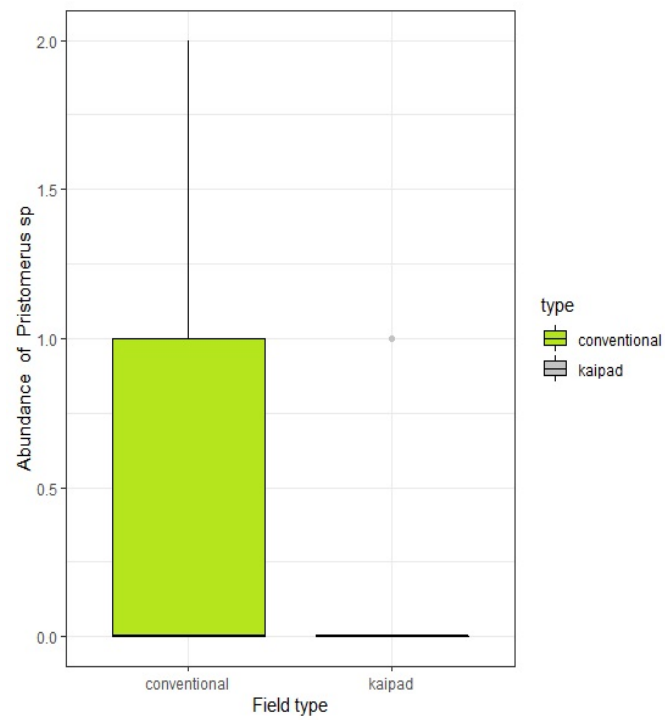


Fig. 3.99: Abundance of *Scenocharops* sp. in Conventional and Kaipad rice fields.

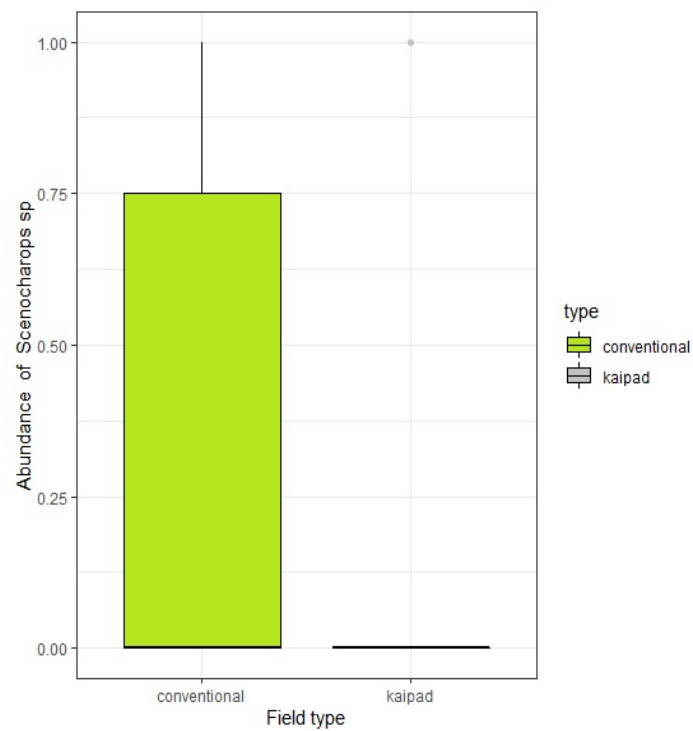


Fig. 3.100: Abundance of *Sinophorus* sp. in Conventional and Kaipad rice fields.

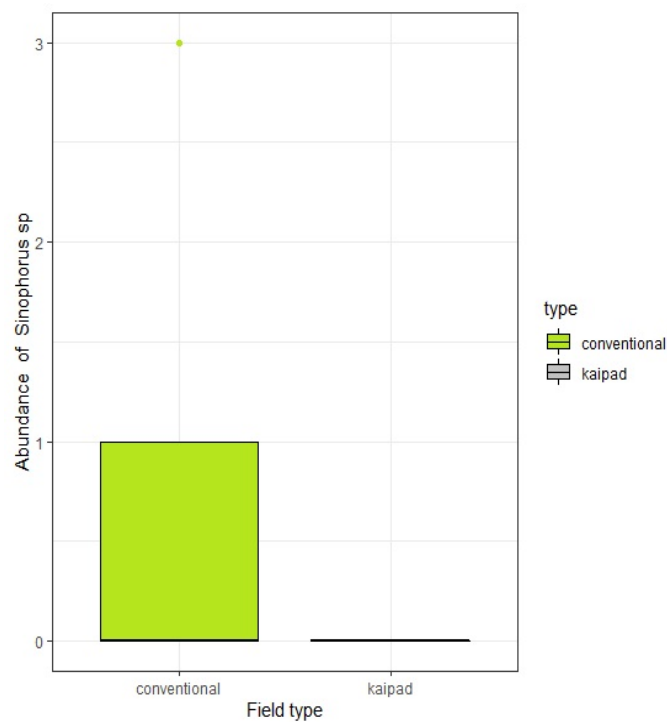


Fig. 3.101: Abundance of *Skeattia* sp. in Conventional and Kaipad rice fields.

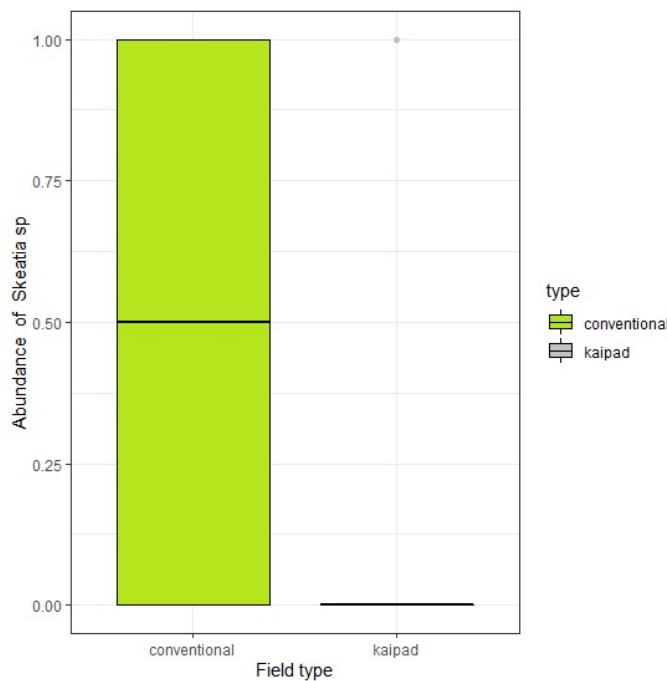


Fig. 3.102: Abundance of *Temelucha* sp. in Conventional and Kaipad rice fields.

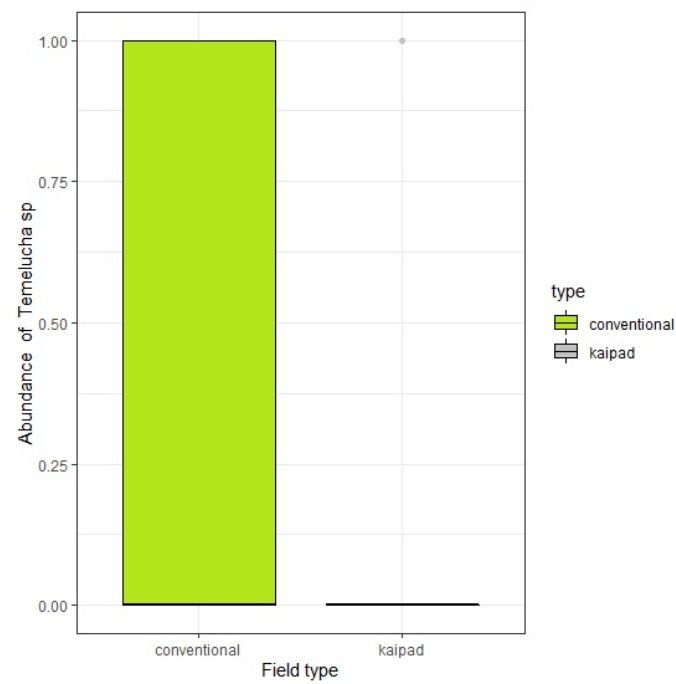


Fig. 3.103: Abundance of *Theronia* sp. in Conventional and Kaipad rice fields.

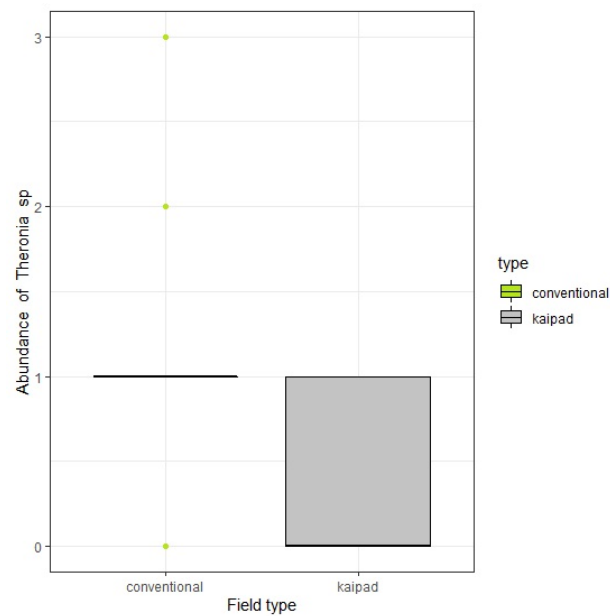


Fig. 3.104: Abundance of *Trathala flavoorbitalis* in Conventional and Kaipad rice fields.

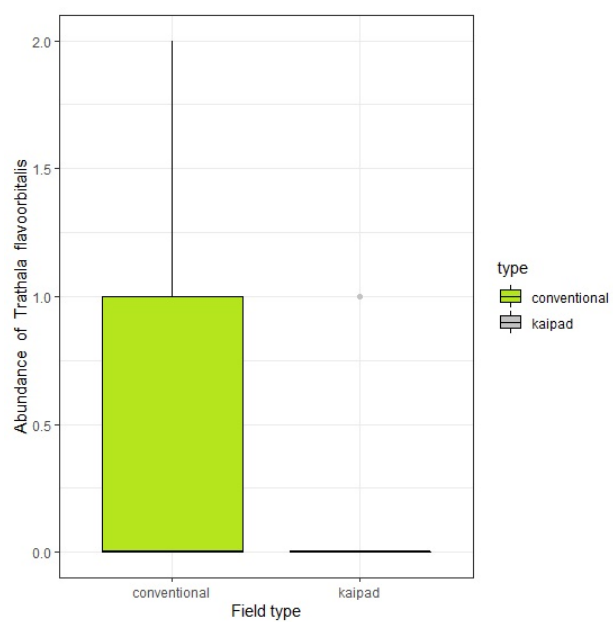


Fig. 3.105: Abundance of *Xanthopimpla flavolineata* in Conventional and Kaipad rice fields.

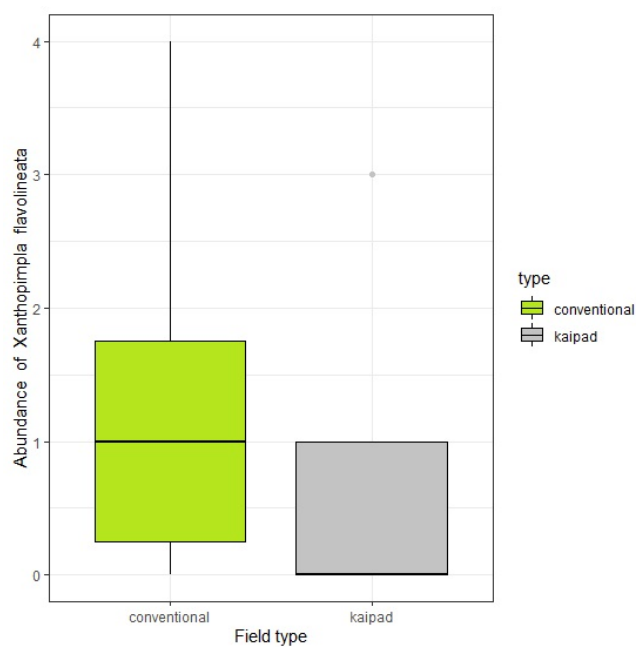
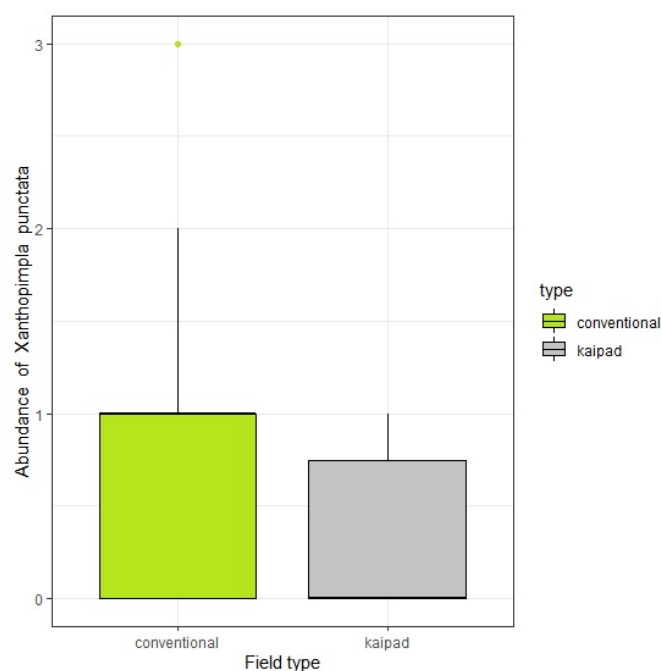


Fig. 3.106: Abundance of *Xanthopimpla punctata* in Conventional and Kaipad rice fields.



Mymaridae

Anagrus sp. ($p=6.909e-05$ ***) (Plate XXVI.76) (Fig.3.107), *Gonatocerus aegyptiacus* ($p=7.348e-08$ ***) (Plate XXVI.77) (Fig.3.108), *Gonatocerus shamimi* ($p=0.002114$ **) (Plate XXVI.80) (Fig.3.110), *Lymaenon aureus* ($p=0.03655$ *) (Plate XXVII.81) showed significant difference in their abundance between Conventional and Kaipad rice fields (Tab. 3.4). But, *Gonatocerus longicornis* ($p=0.6506$) (Plate XXVI.78) (Fig.3.109), *Lymaenon munnarus* ($p=0.05519$) (Plate XXVII.82) (Fig.3.112), and *Mymar taprobanicum* ($p=0.4218$) (Plate XXVII.84) (Fig.3.113) are not showing any significant difference (Tab. 3.4). *Gonatocerus meghaleyensis* (Plate XXVI.79), *L.narayani*, *L.delhiensis*, *M. schwanni* (Plate XXVII.83) and *Mymar* sp. are only noted from Conventional rice fields.

The abundance of all Mymaridae species except *M. taprobanicum* is higher in Conventional rice fields than in Kaipad rice fields. *Gonatocerus meghalaensis*, *L. narayani*, *L. delhiensis*, *M. schwanni* and *Mymar* sp. are the minor Mymaridae parasitoids reported during the present study.

Fig. 3.107: Abundance of *Anagrus* sp. in Conventional and Kaipad rice fields.

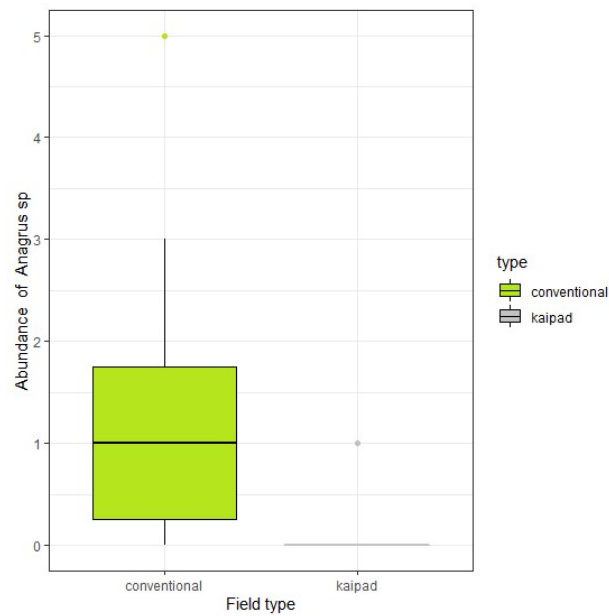


Fig. 3.108: Abundance of *Gonatocerus aegyptiacus* in Conventional and Kaipad rice fields.

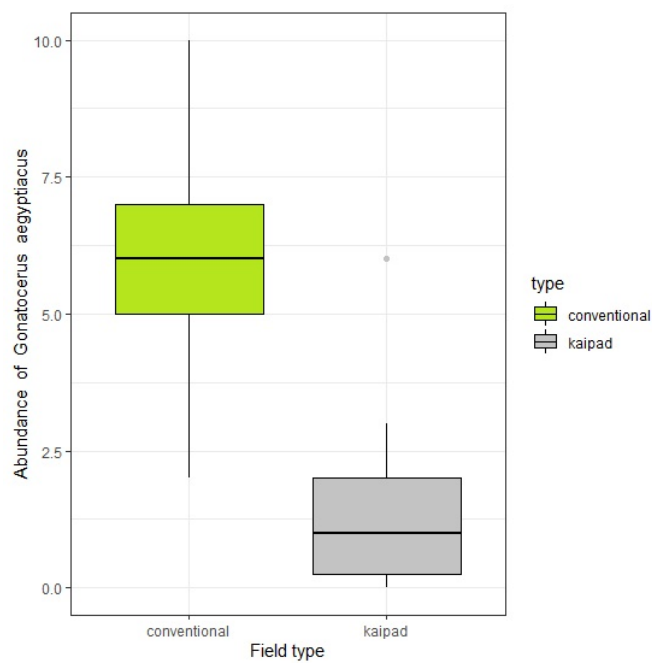


Fig. 3.109: Abundance of *Gonatocerus longicornis* in Conventional and Kaipad rice fields.

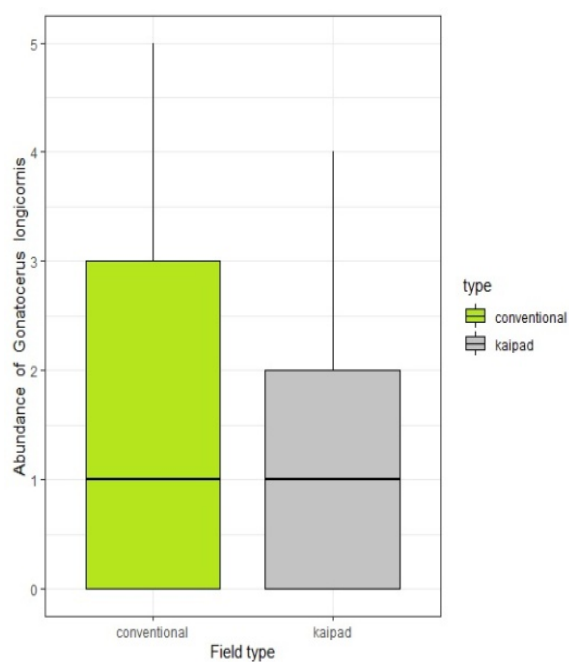


Fig. 3.110: Abundance of *Gonatocerus shamimi* in Conventional and Kaipad rice fields.

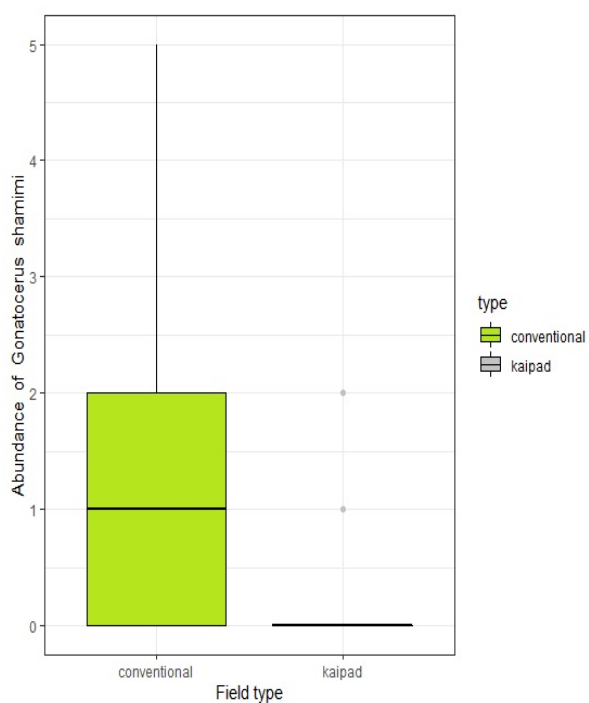


Fig. 3.111: Abundance of *Lymaenon aureus* in Conventional and Kaipad rice fields.

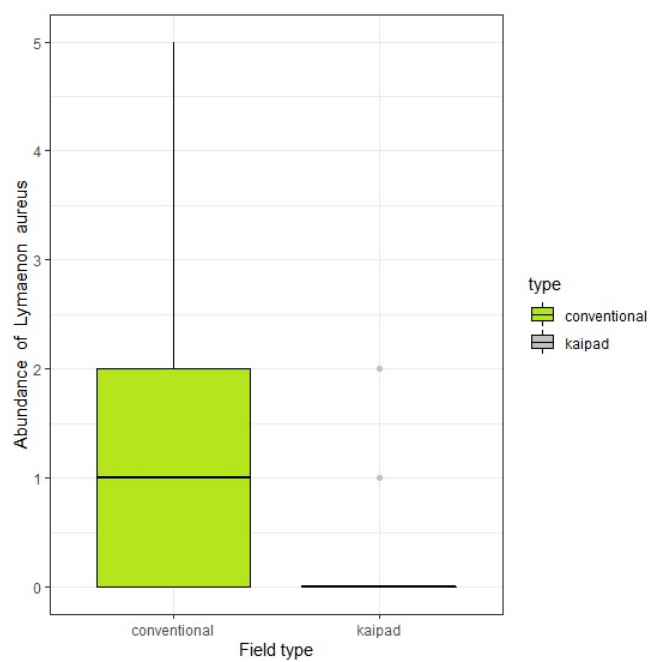


Fig. 3.112: Abundance of *Lymaenon munnarus* in Conventional and Kaipad rice fields.

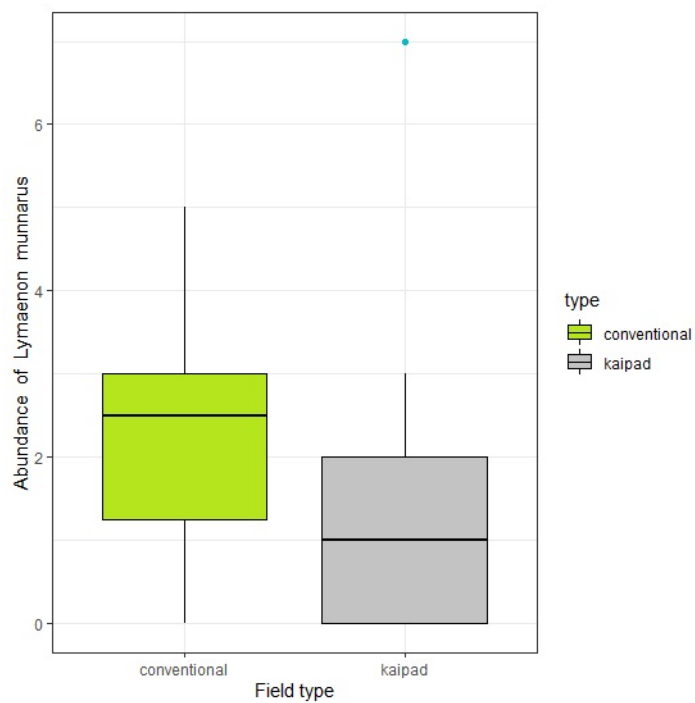
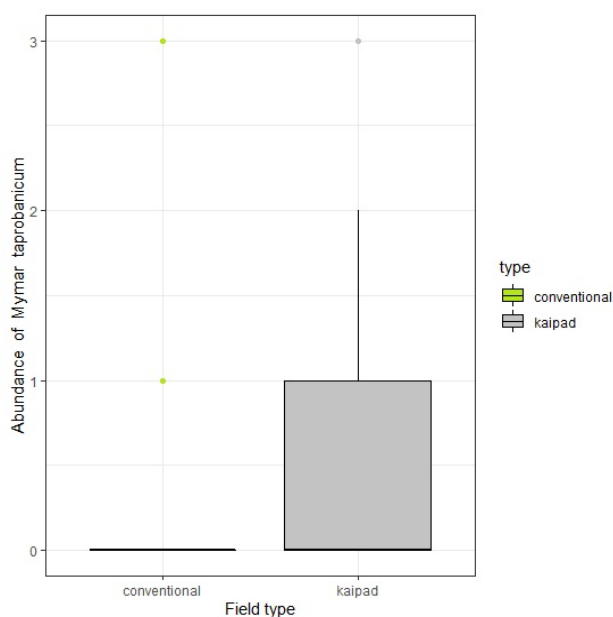


Fig. 3.113: Abundance of *Mymar taprobanicum* in Conventional and Kaipad rice fields.



Platygastridae

In the present study, 23 species of parasitoids are collected, and abundance of all the Platygastridae species reported except *Baryconus* sp. (which is only recorded in Kaipad rice fields)(Plate XXVII.85) are higher in Conventional type of rice fields than in Kaipad rice fields. The species, *Calliscelio* sp. ($p=0.0002122$ ***)(Plate XXVII.86)(Fig.3.114), *Cremastobaeus* sp. ($p=0.0003089$ ***)(Fig.3.115), *Duta* sp. ($p=9.139e-07$ ***)(Fig.3.117), *Fusicornia* sp. ($p=0.003572$ **)(Fig.3.118), *Greyon* sp. ($p=3.813e-06$ ***) (Plate XXVII.87) (Fig.3.119), *Idris* sp. ($p=1.4e-06$ ***) (Plate XXVIII.89) (Fig.3.120), *Macroteleia* sp. ($p=1.965e-05$ ***) (Plate XXVIII.90) (Fig.3.121), *Opisthacantha* sp. ($p=4.762e-05$ ***) (Plate XXVIII.92) (Fig.3.122), *Palpoteleia* sp. ($p=1.241e-06$ ***) (Plate XXVIII.93) (Fig.3.123), *Paridris* sp. ($p=0.00448$ **)(Fig.3.125), *Platygaster* sp. ($p=0.001055$ **)(Plate XXVIII.94) (Fig.3.126), *Probaryconus* sp. ($p=0.0002584$ ***) (Plate XXVIII.95) (Fig.3.127), *Scelio* sp. ($p=5.503e-08$ ***) (Plate XXVIII.96) (Fig.3.128), *Synopeas* sp. ($p=6.828e-06$ ***) (Plate XXIX.97) (Fig.3.129), *Telenomus* sp. ($p=0.000234$ ***) (Plate XXIX.98) (Fig.3.130), *Trimorus* sp. ($p=1.413e-07$ ***) (Plate XXIX.99) (Fig.3.131) and *Trissolcus* sp. ($p=7.726e-10$ ***) (Plate XXIX.100)

(Fig.3.132) are significantly different in their abundance between Conventional and Kaipad rice fields (Tab. 3.4). The species, *Duta indica* (Fig.3.116), *Habroteleia* sp. (Plate XXVII.88), *Odontocolus* sp. (Plate XXVIII.91), *Paratelenomus* sp. (Fig.3.124) and *Psilanteris* sp. are only seen in Conventional rice fields.

Fig. 3.114: Abundance of *Calliscelio* sp. in Conventional and Kaipad rice fields.

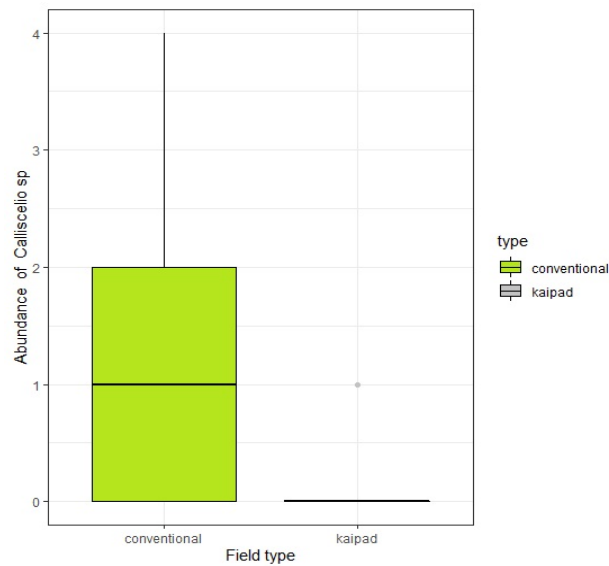


Fig. 3.115: Abundance of *Cremastobaeus* sp. in Conventional and Kaipad rice fields.

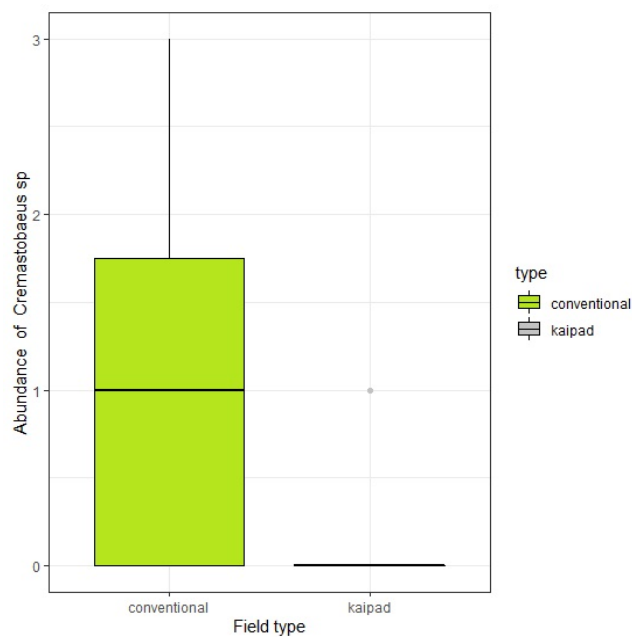


Fig. 3.116: Abundance of *Duta indica* in Conventional and Kaipad rice fields.

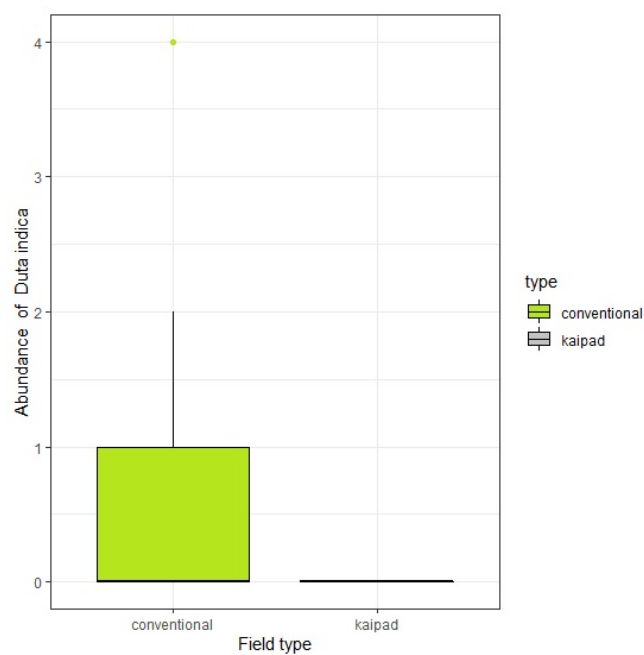


Fig. 3.117: Abundance of *Duta sp.* in Conventional and Kaipad rice fields.

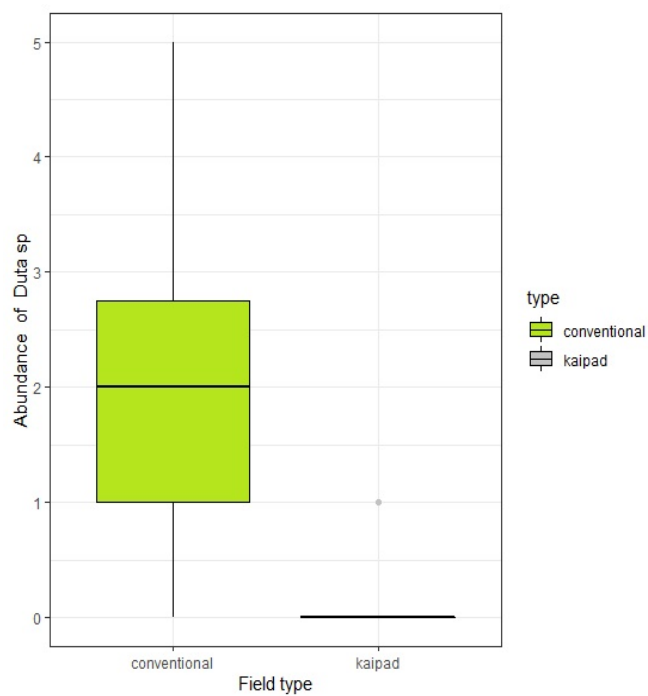


Fig. 3.118: Abundance of *Fusicornia* sp. in Conventional and Kaipad rice fields.

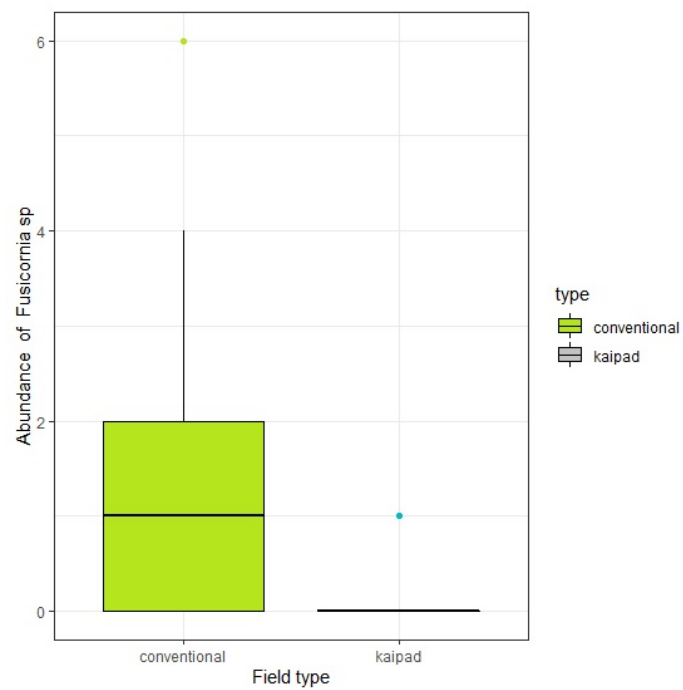


Fig. 3.119: Abundance of *Greyon* sp. in Conventional and Kaipad rice fields.

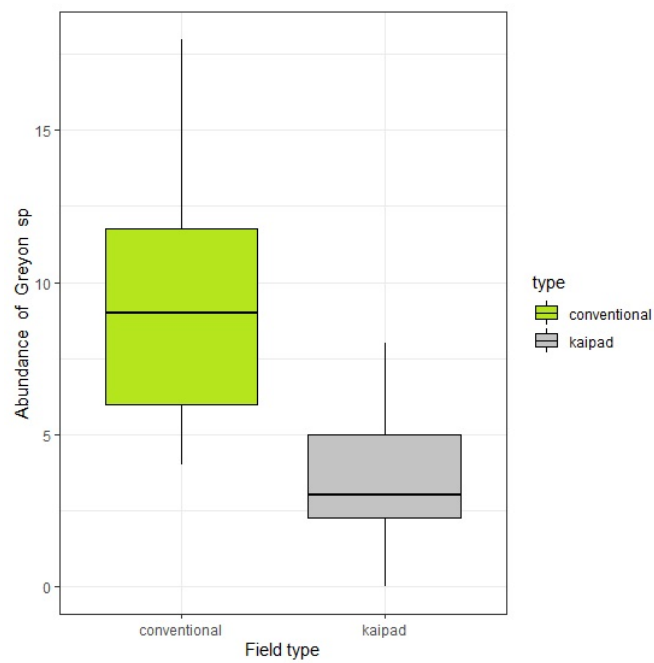


Fig. 3.120: Abundance of *Idris* sp. in Conventional and Kaipad rice fields.

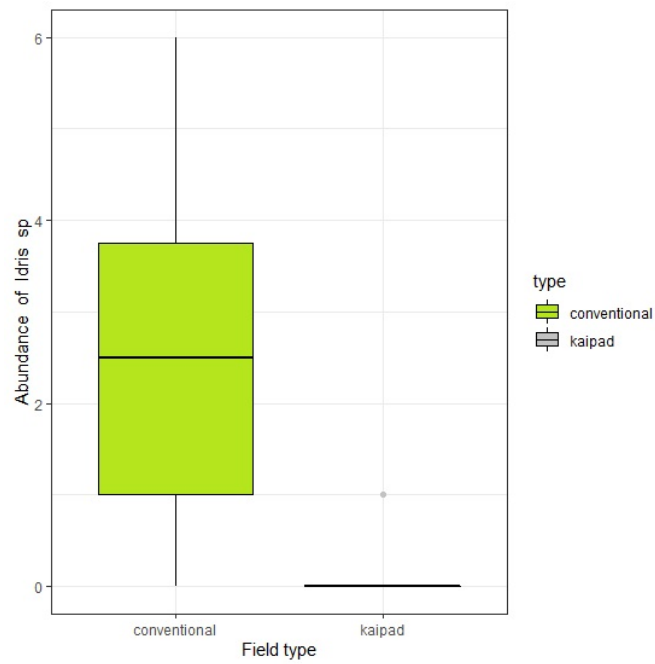


Fig. 3.121: Abundance of *Macroteleia* sp. in Conventional and Kaipad rice fields.

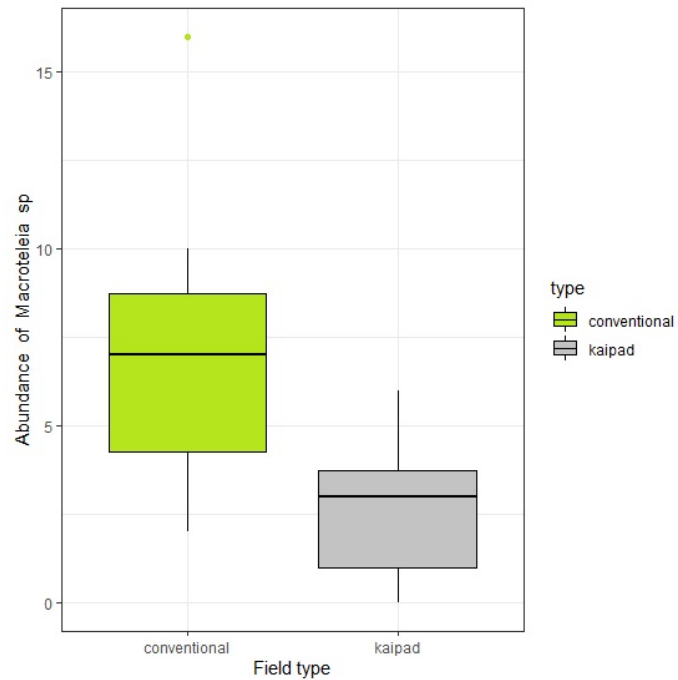


Fig. 3.122: Abundance of *Opisthacantha* sp. in Conventional and Kaipad rice fields.

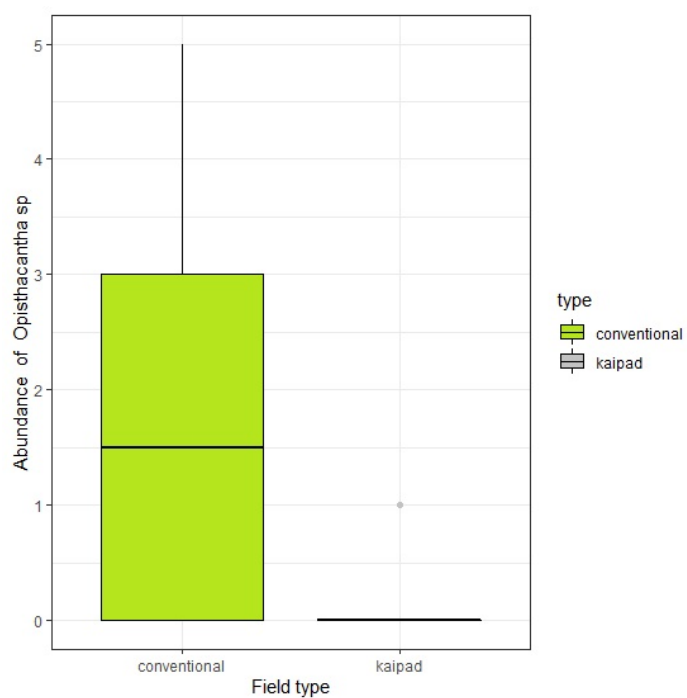


Fig. 3.123: Abundance of *Palpoteleia* sp. in Conventional and Kaipad rice fields.

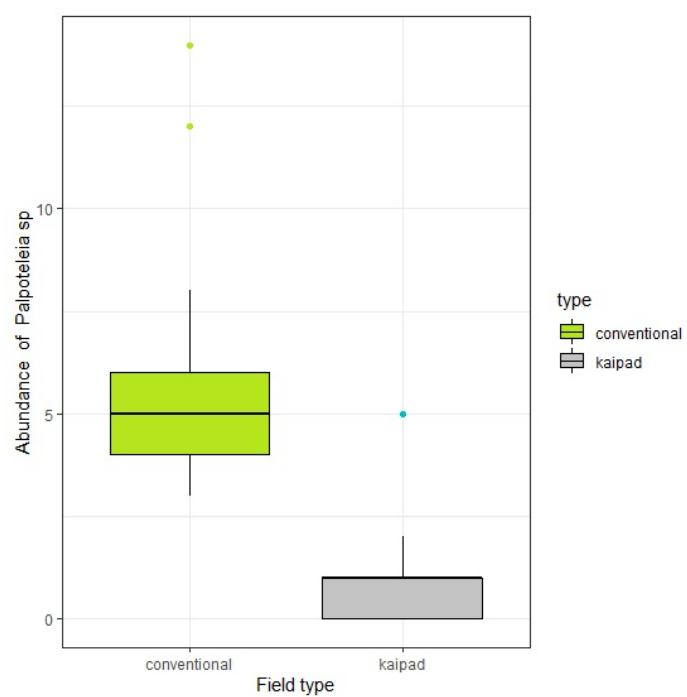


Fig. 3.124: Abundance of *Paratelenomus* sp. in Conventional and Kaipad rice fields.

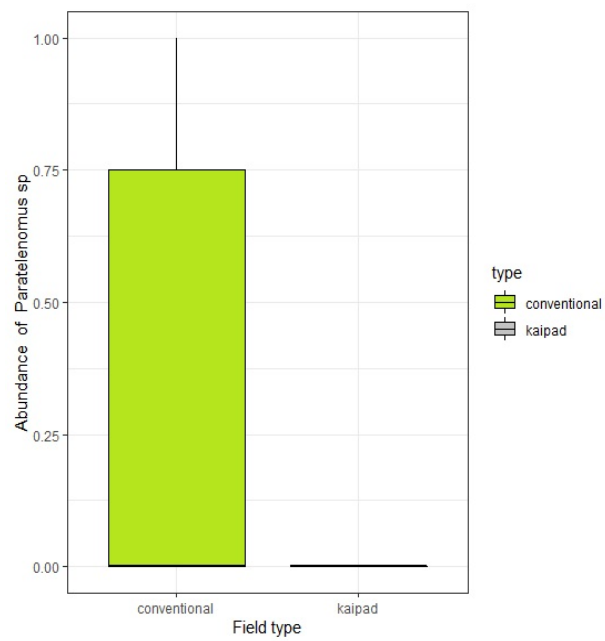


Fig. 3.125: Abundance of *Paridris* sp. in Conventional and Kaipad rice fields.

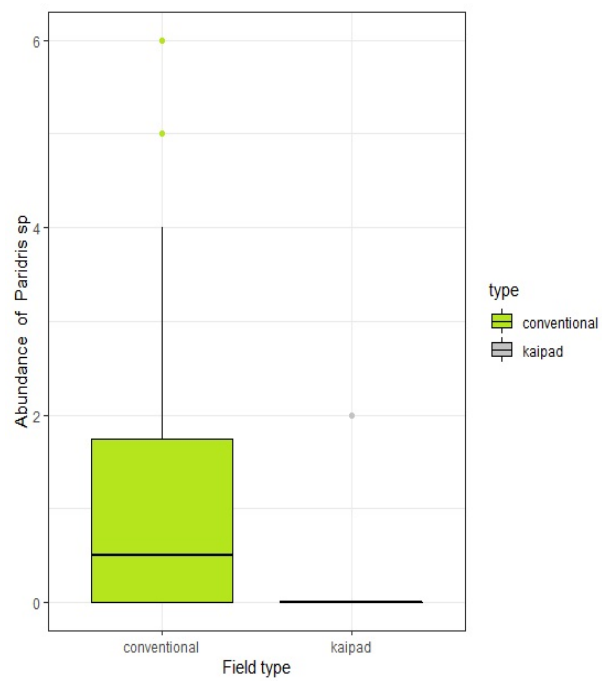


Fig. 3.126: Abundance of *Platygaster* sp. in Conventional and Kaipad rice fields.

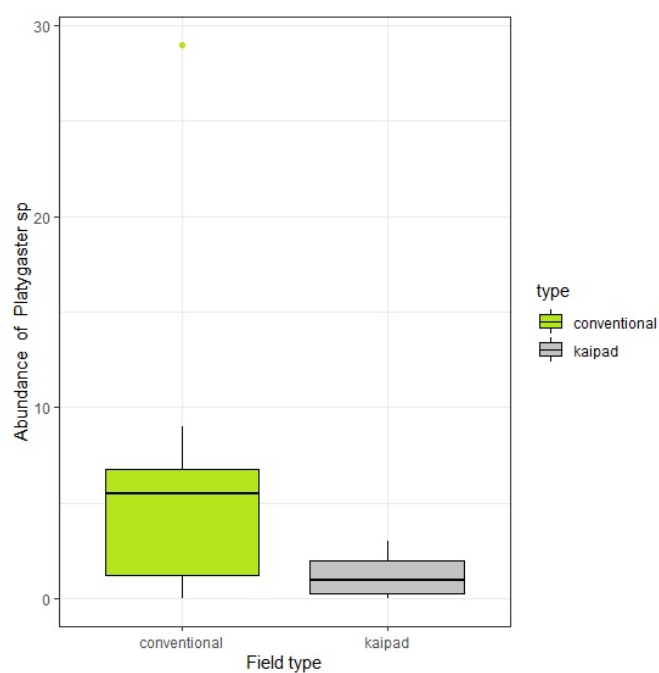


Fig. 3.127: Abundance of *Probaryconus* sp. in Conventional and Kaipad rice fields.

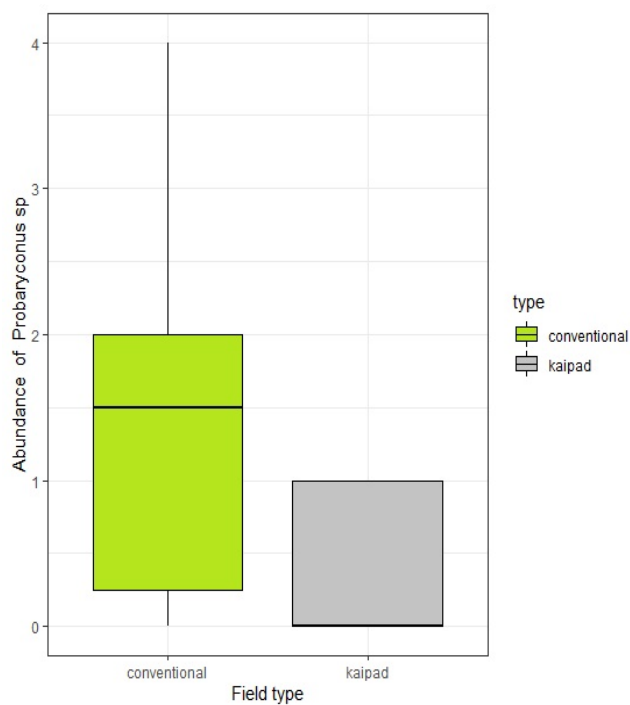


Fig. 3.128: Abundance of *Scelio* sp. in Conventional and Kaipad rice fields.

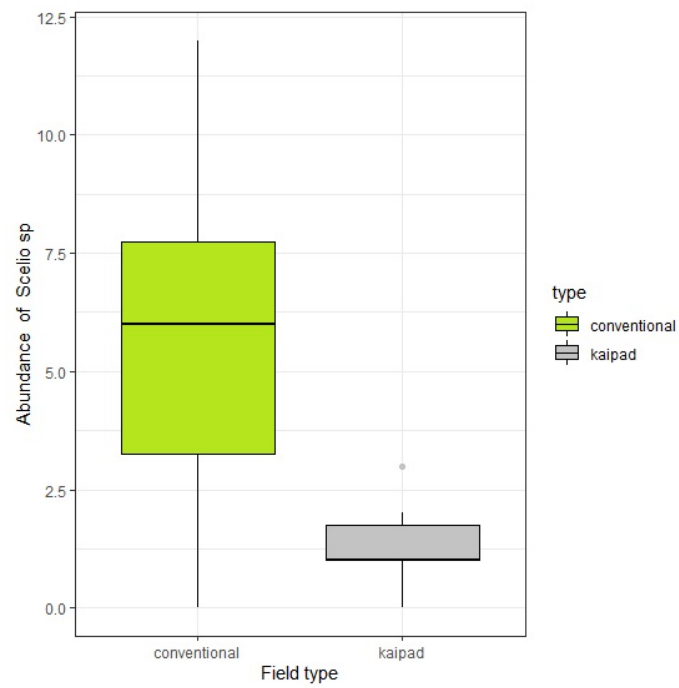


Fig. 3.129: Abundance of *Synopeas* sp. in Conventional and Kaipad rice fields.

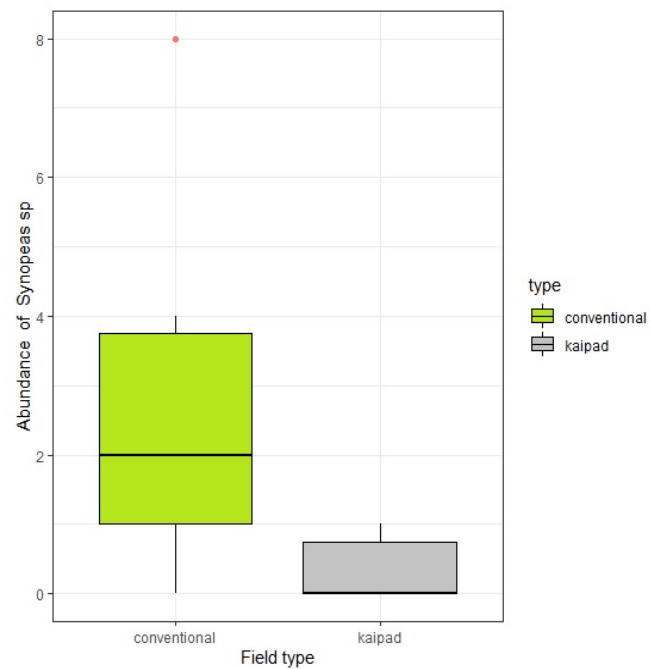


Fig. 3.130: Abundance of *Telenomus* sp. in Conventional and Kaipad rice fields.

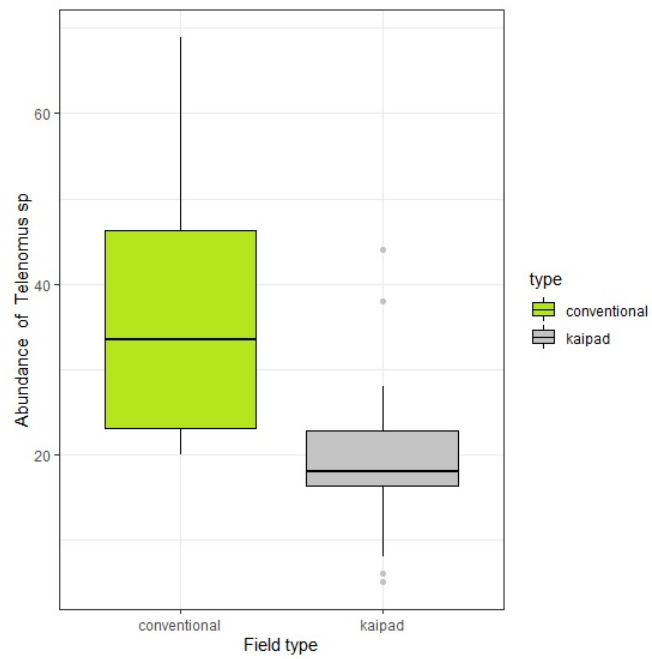


Fig. 3.131: Abundance of *Trimorus* sp. in Conventional and Kaipad rice fields.

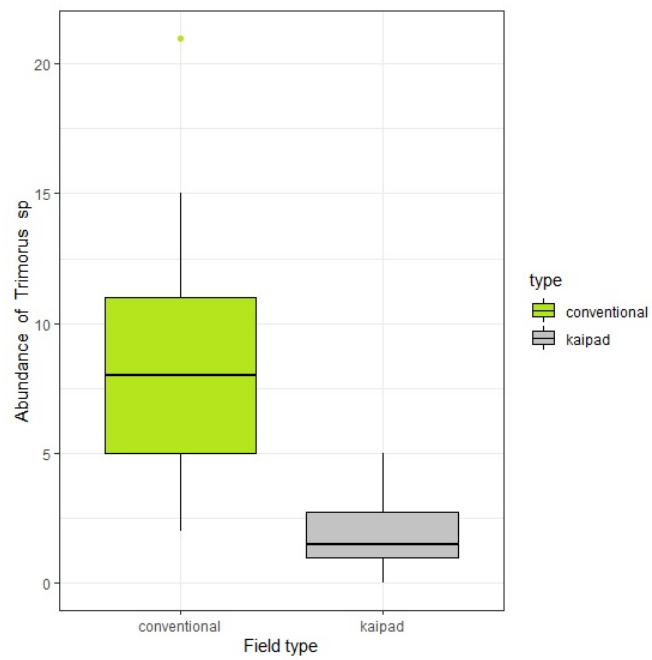
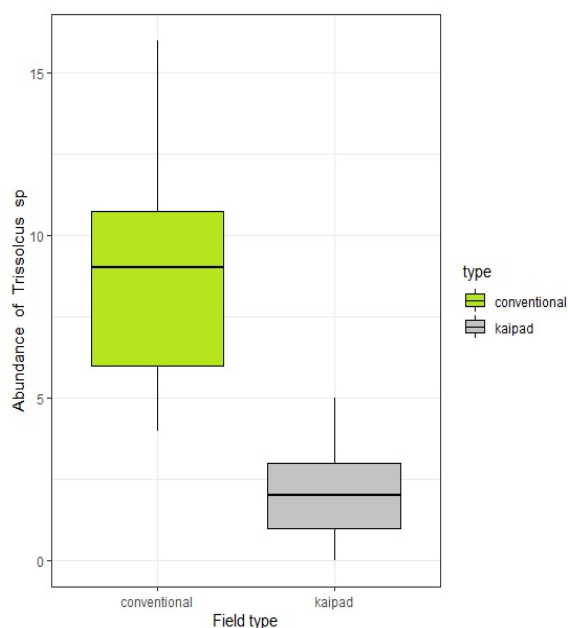


Fig. 3.132: Abundance of *Trissolcus* sp. in Conventional and Kaipad rice fields.



Pteromalidae

The species reported from Pteromalidae during the present study are *Callitula anuguloclypia* (Plate XXIX.101), *Callitula peethapada* (Plate XXIX.102), *Callitula* sp. (Plate XXIX.103), *Callitula travancorensis* (Plate XXIX.104), *Notoglyptus scutellaris* (Plate XXX.105), *Notoglyptus* sp., *Panstenon* sp., *Propicroscytus mirificus* (Plate XXX.107), *Propicroscytus oryzae* (Plate XXX.108), *Propicroscytus* sp. (Plate XXX.109), *Trichomalopsis acarinata* (Plate XXX.110), *Trichomalopsis apanteloctena* (Plate XXX.111), *Trichomalopsis neelagastra* (Plate XXX.112), *Trichomalopsis nigra* (Plate XXXI.113), *Trichomalopsis ovigastra* (Plate XXXI.114), *Trichomalopsis* sp. (Plate XXXI.115), *Trichomalopsis thekkadiensis* (Plate XXXI.116), *Trichomalopsis travancorensis* (Plate XXXI.117), *Trichomalus kannurensis* and *Trichomalus* sp.

Among them, *C. peethapada* ($p=7.49\text{e-}08$ ***), *N. scutellaris* ($p=2.696\text{e-}10$ ***), *Panstenon* sp. ($p=0.0002328$ ***), *P. mirificus* ($p=0.03606$ *), *P. oryzae* ($p=5.935\text{e-}08$ ***), *T. acarinata* ($p=0.001613$ **), *T. apanteloctena* ($p=4.752\text{e-}06$ ***), *T. neelagastra* ($p=7.865\text{e-}07$ ***), *T. ovigastra* ($p=0.0005186$ ***), *T. thekkadiensis* ($p=0.003472$ **), *T. travancorensis* ($p=0.002506$ **) and *T. kannurensis* ($p=3.178\text{e-}06$ ***) are significantly different in their abundance

between Conventional and Kaipad rice fields (Tab. 3.4). But *Trichomalopsis* sp. is not showed any significant difference ($p=0.6871$). Among recorded parasitoid species, *C. anguloclypia*, *Callitla* sp., *C. travancorensis* (Fig.3.134), *Notoglyptus* sp (Fig.3.136), *T. nigra* (Fig.3.142) and *Trichomalus* sp. are seen in Conventional rice fields only.

The range of observations of *C.peethapada* (Fig.3.133), *N. scutellarsis* (Fig.3.135), *Panstenon* sp. (Fig.3.137), *P. oryzae* (Fig.3.138), *T. acarinata* (Fig.3.139), *T. apanteloctena* (Fig.3.140), *T. neelagastra* (Fig. 3.141), *T. ovigastra* (Fig.3.143), *Trichomalopsis* sp. (Fig.3.144), *T. thekkadiensis* (Fig.3.145) and *T. kannurensis* (Fig.3.147) are higher in Conventional rice fields than that of Kaipad rice fields.

Fig. 3.133: Abundance of *Callitula peethapada* in Conventional and Kaipad rice fields.

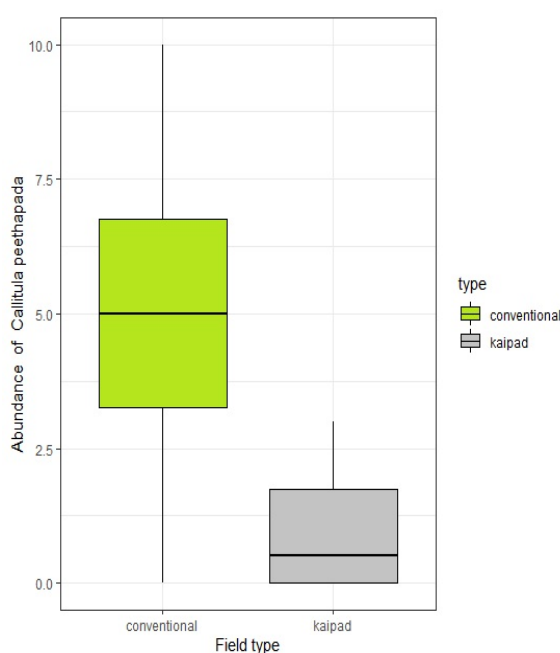


Fig. 3.134: Abundance of *Callitula travancorensis* in Conventional and Kaipad rice fields.

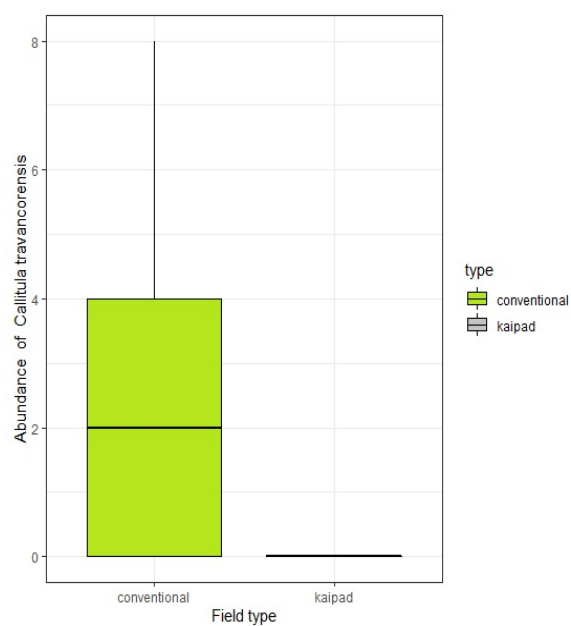


Fig. 3.135: Abundance of *Notoglyptus scutellaris* in Conventional and Kaipad rice fields.

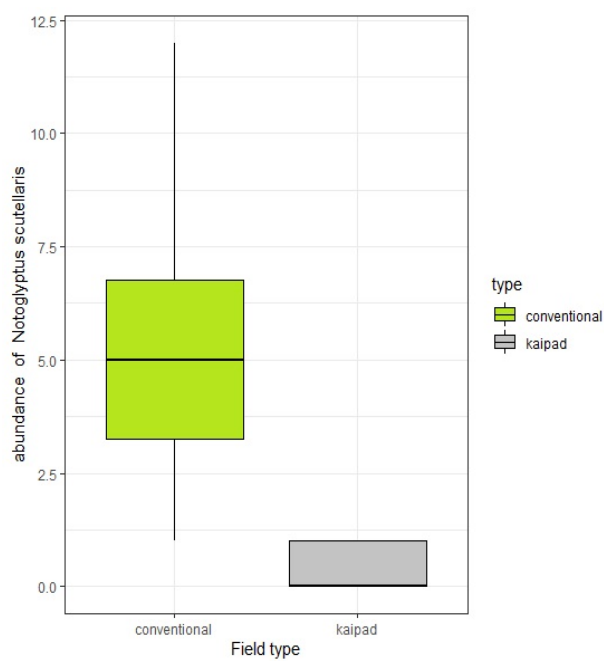


Fig. 3.136: Abundance of *Notoglyptus* sp. in Conventional and Kaipad rice fields.

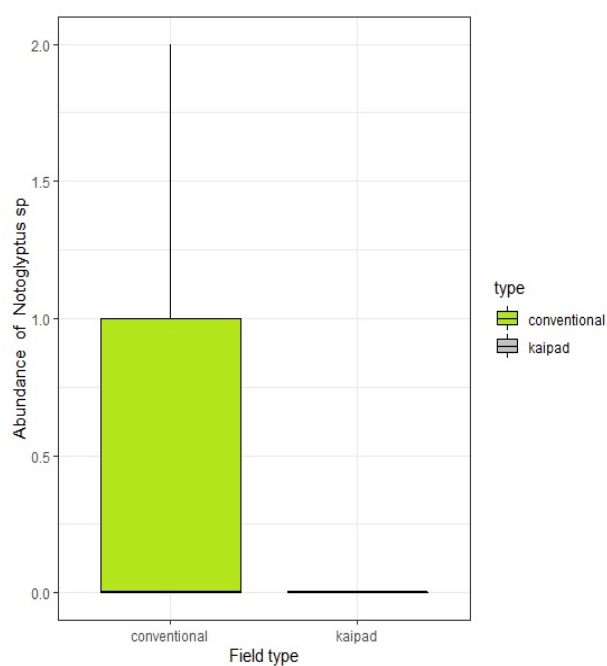


Fig. 3.137: Abundance of *Panstenon* sp. in Conventional and Kaipad rice fields.

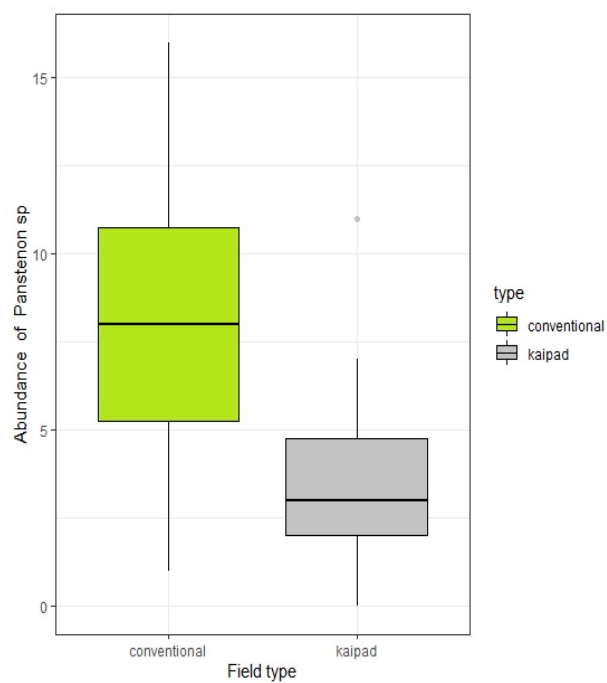


Fig. 3.138: Abundance of *Propicrosytus oryzae* in Conventional and Kaipad rice fields.

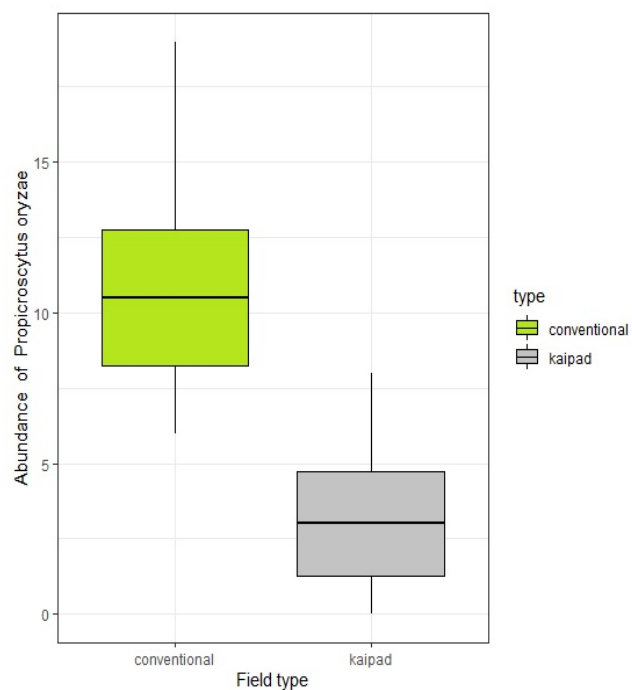


Fig. 3.139: Abundance of *Trichomalopsis acarinata* in Conventional and Kaipad rice fields.

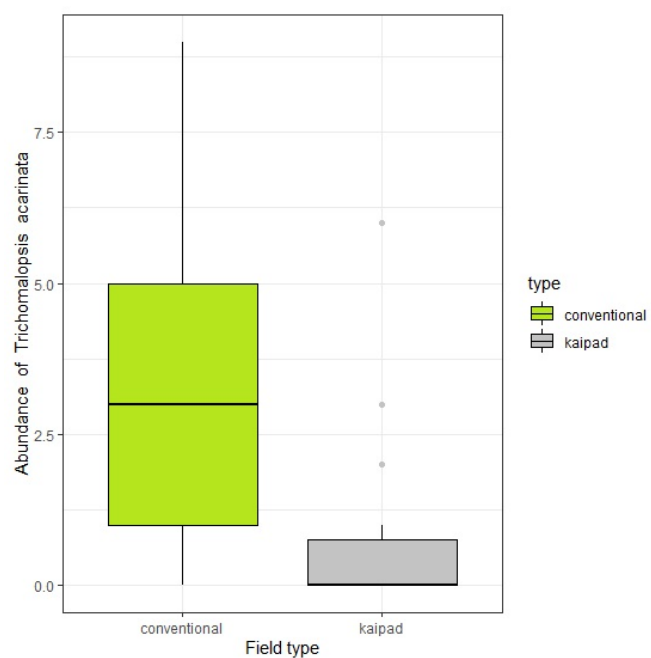


Fig. 3.140: Abundance of *Trichomalopsis apantelectena* in Conventional and Kaipad rice fields.

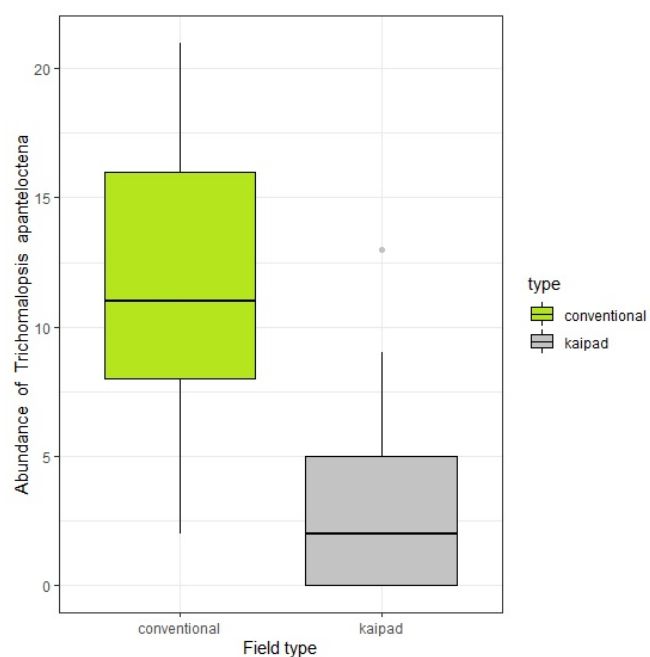


Fig. 3.141: Abundance of *Trichomalopsis neelagastra* in Conventional and Kaipad rice fields.

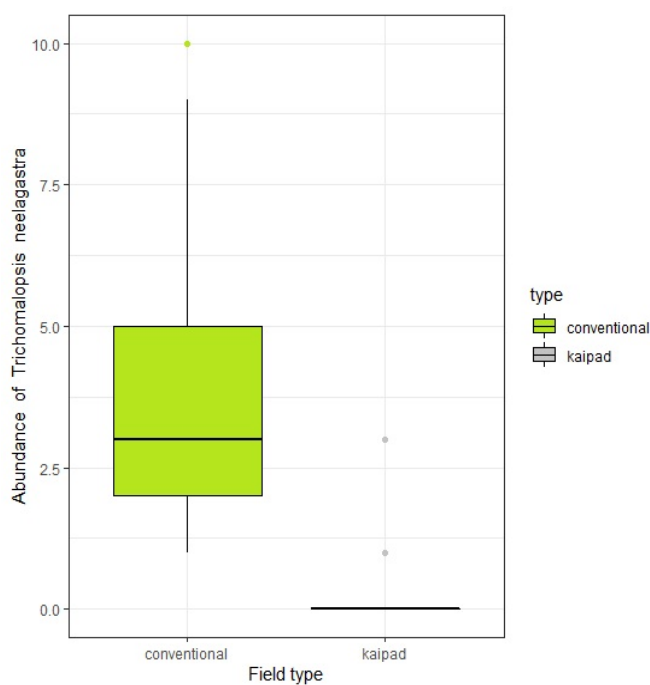


Fig. 3.142: Abundance of *Trichomalopsis nigra* in Conventional and Kaipad rice fields.

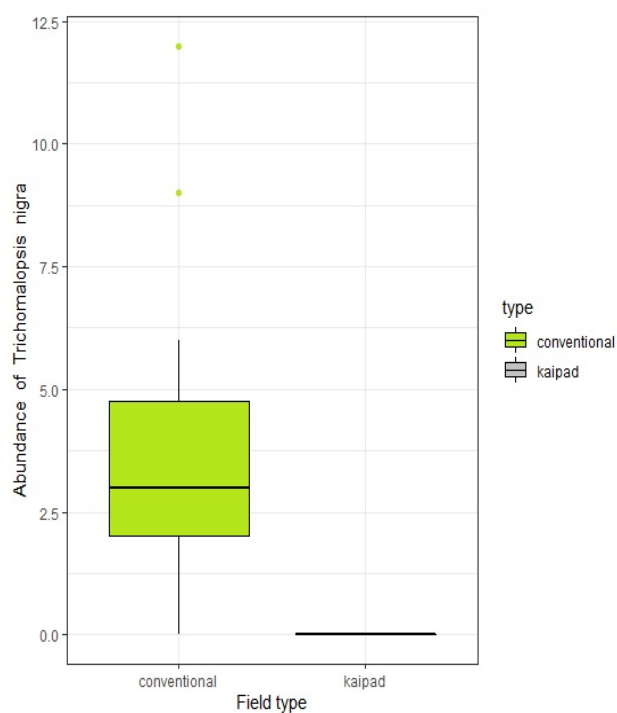


Fig. 3.143: Abundance of *Trichomalopsis ovigastrea* in Conventional and Kaipad rice fields.

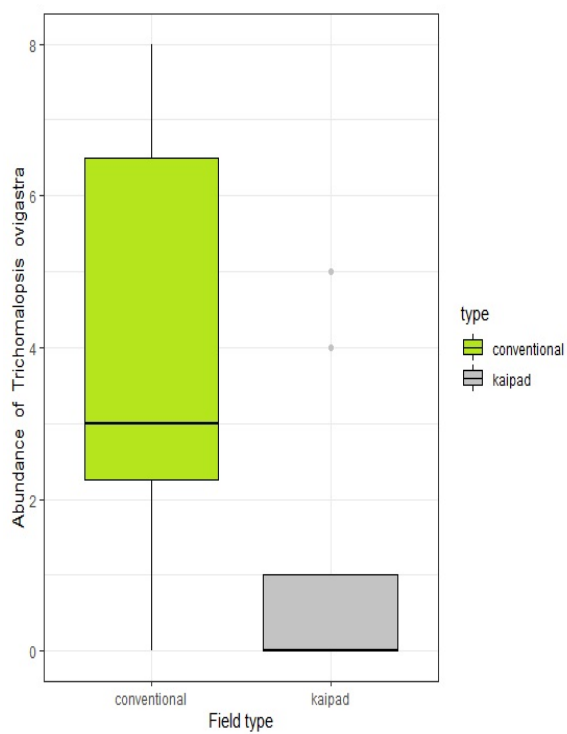


Fig. 3.144: Abundance of *Trichomalopsis* sp. in Conventional and Kaipad rice fields.

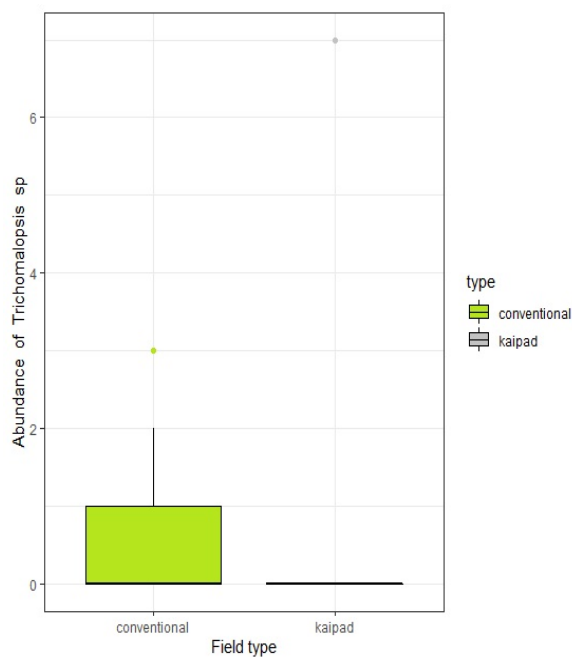


Fig. 3.145: Abundance of *Trichomalopsis thekkadiensis* in Conventional and Kaipad rice fields.

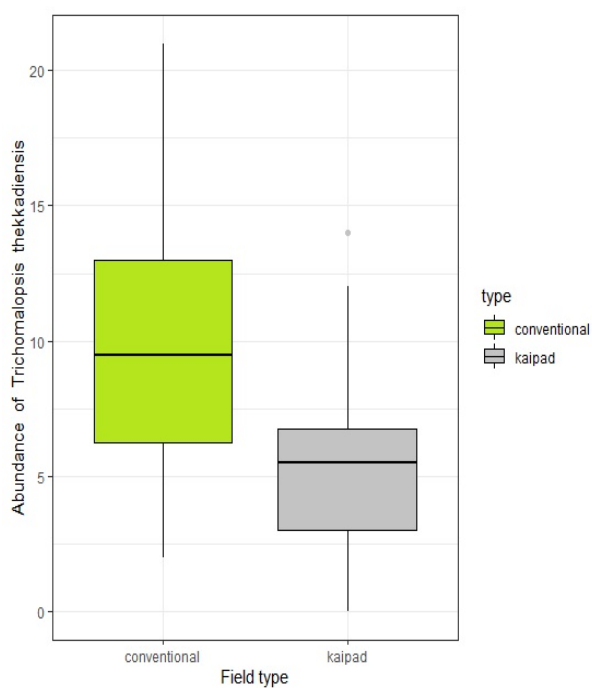


Fig. 3.146: Abundance of *Trichomalopsis travancorensis* in Conventional and Kaipad rice fields.

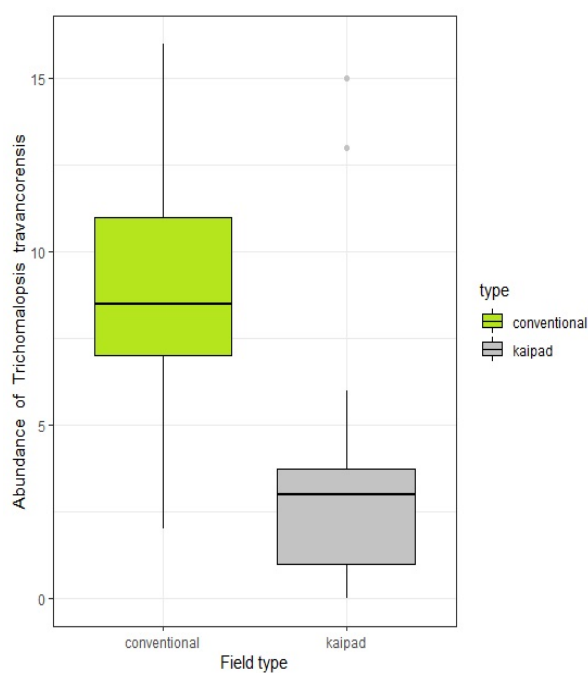
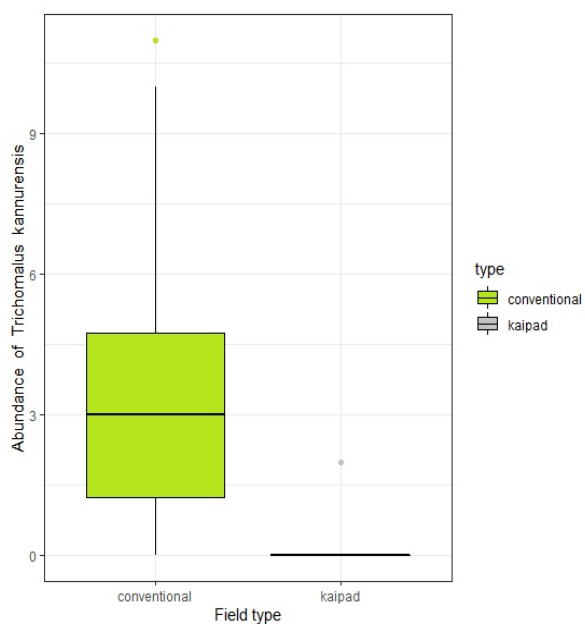


Fig. 3.147: Abundance of *Trichomalus kannurensis* in Conventional and Kaipad rice fields.



Trichogrammatidae

The species under Trichogrammatidae recorded during present study are *Chaetostricha* sp., *Lathromeroidea* sp., *Oligosita* sp., *Trichogramma achaeae* (Plate

XXXI.118), *Trichogramma chilonis*, *Trichogramma hebbalensis*, *Trichogramma japonicum*, *Trichogramma* sp., *Trichogrammatoidea bactrae* (Plate XXXI.119), *Trichogrammatoidea* sp. and *Tumidiclava* sp.. The species *Lathromeroidea* sp. (Fig.3.148) and *Trichogramma achaeae* are only reported from Conventional and Kaipad rice fields respectively.

Among them, *T. chilonis* ($p=8.956e-06$ ***), *T. hebbalensis* ($p=0.007751$ **) and *T. japonicum* ($p=2.477e-07$ ***) are showing significant difference in their total abundance between Conventional and Kaipad rice fields. But *Chaetostricha* sp. ($p=1$), *Oligosita* sp. ($p=0.1048$), *Trichogramma* sp. ($p=0.09776$), *Trichogrammatidea bactrae* ($p=1$), *Trichogrammatoidea* sp. ($p=1$) and *Tumidiclava* sp. ($p=0.3131$) are not showing any significant difference in their abundance between the two categories of rice fields (Tab. 3.4).

The range of *Oligosita* sp. (Fig.3.149), *T. chilonis* (Fig.3.150), *T. hebbalensis* (Fig.3.151), *T. japonicum* (Fig.3.152), *Trichogramma* sp. (Fig.3.153), *Trichogrammatoidea* sp. (Fig.3.154) are higher in Conventional rice fields than that of Kaipad rice fields.

Fig. 3.148: Abundance of *Lathromeroidea* sp. in Conventional and Kaipad rice fields.

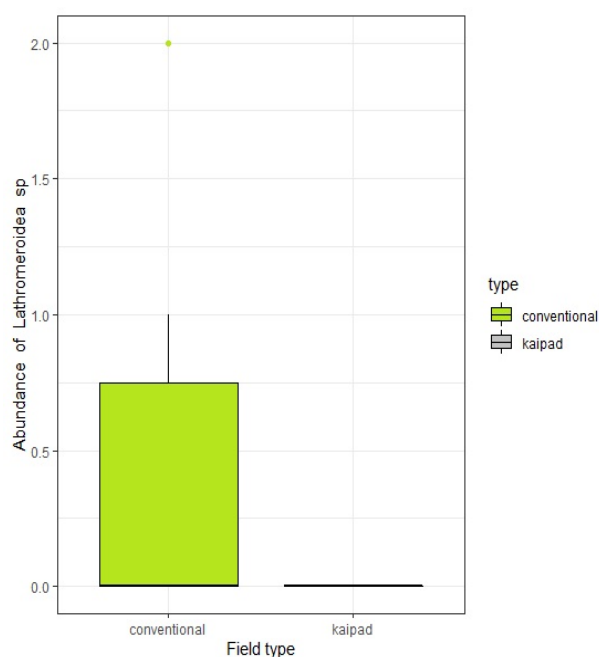


Fig. 3.149: Abundance of *Oligosita* sp. in Conventional and Kaipad rice fields.

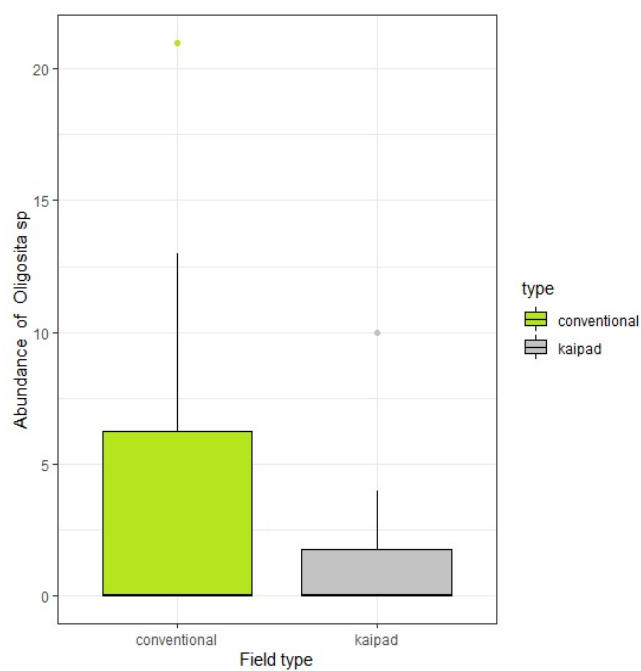


Fig. 3.150: Abundance of *Trichogramma chilonis* in Conventional and Kaipad rice fields.

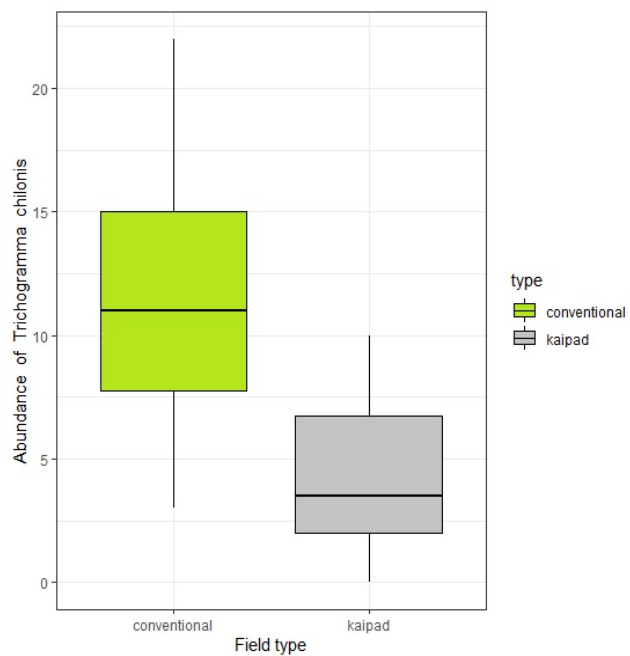


Fig. 3.151: Abundance of *Trichogramma hebbalensis* in Conventional and Kaipad rice fields.

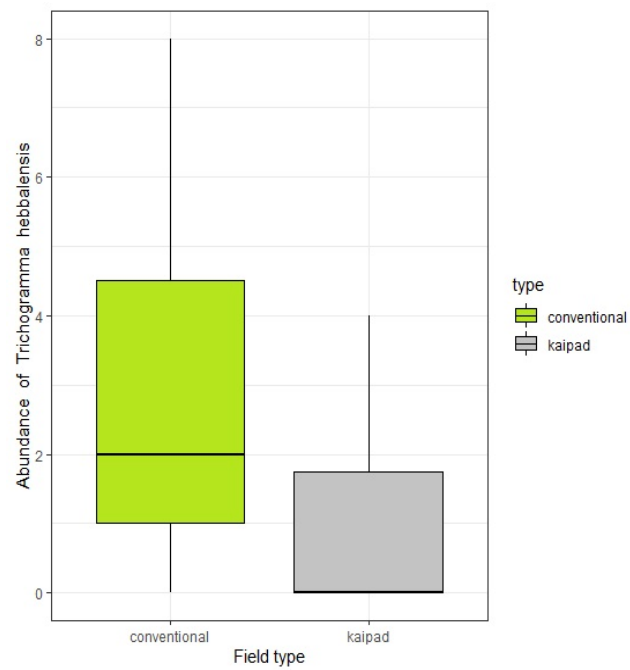


Fig. 3.152: Abundance of *Trichogramma japonicum* in Conventional and Kaipad rice fields.

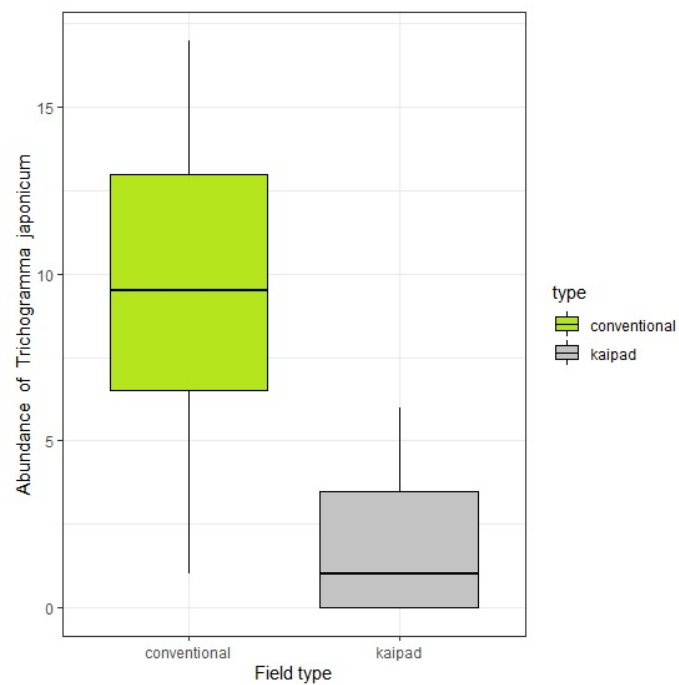


Fig. 3.153: Abundance of *Trichogramma* sp. in Conventional and Kaipad rice fields.

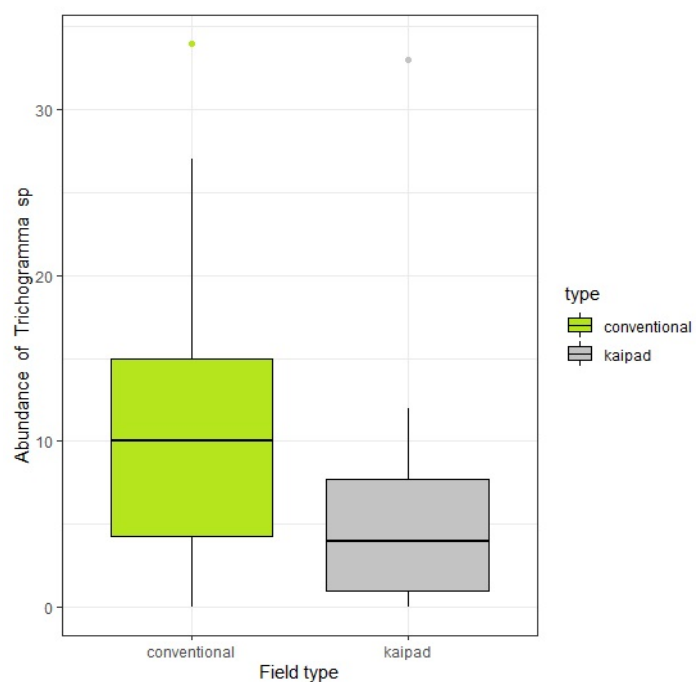
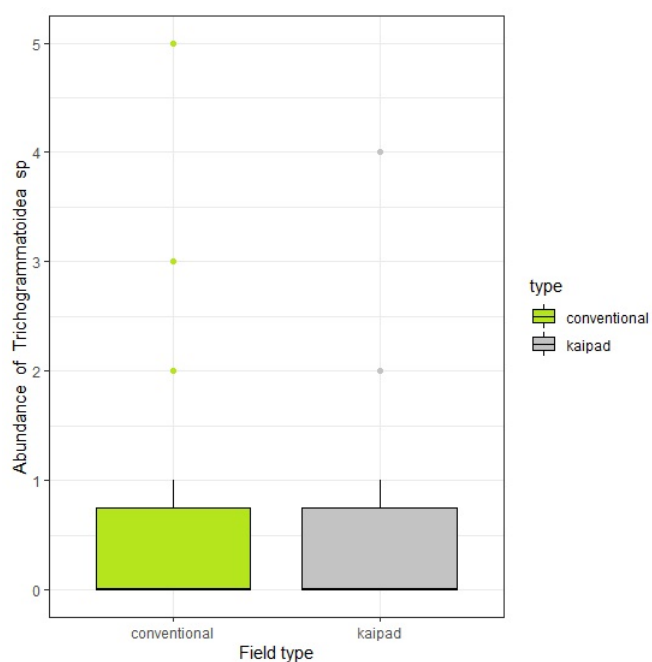


Fig. 3.154: Abundance of *Trichogrammatoidea* sp. in Conventional and Kaipad rice fields.



Tab. 3.4. The abundance of parasitic Hymenoptera between Conventional and Kaipad rice fields

Sl.No	Parasitoid species	Sum sq	Df	F Value	Pr(>F)
1	<i>Aleiodes</i> sp.	8.5472	1	10.161	0.003073 **
2	<i>Amyosoma chinensis</i> (Szépligeti, 1902)	3.977	1	1.2358	0.2741
3	<i>Anagrus</i> sp.	23.658	1	20.529	6.909e-05 ***
4	<i>Anastatus</i> sp.	3.032	1	2.2808	0.1402
5	<i>Anomalon</i> sp.	4.2965	1	6.4671	0.01571 *
6	<i>Antrocephalus phaeospilus</i> Waterston, 1922	10.965	1	12.55	0.001175 **
7	<i>Antrocephalus</i> sp.	33.206	1	19.823	8.706e-05 ***
8	<i>Apanteles</i> sp.	35.30	1	14.541	0.0005511 ***
9	<i>Apanteles</i> sp.1	5.754	1	2.9034	0.09752
10	<i>Aphanogamus</i> sp.	11.252	1	10.015	0.003267 **
11	<i>Aprostocetus</i> sp.	76.034	1	44.745	1.112e-07 ***
12	<i>Aspidobracon noyesi</i> van Achterberg, 1984	56.082	1	6.2066	0.01777 *
13	<i>Aspidobracon</i> sp.	156.03	1	7.3231	0.01057 *
14	<i>Atropha</i> sp.	0.403	1	0.334	0.5671
15	<i>Brachymeria excarinata</i> Gahan, 1925	10.708	1	8.0258	0.007699 **
16	<i>Brachymeria jambolana</i> Gahan, 1942	5.8221	1	7.1721	0.01132 *
17	<i>Brachymeria lasus</i> (Walker, 1841)	51.043	1	23.833	2.443e-05 ***
18	<i>Brachymeria nephantidis</i> Gahan, 1930	7.835	1	5.6155	0.02362 *
19	<i>Brachymeria</i> sp.	21.976	1	10.988	0.002187 **
20	<i>Bracon brevicornis</i> Wesmael, 1838	5.6173	1	6.3016	0.01699 *
21	<i>Bracon</i> sp.	46.526	1	28.212	6.768e-06 ***
22	<i>Calliscelio</i> sp.	17.094	1	17.196	0.0002122 ***

23	<i>Callitula peethapada</i> Narendran& Mohana, 2001	59.436	1	46.563	7.49e-08 ***
24	<i>Cardiochiles</i> sp.	13.682	1	11.143	0.002054 **
25	<i>Casitaria pedunculata</i> (Szepligeti, 1908)	2.093	1	2.5415	0.1201
26	<i>Ceraphron</i> sp.	1.521	1	0.9777	0.3298
27	<i>Chaetostricha</i> sp.	0	1	0	1
28	<i>Charops bicolor</i> (Szepligeti, 1906)	14.905	1	14.197	0.0006264 ***
29	<i>Charops</i> sp.	0.143	1	0.1283	0.7225
30	<i>Chelonus</i> sp.	34.932	1	41.24	2.453e-07 ***
31	<i>Chrysonotomyia</i> sp.	34.752	1	14.053	0.0006612 ***
32	<i>Cotesia</i> sp.	38.244	1	17.775	0.0001736 ***
33	<i>Cotesia</i> sp.1	0.201	1	0.1397	0.7109
34	<i>Cremastobaeus</i> sp.	18.504	1	16.132	0.0003089 ***
35	<i>Diadegma</i> sp.	0.2014	1	0.2208	0.6414
36	<i>Dolichogenidea</i> sp.	31.494	1	23.409	2.781e-05 ***
37	<i>Duta</i> sp.	35.732	1	35.762	9.139e-07 ***
38	<i>Elasmus</i> sp.	373.54	1	63.918	2.57e-09 ***
39	<i>Euplectrus</i> sp.	3.314	1	1.6212	0.2116
40	<i>Eurytoma</i> sp.	241.473	1	164.25	1.425e-14 ***
41	<i>Exoryza schoenobii</i> Wilkinson, 1932	0	1	0	1
42	<i>Exoryza</i> sp.	8.547	1	9.025	0.004971 **
43	<i>Fusicornia</i> sp.	14.778	1	9.8018	0.003572 **
44	<i>Glyptapanteles</i> sp.	3.826	1	2.2366	0.144
45	<i>Gnamtodon</i> sp.	2.942	1	1.6553	0.2069
46	<i>Gonatocerus aegyptiacus</i> Soyka, 1950	54.860	1	46.652	7.348e-08 ***
47	<i>Gonatocerus longicornis</i> Nees 1834	0.334	1	0.2088	0.6506

48	<i>Gonatocerus shamimi</i> Subba Rao & Hayat, 1986	16.934	1	11.072	0.002114 **
49	<i>Goniozuss</i> p.	11.907	1	7.9338	0.008022 **
50	<i>Goryphus</i> sp.	1.6457	1	1.7966	0.189
51	<i>Gotra</i> sp.	5.822	1	4.0234	0.05288
52	<i>Greyon</i> sp.	54.077	1	30.283	3.813e-06 ***
53	<i>Hockeria aligharensis</i> Roy & Farooqi, 1984	3.9624	1	4.6456	0.0383 *
54	<i>Idris</i> sp.	44.098	1	34.076	1.4e-06 ***
55	<i>Ishnojoppa</i> sp.	4.8182	1	7.6076	0.009803 **
56	<i>Isotima</i> sp.	5.8839	1	7.7798	0.008594 **
57	<i>Javra</i> sp.	18.739	1	20.04	8.107e-05 ***
58	<i>Leptobatopsis indica</i> (Cameron, 1897)	3.8549	1	5.041	0.03137 *
59	<i>Leptobatopsis</i> sp.	14.699	1	12.014	0.00145 **
60	<i>Lusius</i> sp.	8.547	1	8.1175	0.007392 **
61	<i>Lymaenon aureus</i> Girault, 1911	7.325	1	4.7377	0.03655 *
62	<i>Lymaenon munnarus</i>	6.494	1	3.9427	0.05519
63	<i>Macrocentrus</i> sp.	19.531	1	29.189	5.15e-06 ***
64	<i>Macroteleia</i> sp.	37.163	1	24.551	1.965e-05 ***
65	<i>Menaforia</i> sp.	7.3613	1	9.6263	0.003846 **
66	<i>Microplitis</i> sp.	25.026	1	34.532	1.246e-06 ***
67	<i>Mymar taprobanicum</i> Ward, 1875	1.159	1	0.6611	0.4218
68	<i>Myosoma</i> sp.	6.8594	1	7.8936	0.008167 **
69	<i>Neanastatus</i> sp.	9.942	1	5.388	0.0264 *
70	<i>Notoglyptus scutellaris</i> (Dodd & Girault, 1915)	90.713	1	77.613	2.696e-10 ***
71	<i>Oligosita</i> sp.	21.67	1	2.7778	0.1048
72	<i>Opiine</i> sp.1	0.731	1	0.431	0.5159

73	<i>Opiine</i> sp.2	20.719	1	16.652	0.0002568 ***
74	<i>Opiine</i> sp.3	14.073	1	11.614	0.0017 **
75	<i>Opisthacantha</i> sp.	25.642	1	21.687	4.762e-05 ***
76	<i>Orgilonia ashmeadi</i> (Viereck, 1911)	17.415	1	11.419	0.001837 **
77	<i>Palpoteleia</i> sp.	62.155	1	34.549	1.241e-06 ***
78	<i>Panstenon</i> sp.	35.913	1	16.931	0.0002328 ***
79	<i>Parapanteles</i> sp.	2.911	1	2.6606	0.1121
80	<i>Paridris</i> sp.	21.942	1	9.2673	0.00448 **
81	<i>Pediobius</i> sp.	45.970	1	26.367	1.148e-05 ***
82	<i>Platygaster</i> sp.	53.936	1	12.828	0.001055 **
83	<i>Pristomerus</i> sp.	5.062	1	5.1929	0.02908 *
84	<i>Probaryconus</i> sp.	15.446	1	16.634	0.0002584 ***
85	<i>Propicroscytus mirificus</i> (Girault, 1915)	8.547	1	4.764	0.03606 *
86	<i>Propicroscytus oryza</i> (Subba Rao, 1973)	79.356	1	47.652	5.935e-08 ***
87	<i>Scelio</i> sp.	54.977	1	48.008	5.503e-08 ***
88	<i>Scenocharops</i> sp.	2.911	1	3.2992	0.07814
89	<i>Skeatia</i> sp.	4.8182	1	6.5527	0.01509 *
90	<i>Synopeas</i> sp.	34.464	1	28.181	6.828e-06 ***
91	<i>Telenomus</i> sp.	94.906	1	16.916	0.000234 ***
92	<i>Temelucha</i> sp.	3.9624	1	4.6456	0.0383 *
93	<i>Tetrastichus schoenobii</i>	70.847	1	18.726	0.0001255 ***
94	<i>Tetrastichus</i> sp.	29.750	1	18.581	0.0001318 ***
95	<i>Theronia</i> sp.	4.6145	1	7.7028	0.008897 **
96	<i>Trathala flavoorbitalis</i> (Cameron, 1907)	4.8182	1	5.6489	0.02324 *
97	<i>Trathala</i> sp.	0.2014	1	0.2208	0.6414

98	<i>Trichogramma achilonis</i> Ishii, 1941	63.778	1	27.227	8.956e-06 ***
99	<i>Trichogramma hebbalensis</i>	16.189	1	8.0109	0.007751 **
100	<i>Trichogramma japonicum</i> Ashmead, 1904	99.594	1	41.197	2.477e-07 ***
101	<i>Trichogramma</i> sp.	25.164	1	2.8991	0.09776
102	<i>Trichogrammatoidea bactrae</i> Nagaraja 1979	0	1	0	1
103	<i>Trichogrammatoidea</i> sp.	0.000	1	0	1
104	<i>Trichomalopsis acarinata</i> Sureshan&Narendran, 2001	31.761	1	11.745	0.001613 **
105	<i>Trichomalopsis apanteloctena</i> (Crawford, 1911)	95.873	1	29.48	4.752e-06 ***
106	<i>Trichomalopsis neelagastra</i> Sureshan and Narendran, 2001	76.576	1	36.366	7.865e-07 ***
107	<i>Trichomalopsis ovigastra</i> Sureshan and Narendran, 2001	36.572 1	1	14.705	0.0005186 ***
108	<i>Trichomalopsis</i> sp.	0.67	1	0.165	0.6871
109	<i>Trichomalopsis thekkadiensis</i> Sureshan and Narendran, 2001	25.638	1	9.8689	0.003472 **
110	<i>Trichomalopsis travancorensis</i> Sureshan and Narendran, 2001	33.544	1	10.655	0.002506 **
111	<i>Trichomalus kannurensis</i> Sureshan and Narendran, 2001	74.896	1	30.956	3.178e-06 ***
112	<i>Trimorus</i> sp.	86.054	1	43.669	1.413e-07 ***
113	<i>Trissolcus</i> sp.	77.098	1	70.991	7.726e-10 ***
114	<i>Tropobracon luteus</i> Cameron, 1905	3.738	1	3.7278	0.06189
115	<i>Tumidiclava</i> sp.	3.397	1	1.0482	0.3131
116	<i>Xanthopimpla flavolineata</i> Cameron, 1907	5.624	1	4.6024	0.03916 *
117	<i>Xanthopimpla punctata</i> (Fabricius, 1781)	4.4389	1	5.0548	0.03115 *
118	<i>Xanthopimpla</i> sp.	1.927	1	1.6383	0.2092

The diversity indices and dominance of hymenopteran parasitoids in Kaipad and Conventional rice fields.

In Conventional rice fields, *Telenomus* sp. (D=0.02653) was recorded as the most dominant parasitoid species, and followed by *Tetrastichus schoenobii*, *Elasmus* sp. and *Eurytoma* sp. The Simpson and Shannon, diversity indices values were 0.9735 and 4.147, respectively (Tab. 3.5).

In Kaipad rice fields, *Telenomus* sp. (D=0.04322) was recorded as predominant parasitoid species, and followed by *Tetrastichus schoenobii*, *Trichogramma* sp. and *Trichomalopsis thekkadiensis*. The Simpson and Shannon, diversity indices values were 0.9568 and 3.819 respectively (Tab. 3.5).

Diversity of parasitoids are higher in Conventional rice fields than in Kaipad rice fields (Tab. 3.5).

Tab. 3.5. The diversity indices and dominance of hymenopteran parasitoids in Kaipad and Conventional rice fields

	Kaipad	Conventional
Taxa_S	124	156
Individuals	2749	8527
Dominance_D	0.04322	0.02653
Simpson_1-D	0.9568	0.9735
Shannon_H	3.819	4.147

The diversity indices and dominance of hymenopteran parasitoids in Kaipad rice fields in different months.

Telenomus sp. was recorded as the most dominant parasitoid during June (D=0.04902), August (D=0.03674), September (D=0.05127) and October (D=0.05295), but in July, *Tetrastichus schoenobii* (D=0.04135) was the predominant one. According to Shannon (3.833) and Simpson (0.9633), the diversity indices parasitoid diversity month was highest during August in Kaipad rice fields (Tab. 3.6).

The diversity indices and dominance of hymenopteran parasitoids in Kaipad rice fields in different Years.

In Kaipad rice fields, during 2015, *Telenomus* sp. (D=0.05068) was the predominant species, and followed by *Tetrastichus schoenobii* and *Trichomalopsis thekkadiensis*. In 2016, the most reported parasitoid species were *Tetrastichus schoenobii* (D=0.04737) and followed by *Telenomus* sp. and *Tetrastichus* sp. But during, 2017, *Telenomus* sp. (D=0.04024) dominated followed by *Tetrastichus schoenobii* and *Trichogramma* sp. According to Simpson (0.9598) and Shannon (3.825), diversity indices the most parasitoid diversity was highest in 2017 (Tab. 3.7).

Tab. 3.6: The diversity indices and dominance of hymenopteran parasitoids in Kaipad rice fields in different months.

	June	July	August	September	October
Taxa_S	69	91	88	87	74
Individuals	482	692	612	508	455
Dominance_D	0.04902	0.04135	0.03674	0.05127	0.05295
Simpson_1-D	0.951	0.9586	0.9633	0.9487	0.9471
Shannon_H	3.561	3.803	3.833	3.687	3.539

Tab. 3.7: The diversity indices and dominance of hymenopteran parasitoids in Kaipad rice fields in different years.

	2015	2016	2017
Taxa_S	97	90	97
Individuals	938	841	970
Dominance_D	0.05068	0.04737	0.04024
Simpson_1-D	0.9493	0.9526	0.9598
Shannon_H	3.647	3.677	3.825

The diversity indices and dominance of hymenopteran parasitoids in Conventional rice fields in different months.

In Conventional rice fields, *Telenomus* sp. was recorded as the most dominant parasitoid during July (D=0.02706), August (D=0.02763), September (D=0.02611) and October (D=0.027), but in June, *Elasmus* sp. (D=0.02955) was predominant species. As per Shannon (4.13) and Simpson (0.9739), diversity indices parasitoid diversity was highest in September in conventional rice fields (Tab. 3.8).

The diversity indices and dominance of hymenopteran parasitoids in Conventional rice fields in different Years.

In 2015, *Telenomus* sp. (D=0.02892) was the more dominant species, and followed by *Tetrastichus schoenobii* and *Elasmus* sp. In 2016, the most reported parasitoid species were *Tetrastichus schoenobii* (D=0.02736) and followed by *Telenomus* sp. and *Elasmus* sp. But during, 2017, *Telenomus* sp. (D=0.02775) dominated, followed by *Elasmus* sp. and *Aspidobracon* sp. According to Simpson (0.9726) and Shannon (4.11), diversity indices, the most parasitoid diversity was observed in 2016 (Tab. 3.9).

Tab. 3.8: The diversity indices and dominance of hymenopteran parasitoids in Conventional rice fields in different months

	June	July	August	September	October
Taxa_S	116	129	127	125	116
Individuals	1635	1755	1890	1747	1500
Dominance_D	0.02955	0.02706	0.02763	0.02611	0.027
Simpson_1-D	0.9705	0.9729	0.9724	0.9739	0.973
Shannon_H	3.998	4.094	4.087	4.13	4.064

Tab. 3.9: The diversity indices and dominance of hymenopteran parasitoids in Conventional rice fields in different years

	2015	2016	2017
Taxa_S	126	132	146
Individuals	2569	2951	3007
Dominance_D	0.02892	0.02736	0.02775
Simpson_1-D	0.9711	0.9726	0.9722
Shannon_H	4.043	4.11	4.093

DISCUSSION

Rice fields carry a rich and diverse fauna than any other crop system (Heckman, 1979; Fritz et al., 2011) and those communities consists of pests, their natural enemies (predators and parasitoids) and other neutral insect groups that visit the vegetation as tourists (Heong et al., 1991). La-Salle and Gauld (1993) revealed that most hymenopteran parasitoids are keystone species and the removal of such insects will lead to cascade effect in the ecosystem.

In the order Hymenoptera, 75% of the species are parasitoids and are highly diverse and specialized to attack a particular host life stage (egg, larvae, pupae and adults) of most arthropods, mainly insects. Noyes (2004 & 2008) also revealed that, parasitoids are hyper-diverse group of insects and almost all species are parasitoids of insects, with many attacking economically important pests such as whiteflies, aphids and scale insects.

The biodiversity of beneficial insect natural enemies is a key resource to foster the productivity and sustainability in rice paddies and conservation of natural enemies should be an important method for sustainable rice production. Several parasitoids belonging to parasitic Hymenoptera have been reported from rice pests (Beevi et al., 2000 and Konishi et al., 2004), and in the present study 171 species of hymenopterans have been reported. Some of these parasitoids may prove useful in future biocontrol programs against rice pests.

In the present study, parasitoids belonging to 12 families belonging to the Order Hymenoptera have been reported. Study revealed that Chalcidoidea is the most dominant super family in Conventional and Kaipad rice fields of North Kerala, followed by Platygastroidea and Ichneumonoidea. During a survey in rice ecosystems of Tamil Nadu, Daniel and Ramaraju (2017) also noted Chalcidoidea as the most dominant super family in that area followed by Ichneumonoidea and Platygastroidea. They listed twenty-eight families, and also updated the existing check list of Dey et al., (1999). Daniel and Ramaraju (2017) listed Bethyridae, Dryinidae, Chalcididae, Encyrtidae, Eulophidae, Eupelmidae, Eurytomidae, Mymaridae, Pteromalidae, Trichogrammatidae, Platygastriidae, Ichneumonidae, Braconidae, Diapriidae, Aphelinidae and Torymidae families from rice ecosystems of India. Among them, all except Dryinidae, Encyrtidae, Diapriidae, Aphelinidae and Torymidae are reported during the present study. Agus et al., (2007) reported Ichneumonids, Braconids and Scelionids as the most abundant hymenopteran parasitoids in organic and conventional agro-ecosystems. Platygastriidae was the most abundant family reported from Kaipad and Conventional rice fields during the present study, followed by Eulophidae, Pteromalidae, and Braconidae.

Braconidae is one of the most diverse groups (Long, 2011), and the most abundant, most difficult family taxonomically and the most diverse group in both solitary and gregarious category, attacking caterpillars. About 1000 species are known worldwide, has a wide host range and plays an important role in controlling insect pests (Salzat and Whitefield, 2004; Long, 2011). In the present survey, it is one of the major families. 34 species of Braconidae were reported from Conventional rice fields, and 27 species from Kaipad rice fields, mainly larval and pupal parasitoids of rice pests. During the present study, Braconid species *Apanteles* sp.2, *Bracon* sp.1, *Bracon* sp.2 and *Macrocentrus philippinensis* were recorded only from Conventional rice fields even though their host stages are reported from both categories of rice fields. The species like *Dacnusa* sp., *Dolichogenidea* sp. and *Opiine* sp. was also recorded from Conventional rice fields only, and their host stage is unknown. *Scutibracon* sp. a parasitoid of larvae of *D. armigera* was collected from Conventional rice fields while its host presence was not recorded. Whereas

Rhaconotus sp. is only noted in Kaipad rice fields, and they are attacking larval stages (Unknown pest species). January et al., (2018) revealed that *Cotesia flavipes* was parasitizing the stem borer larvae. Ahangama and Gilstrap (2007) also recorded *Cotesia flavipes* and *Cotesia* sp. as the natural enemies of *S. incertulas* (Walker) in Sri Lanka. Two species of *Cotesia* were recorded during present study, and they may have some role in regulating the attack of *S. incertulas* in Conventional and Kaipad rice fields. Moolman et al., (2013) reported *Bracon* sp. And *Cotesia sesamiae* as parasitoids of many stem borers species in Poaceae, Cyperaceae, Juncaceae and Typhaceae families in South Africa and Mozambique. Present study also documented the incidence of *Bracon* sp. and *Cotesia* sp. in Kaipad and Conventional rice fields and larvae of *S. incertulas* is one of their major hosts. The abundance of *Bracon* sp. and *Cotesia* sp. are higher in Conventional rice fields than in Kaipad rice fields, this may be because the present study recorded lower abundance of *S. incertulas* eggs from Kaipad rice fields compared to Conventional rice fields. Barrion et al., (1991) also reported *Macrocentrus philippinensis* as parasitoids of *M. patnalis*, and which was recorded from Conventional rice fields in the present study. The *Macrocentrus* sp., associated with *M. patnalis* was reported from India also (Rao (1964) and Abraham et al., 1973). Rani et al., (2007), Yadav et al., (2018) and Parasappa et al., (2017) also noted *Apanteles* sp. as the larval parasitoids of *M. patnalis*. In 2010, Subharani et al., recorded *Bracon* sp., *Temelucha* sp., *Diadegme* sp., and *Cotesia* sp. from *M. patnalis* in Manipur, and these species may controlling *M. patnalis* during the present study. In 2006, Battacharya et al., listed out *Bracon* sp., (from *M. patnalis*), *Tropobracon* sp., (from *Leptocorisa acuta*) from rice fields of Jorhat district of Assam. These are also recorded from Kaipad and Conventional rice fields during present study, and they may have a significant role in keeping check on their hosts in the rice fields.

Aphanogamus sp. and *Ceraphron* sp. among Ceraphronidae are more abundant in Conventional rice fields than in Kaipad rice fields, and this may be because of the higher abundance of their hosts, *P. mathias* and *M. patnalis* larvae in Conventional rice fields.

According to an earlier study by Grissel and Schauff (1990), the majority of Chalcidoidea are parasitoids; attacking egg or larval stage of the host. Among families of Chalcidoidea, the families like, Chalcididae, Elasmidae, Eulophidae, Eupelmidae, Eurytomidae, Mymaridae, Pteromalidae and Trichogrammatidae were recorded in the present study.

In family Chalcididae, even though the hosts of *Dirhinus anthracia* and *Kriechbaumerella pulvinata* are reported from both categories of rice fields, these two parasitoids are recorded from Conventional rice fields only. *Hockeria* sp. is also reported from Conventional rice fields only, and their host is unknown. All other reported species of parasitoids belonging to Chalcididae have higher abundance in Conventional rice fields. Amongst Chalcididae, *Brachymeria* sp. was reported as a parasitoid of *M. patnalis* (Barrion et al., 1991), and may be controlling *M. patnalis* in both categories of rice fields in the present study. The *Brachymeria* sp. (Rao, 1964 and Abraham et al., 1973) and *Brachymeria excarinata* parasitizing *M. patnalis* (Subharani et al., 2010) was reported from India. These two species of parasitoids may be playing a role in keeping in check the population of *M. patnalis* in both categories of rice fields in the present study. In the present study, the abundance of *D. anthracia* is higher in Conventional rice fields, and it coincides with the fact that its host, pupae of *M. patnalis* is recorded in higher abundance from Conventional rice fields.

Gurr et al., (2011) listed *Aprostocetus formosanus* as a parasitoid of Delphacidae in the rice fields of Philippines, Vietnam, Malaysia and Thailand. Other authors have also documented Eulophidae species in rice crops (Nacro et al., 1997; Williams et al., 1999; Bayegan et al., 2015). Fritz et al., (2011) reported Eulophidae as the most abundant parasitoid family controlling Curculionidae, Pentatomidae, Delphacidae and Cicadellidae. During the present study, the Eulophid parasitoids, viz. *Aprostocetus uthonia*, *Asecodes* sp., *Derostenoides* sp., *Elasmus hyblaeae*, *E. viridiscutellatus*, *E. zatonus*, *Entedon* sp., *Hemiptarsenus* sp., *Minotetrastichus* sp., *Neotrichoporoides* sp., *Quadrastichus dicleus*, *Stenomesus* sp. and *Tetrastichus sissoo* are only reported from Conventional rice fields. Among them *Stenomesus* sp.

was recorded from Conventional only, even though its host, larvae of *M. patnalis* larvae was reported from both categories of rice fields. While *Omphale* sp. and *Tetrastichus parapyxi* are only seen in Kaipad rice fields even though their hosts, larva of Cecidomyiidea and pupa of *P. stagnails* are recorded from both type of fields. Even after many collection efforts during three cropping seasons, the reason for the absence of these parasitoids from the conventional rice fields even in the presence of their hosts needs to be further studied. The higher abundance of *Pediobius* sp. (Hosts: Larvae of *M. patnalis* and *P. mathias*), *Tetrastichus schoenobii* (Hosts: Larvae of *M. patnalis* and eggs of *Scirpophaga incertulas*) and *Tetrastichus* sp. (Hosts: Larvae of *M. patnalis*, *Scirpophaga incertulas* and Pupa of *M. patnalis*) in Conventional rice fields may be due to the presence high abundance of their hosts in Conventional rice fields than in Kaipad rice fields.

Tetrastichus schoenobii was reported as egg parasitoids of *S. incertulas* from different parts of the world (Chakraborty, 2012; Reuolin et al., 2018 and Ahangama and Gilstrap, 2007). The present study documented this species in both categories of rice fields. *Tetrastichus* has been reported as egg parasitoids of *N. lugens* and *Sogatella furcellata* (Horvath) by different workers (Pathak and Khan 1994; and Gurr et al., 2011; Vungsilabutr et al., 2002 and Sriratanasak et al., 2007). Rai et al., (1976) collected *Tetrastichus* sp. from reared *O. oryzae* in Karnataka.

The abundance of *Chrysonotomyia* sp. was higher in Conventional rice fields even though their host (larvae of *D. armigera*) is noted from Kaipad rice fields only. The possibility of *Chrysonotomyia* sp. parasitizing other hosts should be investigated. Earlier, *Chrysonotomyia* sp. was reported as a larval parasitoid of *D. armigera* by several researchers (Srivastava et al., 2015; Gumovsky et al., 2006 and Bhattacharyya et al., 2000). Furthermore, Sriratanasak et al. (2007) recorded that *Aprostocetus* sp. attacked pupae of *Orseolia oryzae*. In 2010, Subharani et al., recorded *Elasmus* sp., from *M. patnalis* in Manipur.

The Eupelmid parasitoid, *Eupelmus* sp. is only noted from Conventional rice fields which synchronize with the presence of their larval/pupal host stages in Conventional rice fields. Several authors reported *Neanastatus* sp. as a parasitoid of

O.oryzae (Joshi et al.,1984), Kobayashi et al., 1990 and Das et al., 1987). But in the present study, eventhough its host is not present in both conventional and Kaipad rice fields, *Neanastatus* sp. have been collected from both types of fields. The higher number of *Anastatus* sp. in Conventional fields may be due to the abundance of their hosts (eggs of Pentatomidae and Acrididae) in Conventional field than in Kaipad rice fields.

Eurytoma sp. is the only species coming under Eurytomidae recorded during the present study, and they are the larval parasitoids of *M. patnalis*, *O.oryzae* and Hesperidae. Their presence is in synchrony with the presence of one of their host, *M. patnalis* in the Conventional rice fields.

Goniozus sp. is reported from larvae of *M. patnalis* in earlier studies by Rani et al., (2007) and Manisegaran et al., (1997). In the present study, *Goniozus* sp. was collected in higher numbers from conventional rice fields which coincide with the abundance of their host, viz. larvae of *M.patnalis*.

The Ichneumonids, *Atropha* sp.1, *Caenopimpla* sp., *Caenopimpla* sp.1, *Casinaria* sp. and *Sinophorus* sp. are recorded only from Conventional rice fields. In addition to the above mentioned parasitoids, *Charops bicolor*, *Charops* sp., *Diadegma* sp., *Goryphus* sp., *Ishnojoppa* sp., *Leptobatopsis indica*, *Scenocharops* sp., *Temelucha* sp., *Trathala flavoorbitalis*, *Xanthopimpla flavolineata*, *X. punctata* and *Xanthopimpla* sp. are also recorded in higher numbers from conventional rice fields which may be due to the presence of higher number of their hosts in Conventional rice fields than in Kaipad rice fields. Ahangama and Gilstrap (2007) reported *Isotima* sp. as the natural enemies of *S. incertulas* (Walker) in Sri Lanka. Although *Isotima* sp. – a larval parasitoid- is collected from both types of fields, its higher abundance in Conventional rice fields is in tune with the higher presence of *S. incertulas*, their host.

Mymarids, the egg parasitoids, mostly attack, Auchenorrhyncha (Hemiptera), in addition to Coleoptera, Orthoptera and other Hemiptera (Hanson and Gauld, 2006). They are mostly responsible for the biological control of leafhopper (Cicadellidae), Planthopper (Delphacidae), and treehopper (Membracidae) species

including economically important pests (Triapitsyn, 2013). Eleven species of mymarids were recorded from the two types of rice fields during the present study. *Anagrussp.* (eggs of *Nilaparvata lugens*, *Sogatella frucifera* and *Recilia dorsalis*), *Gonatocerus aegyptiacus* (eggs of *R. dorsalis*), *Lymaenon aureus* (eggs of planthoppers), *L. delhiensis* (eggs of planthoppers) and *Mymar taprobanicum* (eggs of *R.dorsalis*, *N.lugens* and *S.frucifera*) have been collected during the present study. Gurr et al.,(2011) recorded mymarids as egg parasitoids of rice pests in Delphacidae family in Asia and Oceania (India, China, Japan, Malaysia, Singapore, Vietnam, Sri Lanka, the Philippines, Thailand, Korea, Taiwan, Indonesia). Rajesh et al., (2019) recorded *Gonatocerus aegyptiacus*, *Gonatocerus shamimi*, *Anagrussp.* from Kerala for the first time, and new distributional records of ten species of Mymarids from the rice-agroecosystems of Kerala. *Gonatocerus meghalayensis*, *G. narayani*, *Lymaenon delhiensis* (Host: eggs of planthoppers), *Mymar schwanni* and *Mymar sp.* were collected from Conventional rice fields only, and which correlates with the presence of their hosts in the field. Sann et al., (2018b) also recorded *Gonatocerus sp.* from the eggs of *Nephotettix sp.* Yasumatsu et al., (1975) also documented the contribution of *Anagrussp.*, *Mymar taprobanicum* and *Gonatocerus sp.*, in the reduction of plant hoppers in rice ecosystem. The presence of low number of insect pests including hoppers in Kaipad rice fields and higher species richness of the mymarids, the egg parasitoids, may be explained by the observation of Marc and Canard (1997) that in unsprayed rice, BPH populations are normally low, which supports the finding that presence of more natural enemies improve biological control of BPH.

The taxonomy of Platygasteridae is well worked out and is known to parasitize mainly arthropod groups like Orthoptera, Hemiptera and spiders (Galloway and Austin 1984; Austin et al., 2005), with more than 75 percent having Orthopterans as their hosts. During the present study, twenty-three species of platygasterids have been collected from Conventional and Kaipad rice fields. Of these, *Duta indica*, *Odontocolus sp.*, *Paratelenomus sp.* (egg parasitoids of insect and spiders), *Habroteleia sp.* (egg parasitoid of Orthoptera), and *Psilanteris sp.* (egg parasitoid of spider) are only recorded from Conventional rice fields, while

Baryconus sp. (egg parasitoid of unknown host) is only noted from Kaipad rice fields. *Platygaster* sp. and *Synopeas* sp., egg parasitoids of *Orseolia oryzae* have been collected from both types of rice fields in the present study even though their host (eggs of *O. oryzae*) has not been recorded in the fields. This may be because either the host, *Orseolia oryzae* escaped collection (which is highly unlikely as collections were made throughout the three whole rice cultivating seasons) or the above mentioned parasitoid species may be surviving on alternate hosts, which needs to be investigated. Reuolin et al., (2018) reported *Telenomus* sp. from rice stem borers. Ahangama and Gilstrap (2007) also reported *Telenomus* sp., as the natural enemies of *S. incertulas* (Walker) in Sri Lanka. The abundance of *Telenomus* sp. is also higher in Conventional rice fields during the present study; this may be due to the higher number of their host, i.e. eggs of *Scirpophaga incertulas* in Conventional rice fields. The eggs of the *Leptocorisa acuta* and *Nilaparvata lugens* are the host stage of *Gryon* sp. (Battacharya et al., 2006); and *Gryon* sp. was more abundant in Conventional rice fields, but the abundance of their host *L. acuta* is lower in Conventional rice fields (may be due to their control by the parasitoid *Gryon* sp.) than in Kaipad rice fields and the eggs of *N. lugens* are not recorded from both categories of rice fields.

The egg parasitoid *Trissolcus* sp. is recorded from *L. acuta* (Purohit et al., 2013). In the present study, *Trissolcus* sp. and *Gryon* sp. were recorded from both categories of rice fields. Their abundance was higher in Conventional rice fields, even though the host of *Trissolcus* sp. is present in both categories of rice fields and host of *Gryon* sp. is higher in Kaipad rice fields. Hidaka et al., (1988) and Joshi et al., (1984) documented the presence *Platygaster* sp. from *O. oryzae*. So, the higher number of *Platygaster* sp. in Conventional rice fields may be due to the presence of higher abundance of *O. oryzae* in Conventional rice fields. Shweta and Rajmohana (2016) collected 38 species in 21 genera of different parasitoid families from irrigated rice ecosystems across varied elevational ranges in southern India. The *Duta* Nixon with six species was the most dominant and species rich. During present study, we recorded 23 species in 22 genera, and *Duta indica* (seen in Conventional rice fields only) and *Duta* sp. was the two species under *Duta* genera.

Pteromalidae is another largest and taxonomically difficult family of Chalcidoidea and are primary or secondary parasitoids attacking a wide range of insects under different orders in their various stages of development thereby playing a key role in the control of insect pests (Sureshan, 2011). Twenty species of pteromalids were recorded during the present study from both Kaipad and conventional rice fields. Among Pteromalidae, *Trichomalopsis apanteloctena* was more abundant in Conventional rice fields which coincides with the higher abundance of their hosts *M. patnalis* and *P. mathias* larvae in Conventional rice fields. The hosts of parasitoids viz. *Callitula anguloclypea*, *C. peethapada*, *C. travancorensis*, *Notoglyptus scutellaris*, *Notoglyptus* sp., *Trichomalopsis acarinata*, *T. neelagastra*, *T. nigra*, *T. ovigastra*, *T. thekkadiensis*, *T. travancorensis*, *Trichomalus kannurensis* and *Trichomalus* sp. are still not known although they have been collected from the rice fields.

The members of the family Trichogrammatidae are small with short development period and can parasitize over 300 species belonging to at least eight insect orders (Schmidt, 1994), and they oviposit predominantly in the eggs of Lepidoptera (Huang and Gordh, 1998; Losey and Calvin, 1995). Triapitsyn, (2013) also noted that they were mostly responsible for the biological control of leafhopper (Cicadellidae), Planthopper (Delphacidae), and treehopper (Membracidae) species including economically important pests. *Oligosita* sp. is an egg parasitoid of *Nephotettix nigropictus*, *N. virescens*, *N. lugens* and *S. frucifera*. During the present study eleven species of trichogrammatids were collected from the Conventional and Kaipad rice fields. The genus, Trichogramma and Trichogrammatoidea, have been studied extensively and intensively all over the world for their use in biological control (Navik and Varshney, 2018). Jalali et al., (2016) observed that over 200 insect species belonging to 70 different families were parasitised by more than 230 species and subspecies of *Trichogramma* worldwide. Among them, the most dominant and common species were *Trichogramma chilonis*, *T. japonicum* and *T. achaeae*. Among Trichogrammatidae, *Lathromeroidea* sp. and *T. achaeae* are only reported from Conventional and Kaipad rice fields respectively, and the presence of their hosts are restricted to Conventional and Kaipad rice fields respectively.

Ahangama and Gilstrap (2007) reported *Trichogramma* sp., as the natural enemy of *S. incertulas* (Walker) in Sri Lanka. The abundance of hosts, especially the eggs of *S. incertulas* are higher in Conventional rice fields, and this may be the reason for the higher abundance of *Trichogramma chilonis*, *T. japonicum* and *Trichogramma* sp. in Conventional rice fields than in Kaipad rice fields. Sangha et al., (2018) noted that the use of *T. japonicum* against *S. incertulas* was good for the management of stem borer in rice (Anonymous, 2004). Tang et al., (2017) also assessed two *Trichogramma* species for their effectiveness against *S. incertulas* and suggested potentially higher effectiveness on their eggs after at least one generation on the target host. *Trichogramma chilonis*, *T. japonicum* and *Trichogramma* sp. may reduce the damage of *S. incertulas* in Conventional and Kaipad rice fields by parasitizing their eggs. Many authors have observed that the eggs of *Nilaparvata lugens* were parasitized by *Oligosita* sp. and *Anagrus* sp. (Sann et al., 2018b; Chiu, 1979; Yasumatsu et al., 1983; Watanabe et al., 1992; Gurr et al., 2011) and they may be attacking *N. lugens* in the present study.

Twelve families were recorded during the present study, and among them, Platygasteridae was most abundant, followed by Pteromalidae, Eulophidae, Braconidae and Trichogrammatidae, with genus *Telenomus*, *Trichomalopsis*, *Tetrastichus*, *Aspidobracon* and *Trichogramma* found to be most speciose. Menon et al., (2016) reported eleven parasitoid families from rice fields of Palakkad district, Kerala, and Eurytomidae was the dominant one, followed by Eulophidae, Pteromalidae and Chalcididae, with the genus *Eurytoma*, *Tetrastichus*, *Dinarmus* and *Brachymeria* dominating.

Of the total parasitoid species collected during the present study, egg parasitoids constituted 45% in Conventional rice fields, and 55% in Kaipad rice fields. The control of insect pests in the egg stage is important as they prevent the emergence of larval stages of the pests (Mills, 1994) and the members belonging to Mymaridae, Trichogrammatidae and some sub families of Platygasteridae (Telenominae, Teleasinae and Scelioninae) are exclusively egg parasitoids (Austin et al., 2005). The dominance of egg parasitoids in both Kaipad and Conventional

rice fields is a good indication of an effective natural pest control, which needs to be enhanced so that control of the pests are achieved before they enter the more damaging larval stages.

Hymenopteran parasitoids are highly susceptible to extinction than phytophagous arthropods, and their loss can have devastating effects on environmental stability and community balance. Recently, biodiversity in agricultural land has received growing attention because it plays a significant role in agro-ecosystem function by keeping the pest populations under check (Jervis et al., 2007). It is necessary to identify groups of high priority and parasitic Hymenoptera is one such group (La-Salle and Gauld, 1991 & 1993). Wagge (1991) has pointed out that it is fundamentally important to conserve a large reservoir of parasitic hymenopteran diversity. It has also been opined that positive interactions will be more common when more prey is available; and thus, agrees with the finding that, where both predator, herbivore and plant diversity can influence biocontrol, a positive effect of increased predator biodiversity may be most likely (Aquilino et al., 2005).

Daniel and Ramaraju (2019) listed out the hymenopteran parasitoid diversity inhabiting rice agroecosystem of Indian subcontinent, and observed that among them, Aculeata accounted for only six percent and remaining were Parasitica, which indicates that there is much scope in studying the diversity of parasitic hymenopterans in rice ecosystems of India with focus on using them as biocontrol agents to make Indian agriculture less dependent on insecticides. The high species richness of ichneumonids recorded during the present study is beneficial in terms of pest control as noted by Marc and Canard (1997) who opined that while control of a single herbivore species is not always improved by increased diversity of natural enemies, the diversity will make sure of a better overall defense against a variety of pests, as shown for a spider community in apple.

Studies by several authors have demonstrated enhanced insect pest control using diverse species of parasitoids through their complementary function (Bianchi et al., 2006; Crowder et al., 2010). Noyes (1982) reported that, even though

parasitoids are important, our understanding of their diversity is clearly insufficient, partly because of their small size and difficulty in collection and study. Therefore, biodiversity surveys will enable the identification of hotspots of species richness (Graham, 1987). Limited number of studies are there regarding the abundance and diversity of parasitic Hymenoptera in rice agro eco systems of Kerala. In Kaipad, this study may be the first of its kind for inventorying the hymenopteran parasitoids. This study may provide information on the abundance, diversity and use of hymenopteran parasitoids to control insect pests in Kaipad and Conventional rice fields. In conclusion, it is opined that environmentally sound agriculture, which is desirable as a means of providing safe food for humans, should go hand in hand with the conservation of biodiversity by minimizing use of agrochemicals and other environmentally unsafe practices (Ueno, 2010, 2012 a and 2013).

The present study has shed some light on the fact that natural enemies can be useful to assess what extent a given practice is friendly to the environment, on the basis of the diversity and abundance of natural enemies. As biodiversity monitoring is time and labor consuming, it is desirable to identify indicator species that reflect both the level of biodiversity and environmentally sound practices.

CHAPTER 4

TO DETERMINE THE ROLE OF *Eleocharis dulcis* (BURM.F) AS A TRAP PLANT FOR WHITE STEM BORER, *Scirpophaga innotata* (WALKER) IN KAIPAD RICE FIELDS.

INTRODUCTION

This chapter deals with the role of *Eleocharis dulcis* (Burm.f) as a trap plant for white stem borer, *Scirpophaga innotata* (Walker) in Kaipad rice fields of North Kerala.

The rice plants are attacked by different types of insect pests, like stem borers, leaf defoliators, sap feeders etc. in all the growth stages of their life cycle. The white stem borer, *S. innotata* cause severe damages to the crop by making symptoms of dead heart and white ear heads caused by the aggressive boring of stem by the pest, which leads to drying and dying of the plant.

In 2002, Banwo observed the Rice white stem borers, *S. innotata* (Walker) attacking rice throughout the growing stages i.e., from seedling to ear setting stages, and its damage was assessed by symptoms of dead heart and white head. The amount of injury to rice caused by white stem borer *S. innotata* (Walker) depends on cultivar, and stage of plant and insect development, as well as insect abundance (Sanches et al., 1998).

The widespread use of various insecticides to control crop pests has created various well-known problems. Therefore, studies have focused on various cultural practices to suppress insect pest populations (Javaid and Joshi, 2010). Managing insect pests without harming the environment requires innovative practices and there is an increasing interest in habitat management amongst organic growers, researchers, and nongovernmental organizations in developing (Zehnder et al., 2007; Reddy, 2017) and developed countries (Reganold and Wachter 2016).

Cultural control in cultivated crops include use of resistant plant varieties, planting and harvesting time, irrigation, fertilization, crop rotation, and trap crops. A good cultural practice provides a compatible environment for the crop while making it detrimental for pest development and it prevents the build-up and outbreaks of pests. It refers to the manipulation of the crop production system or cultural practices to reduce or eliminate pest populations (Walgenbach, 2017). In addition, the cultural control methods are useful in conservation of beneficial insects, and accordingly, they are essential and effective component of IPM (Kumar et al., 2017).

Trap cropping, the use of alternative host plants to attract, intercept and or retain targeted insect pests for the purpose of minimizing damage to a main crop, is a strategy advocated to reduce the impact of pest attack on the main crop. For agricultural pest management, trap cropping potentially reduces crop damage inexpensively and simultaneously reduces harmful pesticide applications (Cavanagh et al., 2009; Lu et al., 2009). The concept of trap cropping perfectly fits into the ecological framework of habitat manipulation of an agro-ecosystem for the purpose of pest management.

Several examples of Trap cropping management of insect pests were reported from agro ecosystems of India. In cotton fields, Alfalfa, Castor plants, Chick pea, Corn, Cowpea, Okra, Sunflower and Tobacco are used as a trap plant to control damages by *Lygus* bug, *Heliotis* sp. and Flower cotton weevil. The corn stalk borers, Stem borers, *Heliothis* sp., Leaf hoppers, Leaf beetles, Stalk borers, Fall armyworm are the major pests which attacks the corn plant. Their attack is reduced by using the trap plants like Vetiver grass, Sudan grass, Soybean and Napier grass, Desmodium, beans and other legumes (Singh, 2010).

An exhaustive review of literature did not provide any studies on the use of trap crop in rice agro ecosystems of Kerala, and in Kaipad areas.

The rice plant, *O. sativa* is the primary host plant of White stem borer which also oviposit /attack many other alternative host plants. *S. innotata*, is attracted to a Chinese water chestnut, *Eleocharis dulcis* (Cyperaceae) growing in rice fields (Ranganth et al., 2002). *Eleocharis dulcis* (Burm f) commonly known as Chinese

water chestnut or water chestnut, is a grass-like erect, perennial sedge that grows in marshes. It has stem-like, tubular green pseudostems that grow to about 1.5 m height. The plant originated from South-East Asia and later it has spread to tropical West Africa, Madagascar, India, China, Taiwan, Japan, Northern Australia and the Pacific Islands (Kostermans et al., 1987).

Ranganath et al., (2002) observed female moths of *S. innotata* ovipositing on *E. dulcis* in rice fields of southern Andaman Islands. Gazali and Ilhamiyah (2012) also noted its egg clutches on *E. dulcis* in Indonesian rice fields. However, both these studies have not assessed its use as a trap plant or quantified the fitness traits of the stem borer growing on *E. dulcis*. This study, through a quantitative assessment of the preference of *S. innotata* for *E. dulcis* as a potential oviposition site, inquires whether *E. dulcis* can be a potential trap crop to manage this pest in rice fields. We asked: 1) What is the abundance of adults and egg clutches of *S. innotata* on *O. sativa* and *E. dulcis*? 2) What is the egg and larval fitness of *S. innotata* reared on *E. dulcis* and on *O. sativa* plants? 3) Whether the egg parasitism differed in egg clutches sampled from *O. sativa* and *E. dulcis*?

REVIEW OF LITERATURE

Many different methods alter the habitat as part of an integrated pest management (IPM) strategy, and such manipulation can occur at the within-crop, within-farm, or landscape level (Landis et al., 2000). Prior to the commencement of modern synthetic insecticides, trap cropping was a common method of pest control for several cropping systems (De Sahagun, 1969; Talekar and Shelton, 1993, Thurston, 1991).

The rice cultivating Southern region of India comprises of Andhra Pradesh, Karnataka, Tamil Nadu, and Kerala. Kerala has many unique types of rice cultivation viz: Kole land rice cultivation, Pokkali rice cultivation, Kayal land rice cultivation, Kuttanad rice cultivation, Kari land rice cultivation and Kaipad rice cultivation.

Kaipad is a saline affected paddy field of North Kerala and is an unique, coastal wet land rice production tract which is naturally organic. This tract is mainly seen in north Malabar region of Kerala, i.e., Kasaragode, Kannur and Kozhikode, with an approximate area of about 4100 ha. The cropping system Kaipad involves cultivation in low salinity phase (June-October) followed by Shrimp/fish cultivation in the high salinity phase (November – April). Kuthiru, Orkayama are the traditional varieties of rice mostly cultivated in the area, and Mundon, Kundorkutty, Orppandy, Odiyan, Orissa and Punchakayama and Kuttussan were the other land races cultivated in some pockets of Kaipad (Vanaja et al., 2009). Cloned varieties developed recently by Kerala Agricultural University, Padannakkad are named as Ezhome-I, Ezhome-II, Ezhome-III and Ezhome IV.

Around the world, the stem borers have been controlled by integrated pest management practices suitable for each species, but including the following basic outlay: 1) selection of an appropriate crop planting technique or scheme; 2) using insect pest resistant plants (Baloch and Abdullah, 2011); and 3) using natural enemies. Insecticides have less efficacy for controlling the notorious stem borers, including the white-stem borer of rice. Van der Goot (1948) recorded three hymenopteran parasitoids, viz. *Telenomus rowani* (Gahan) (Scelionidae), *Tetrastichus schoenobii* Ferriere (Eulophidae), and *Trichogramma japonicum* Ashmead (Trichogrammatidae) as egg parasitoids of *S. innotata*.

The infestation degree depended upon population of stem borer moths or planting time. Stem borer infestation in the first planting time was higher (average 37.90%) than those found in the second and third planting time, i.e. 65% and 54%, respectively (Hendarsih and Usyati, 2005).

The widespread use of insecticides to control crop pests has created various well-known problems. Insect pest attacks frequently occur with varying intensities and frequencies possibly induced by the changes in climate and cropping systems in modern rice cultivation. Intensive rice production with the primary goal of achieving high yield is often characterized by the excessive application of pesticides and fertilizers. It has led to many negative environmental effects, such as the reduction

of biodiversity and natural biological control, high inputs of pesticide residues in rivers, drinking water and agricultural products, rapid and high insecticide resistance in pests, secondary pest outbreaks, environmental pollution and ecological imbalance. These severe negative effects will damage the ecosystem, lead to frequent pest outbreaks and in turn require an increased pesticide dosage, which form a vicious circle (Conway and Pretty, 1991).

Therefore, attention has been focused to include various cultural practices to suppress insect pest populations (Javaid and Joshi, 2010). Ecological engineering is a relatively new concept of environmental management for wellbeing of human and environment. The application of ecological engineering for insect pest control includes use of cultural practices, usually based on vegetation management, to enhance biological control or the ‘bottom-up’ effects that act directly on pests (Gurr et al., 2004). The latter include methods such as trap crops that divert pests away from crops.

Recently, China has made a pioneering attempt to see if rice insect pest damages could be solved through ecological engineering. And those practices increased biodiversity in the ecosystem, significantly increased biological control of rice pests and provided biological stability in the ecosystem (Lu et al., 2015).

Habitat management can strongly promote ecosystem services. Thus, it offers much to the grand challenge of sustainable intensification to meet the escalating needs of humanity while minimizing adverse impacts on the biodiversity on which we ultimately depend (Gurr et al., 2016). Habitat management has been suggested as an important strategy in integrated pest management (IPM) programs during late 1990s, particularly in less biodiverse industrial countries and in monoculture systems of developing countries (Landis et al., 2000). After about 2 decades, habitat management is still considered a viable environment-friendly practice for management of pests and conservation of natural biological control, as the ecosystem service outweighed the ecosystem dis-service they render (Chang et al., 2019). One important tool of habitat management specific for a pest species is

finding and using trap plants in agro-ecosystems (Chang et al., 2019; Wan et al., 2016; Badenes Perez, 2018; Sarkar et al., 2018).

Chang et al., (2019) also reported that the habitat management is an important strategy for pest control in integrated pest management (IPM) and various categories of habitat management such as trap cropping, intercropping, natural enemy refuges such as 'beetle banks', and floral resources for parasitoids and predators have been used in applied insect ecology for many years.

Trap cropping, the use of alternative host plants to attract, intercept and/or retain targeted insect pests for the purpose of reducing damage to a main crop, is one such strategy. Similar trapping designs have also been suggested as a potential method for the control of invasive insects in natural ecosystems (El-Sayed et al., 2006; Mercader et al., 2011). For agricultural pest management, trap cropping potentially reduces crop damage inexpensively and simultaneously reduces conventional pesticide applications (Cavanagh et al., 2009; Lu et al., 2009, Ulmer et al., 2020). However, without assistance from other management inputs, including pesticide treatments, trap cropping has frequently failed to adequately reduce insect density, even when the pest shows a strong preference for the trap plant in laboratory or semi-field experiments (Shelton and Nault, 2004; Shelton and Badenes-Perez 2006).

Based on characteristics, we have three types of trap crops, conventional trap crop, dead end trap crop and genetically modified trap crop, and based on spatial distribution, they are perimeter trap cropping, sequential trap cropping, multiple trap cropping and push-pull trap cropping (Dewangan and Sahu, 2014).

Gurr et al., (2017) noted that the aim of trap cropping is not only to divert the pest away from the crop, but also to provide ecosystem services including shelter, nectar, alternative hosts, and pollen for the pest's natural enemies which can improve conservation biological control.

Sharma et al., (2019a) has reviewed the studies done on trap cropping in various cereal crops and has concluded that trap crops remain an important tool of

integrated pest management. They recommend that future studies should work in a direction to find and promote alternate or trap host plants for managing key pests for cost-efficient and environmental-friendly cereal production, which at present rely predominantly on chemical pesticides. The most important task in this is to find a trap crop that can attract the pest species for foraging or ovipositing. The second major task is to assess its suitability in existing agricultural practices of the crop. Differences in attractiveness could be based on either a more attractive plant species or cultivar and/or a more preferred development stage of the same plant species (Hokkanen, 1961).

Schoonhoven et al., (2005) documented that the trap crop species are highly attractive to pest species and are inter-planted with susceptible crops, which can attract and divert pests from the main crop. This practice relies on the exploitation of insect preferences for certain host plants, based on visual, tactile or olfactory cues.

Pest management using trap cropping has been used widely to target Coleoptera, Diptera, Lepidoptera, Thysanoptera, Orthoptera, Hemiptera, and Homoptera pests (Hokkanen 1961, Reddy 2017, Badenes-Perez 2018, Sarkar et al., 2018). As a trap crop is a plant species, which harbors more herbivore individuals than the main crop (Wan et al., 2016), this technique has been successful in managing several insect pests as part of IPM programs (Badenes-Perez, 2018, Sarkar et al., 2018).

Detailed and updated lists of target insect species, their potential trap crops, and application strategies have been published by Hokkanen (1961), Shelton and Badenes-Perez (2006), Pinero and Manandhar (2015), Reddy (2017), Sarkar et al., (2018), and Badenes-Perez (2018).

Various types of trap cropping have been reported and classified based on trap plant characteristics and their deployment in fields (Hokkanen 1961, Shelton and Badenes-Perez 2006). The attractiveness of the trap crop and its spatial coverage/arrangement are critical in successful and effective pest management schemes (Gillespie et al., 2011, Sarkar et al., 2018). Different modalities of trap cropping were used in the past and 'dead-end' trap cropping has been one of the most effective systems against pests (Shelton and Nault, 2004).

In the conventional type, a crop that is preferred by the target pest species as their food source or reproduction location is planted nearer to the main crop. This trapping system diminish the arrival of the insect pest to the main crop and centralize pest populations in the trap crop where they can be economically controlled further. The insect pests were attracted to the trap plant but on which they or their progeny cannot survive in the case of dead end trap and such trap crops serve as a sink for pests, hindering pest movement from the trap crop to the main crop later in the growing season (Shelton and Nault, 2004).

Trap cropping practices have been well known for centuries in South Asian countries such as India, Pakistan, Afghanistan, Sri Lanka, Nepal, Bhutan, the Maldives, and Bangladesh, and they are still used at the subsistence level, particularly as part of cultural farming practices (Sharma et al., 2016).

Gurr et al., (2017) suggested that for establishing a successful trap cropping system in different agronomic situations, primarily a thorough understanding is required of the behavior and preferences of the targeted insect pests, as well as the dispersal and the attraction of natural enemies for the trap crop species.

Eigenbrode et al., (1991) suggested that the plant breeding can be utilized to develop trap crop species with enhanced attractiveness to the insect pest and/or low larval survival, such as glossy wax traits, or attractiveness to natural enemies (Loughrin et al., 1995; Poppy and Sutherland, 2004). Enhancing the effectiveness of the trap crop is necessary to lower the land sacrificed to production when using trap cropping (Badenes- Perez et al., 2005). Hokkanen (1961) recommends that about 10% of the total crop area be planted with the trap crop, although the percentage of trap crop needed for each particular system has to be determined for each case. Shelton and Badenes-Perez, (2006) and Holden et al., (2012) also documented that an efficient trap crop system need at least double the pest attraction capacity of the cash crop during its vulnerable stage with an easy management strategy and should cover no more than 2%–10% of the total crop area.

Once the pest is collected in a trap crop, it can be managed by the use of localized applications of pesticides or by the physical destruction of the trap crop along with the pests (Hokkanen, 1961, Pickett et al., 2014, Reddy, 2017). Although

trap cropping has been usually deployed to target one pest species, sometimes it can be useful against more than one.

Sarkar et al., (2018) observed that the trap crops not only attract the insects for feeding and oviposition, but also act as a sink for any pathogen that may be a vector. They added that this secondary effect of attracting natural enemies may be an advantage compared to the Conventional means of pest control.

The studies regarding the use of trap crops in rice fields are very scanty in Kerala, and in Kaipad rice fields. The use and quantitative assessment of *E.ducis* as a trap plant for *S. innotata* in Kaipad rice fields are studied in this chapter.

MATERIALS AND METHODS

Kaipad rice cultivation system

It is a unique, coastal brackish wetland rice production system which is naturally organic (Vanaja et al., 2009). It is cultivated in approximately about 4100 ha in north Malabar region of Kerala, i.e., Kasaragod, Kannur and Kozhikode in peninsular India. In Kaipad fields, *Eleocharis dulcis* (Cyperaceae) – the Chinese water chestnut or water chestnut – grow abundantly during the period of rice cultivation.

Study area

We selected four Kaipad fields (plots) of Munderi Kadavu region in Kannur district, Kerala (11°93'7.137" N;75° 42'9.402" E) for the present study. The source of saline water in Kaipad fields of this region is Munderi Kadavu backwaters. The farmers here do cultivate rice in cent per cent organic mode with no chemical inputs either in the form of pesticide or in the form of fertilizer. Kaipad cultivation is practiced here for last several decades. *Kuthiru* and *Orkayama* are the traditional varieties of rice cultivated in the study area (Vanaja et al., 2009). Because the cultivars are native, pest incidence is low, except for the rice white stem borer, *S. innotata*. The Kaipad fields in this region covers 10 ha area, and it produces approximately 35-40 tons of rice annually. Fish cultivation was not active during our survey period in this area.

The nearest Conventional rice fields are approximately 2 km away. Therefore, the Conventional field is unlikely to have an impact on the population of insect pest and natural enemies in Kaipad fields. Our study spanned across three cultivation years – 2015, 2016 and 2017. Rice cultivation in Kaipad fields begins at the onset of southwest monsoon. The monsoon rainfall reduces salinity of water in Kaipad fields. During the study period, *Kuthiru* was the rice cultivar used in the study area.

E. dulcis grows abundantly in Munderi Kadavu field. They are seen in linear strips/clusters adjacent to the rice crop on two sides of the bund submerged in approximately 10 cm of water. The presence of *E. dulcis* is observed throughout the year but grow more densely during the rice cultivation season. Stem leaves are bladeless sheaths (Fig. 1). Plants produce horizontal rhizomes that terminate in rounded tubers. Each tuber produces a dense clump of erect, branchless, green stems, many of which are topped by a cylindrical, straw-brown, flower spikelet (to 2” long). Flowering in *E. dulcis* is uncommon in Kaipad area.

Sampling

We sampled the pest – adults and egg clutches of *S. innotata*– every month of the rice cultivating season – June-October, because it infests rice throughout its vegetative and productive phases. For counting egg mass and adult, quadrat sampling method was followed in main crop (*O. sativa*) and trap crop (*E. dulcis*). In the main crop, 25 paddy hills in one corner form a sampling unit, which is about 2 x 2sq m with approximately 375 plants. Four such sampling units were taken in one field. In the trap crop, sampling was done in a 2m x 2m square in each corner of the field. Approximately 350-400 plants of *E. dulcis* are seen in one quadrat. Same quadrates were maintained throughout the five months in a year for the survey.

We sampled both the egg clutches and adults on main crop and trap crop in all sampling units. In *O. sativa*, the moth laid eggs on leaves only; in *E. dulcis*, the eggs were laid on pseudostem.

We brought egg masses (along with plant part) to the laboratory in air-filled labeled zip lock covers, and reared them in laboratory conditions. The area of the egg clutch, number of larva emerged and number eggs per egg clutch were recorded using Stereo zoom microscope, Leica M205A with DMC2900 camera. The collected egg masses were enclosed in glass tubes individually and plugged with cotton balls and maintained at room temperature (Max. 29 ± 1 °C and Min. 23 ± 0.5 °C and Average RH 65%) for studying hatching rate. We reared a total of 253,053 eggs in 691 egg clutches sampled from rice (N=10,995 eggs in 91 clutches) and *E.dulcis* (N=242,058 eggs in 600 clutches) to study egg parasitism and hatching rate.

Data analysis

Together, we had 240 sampling units each for *E. dulcis* and *O. sativa*. We pooled sampling units in sites before analyzing the data. We modeled abundance of egg clutches and adult moths, egg clutch area, number of eggs in clutches, and larval hatching rate (response variables) on plant species, month, and year of sampling (fixed effects) using the Generalized Linear Models. We used Poisson distribution as the error and log as link function in the models when numbers were in response variable. We used Gaussian distribution when egg clutch measurements were the response variables in the models. Binomial distribution with log as link function was used when proportions were the response variables. Significance of the models was tested using Wald's Chi-square value available in the R-package "car". We modeled (x+1) parasitized eggs in egg clutches on plant species to understand whether egg parasitism was predicted by oviposition plant species.

RESULTS

The abundance of eggs and adults of *Scirpophaga innotata* on *Eleocharis dulcis* and *Oryza sativa*.

The *Scirpophaga innotata* preferred *Eleocharis dulcis* for oviposition when given a choice between *E. dulcis* and *Oryza sativa* (Chisquare=668.4, d.f.=1, $p < 0.00005$). A significant difference (Chi square=1400.3655, dF=1, $p < 2e-16$ ***)

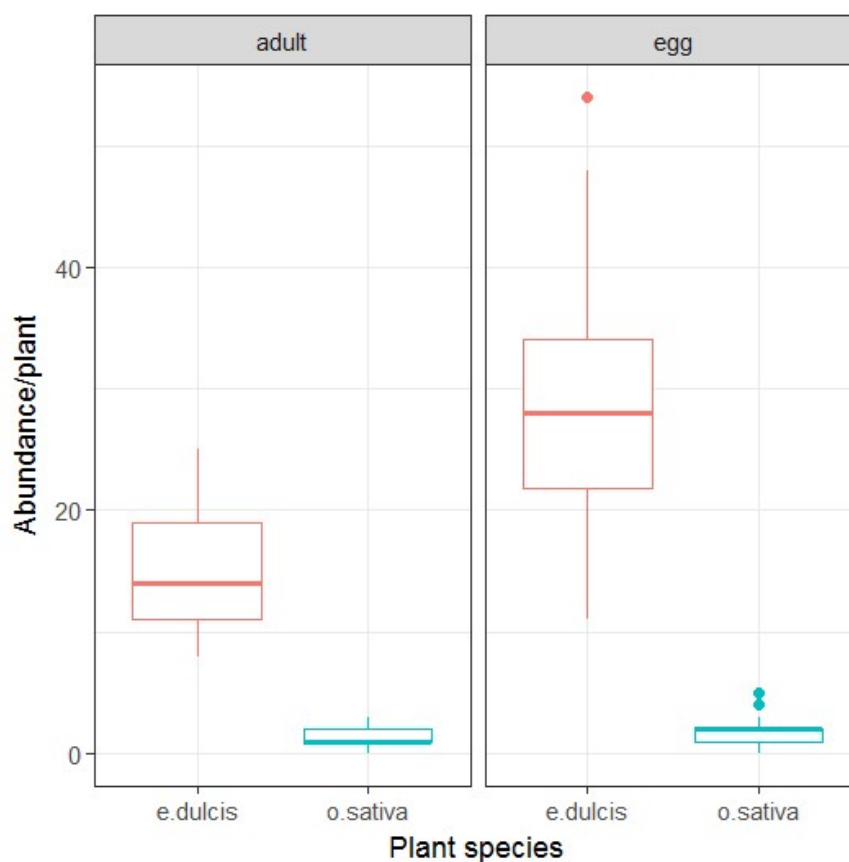
in the abundance of adult *S. innotata* on *E.dulcis* and *O.sativa* was observed (Fig.4.1).

Significantly more number of eggs and adults were observed on *E. dulcis* than on *O. sativa* over the three years (Fig.4.1).



FIGS 4.1. A-C. The plant *Eleocharis dulcis* (Burm.f) on the bund near the rice fields; D. The egg mass of *Scirpophaga innotata* (Walker) on *Eleocharis dulcis* (Burm.f) plant; E. The adult of *Scirpophaga innotata* (Walker) on *Eleocharis dulcis* (Burm.f) plant; F. The adult of *Scirpophaga innotata* (Walker) on *Oryza sativa* (L.)

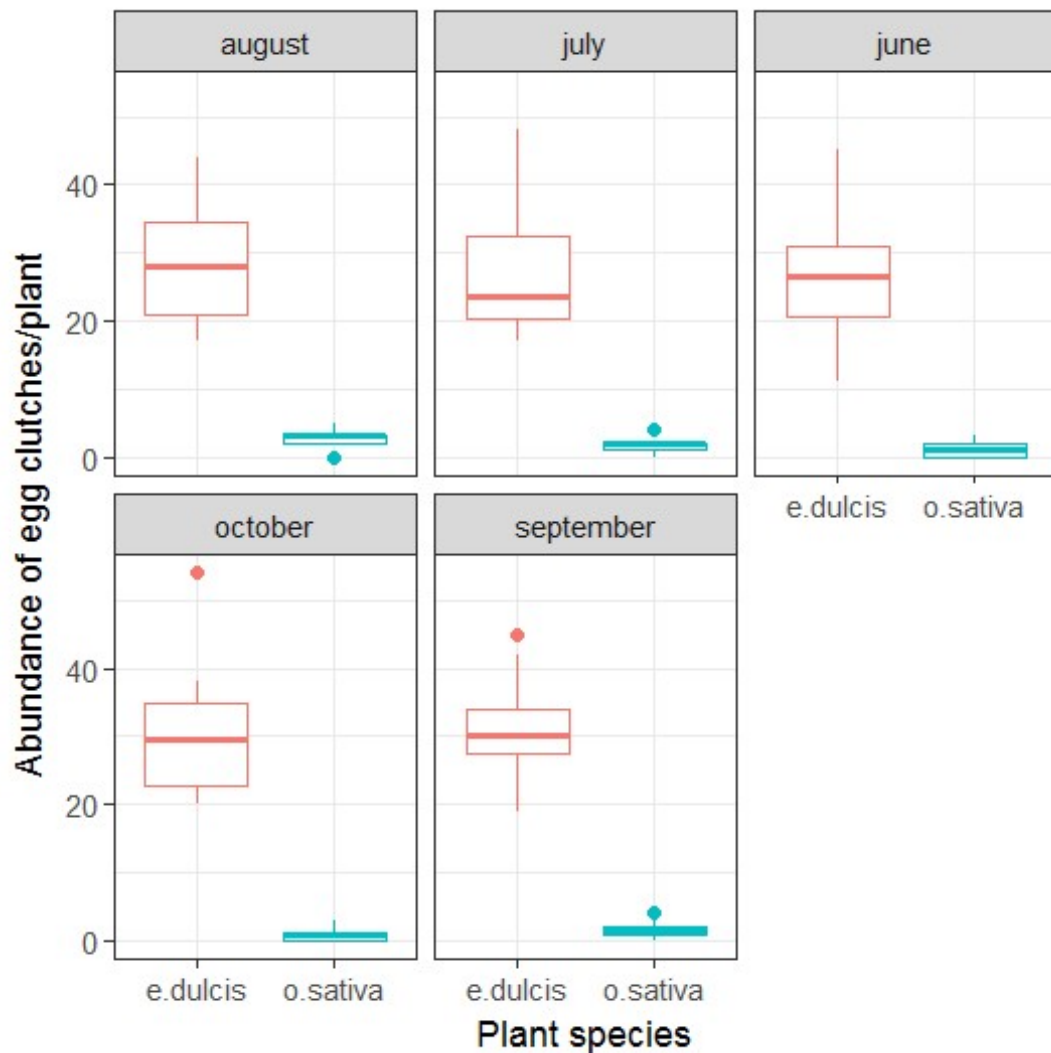
Fig. 4.1: The abundance of eggs and adults of *Scirpophaga innotata* on *Eleocharis dulcis* and *Oryza sativa*.



Abundance of Egg clutches of *S.innotata* on *E.dulcis* and *O.sativa* in different months.

The abundance of *S.innotata* egg clutches on *E.dulcis* and *O.sativa* was significantly different between months (Chi square=9.4712 , df=4 , p=0.05034). The highest abundance of egg clutches on *E.dulcis* was found in October, followed by June, July, September and August. In *O.sativa*, the highest abundance was during September (Fig.4.2).

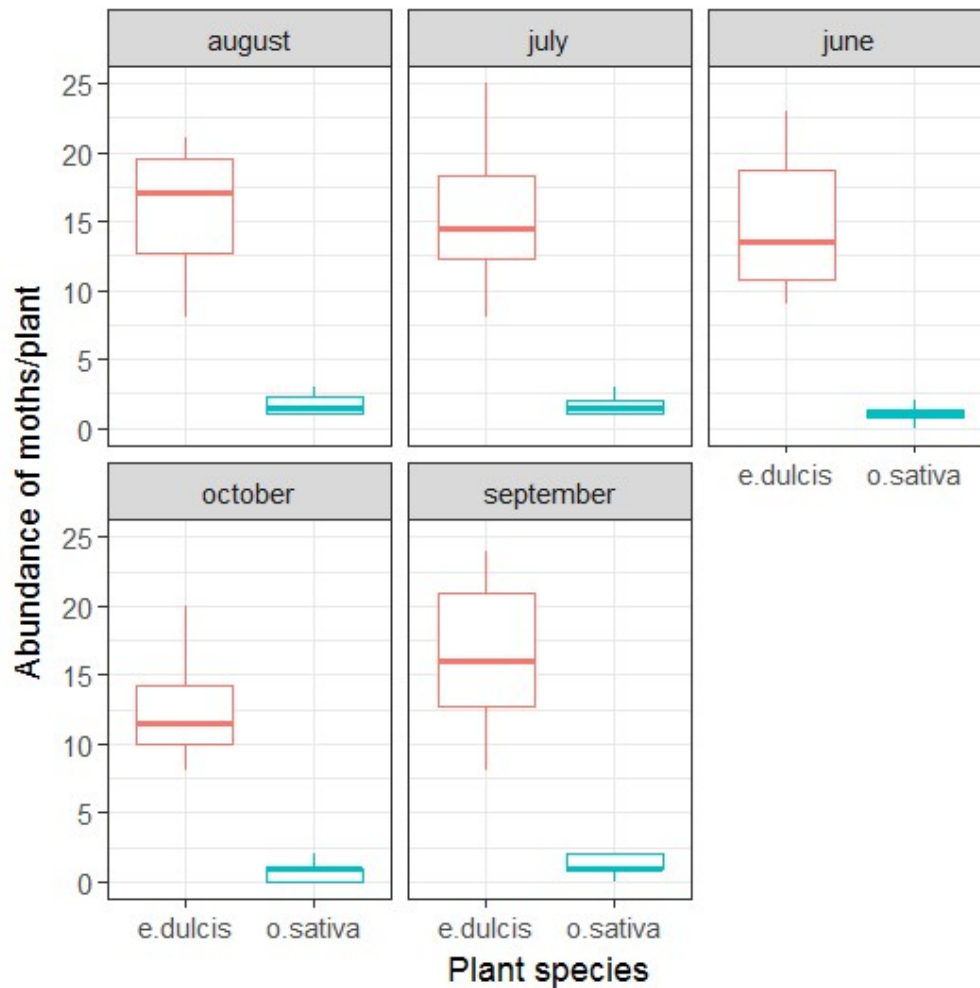
Fig. 4.2: The abundance of *Scirpophaga innotata* egg clutches on *Eleocharis dulcis* and *Oryza sativa* during different months.



Abundance of Adult moths of *S.innotata*/per plantson *E.dulcis* and *O.sativa* in different months

The abundance of adult moths of *S.innotata* per plants in different months (Chi square=9.1592, df=4, p=0.05724) was weakly significant. In *E.dulcis* and *O. sativa*, the peak abundance of *S.innotata* was observed in July (Fig.4.3).

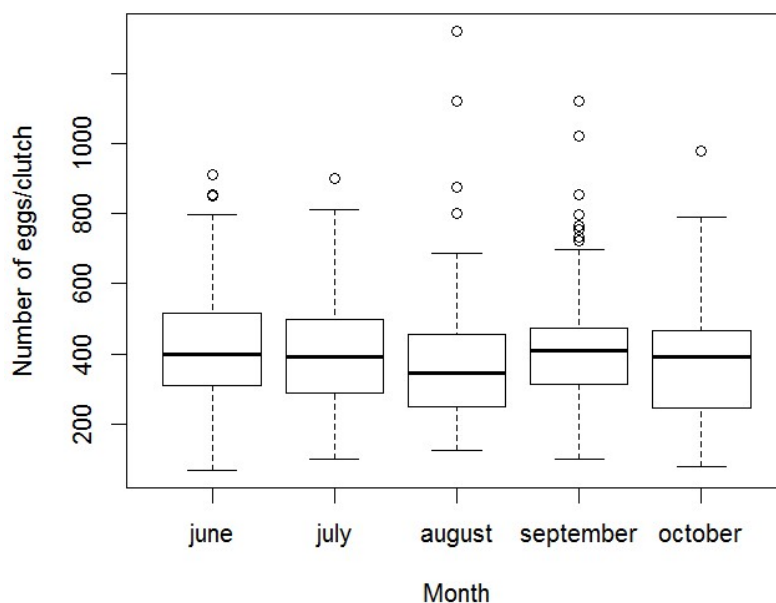
Fig. 4.3: The abundance of *Scirpophaga innotata* moths/plant on *Eleocharis dulcis* and *Oryza sativa* in different months.



The abundance of *S.innotata* eggs/clutch on *E.dulcis* in different months

The abundance of *S.innotata* eggs/clutch on *E.dulcis* across months (Chi square=492.36, df= 4, $p < 2.2e-16$ ***) showed significant difference (Fig. 4.4).

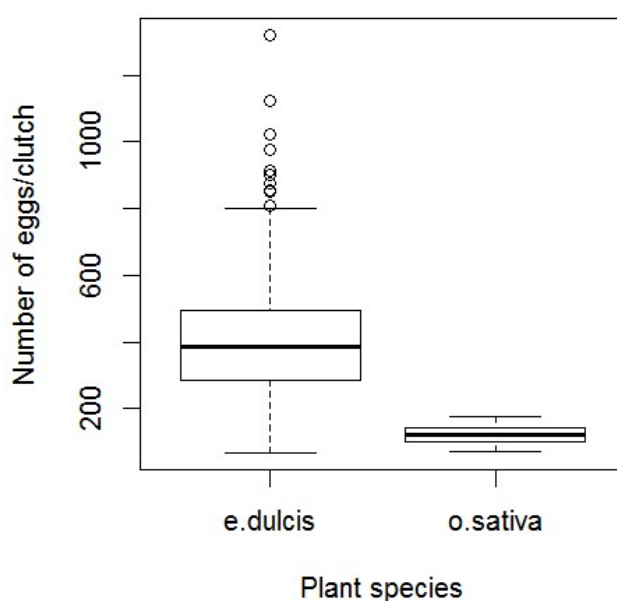
Fig. 4.4: The abundance of *Scirpophaga innotata* eggs/clutch on *Eleocharis dulcis* in different months.



The abundance of *S. innotata* eggs/clutch in *E. dulcis* and *O. sativa*.

The plant species ($p=1.587e-10$ ***) alone had an impact on number of egg clutch of *S.innota* laid on *E.dulcis* and *O.sativa* (Fig. 4.5). But the month does not have any impact on the same ($p=0.3965575$).

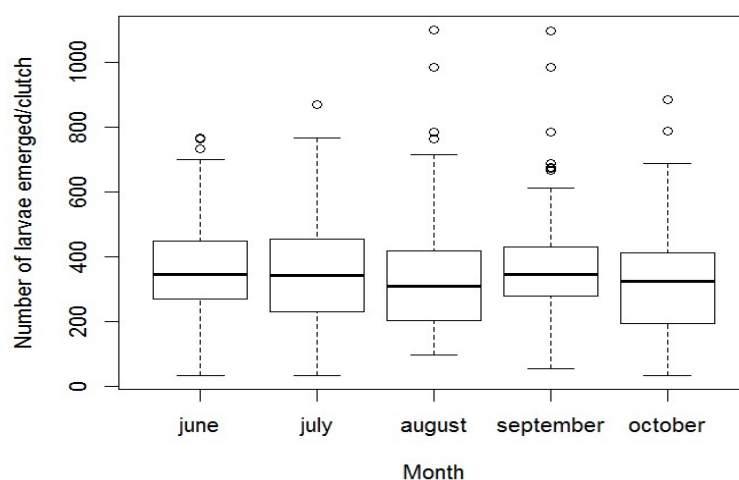
Fig. 4.5: The number of *Scirpophaga innotata* eggs/clutch on *Eleocharis dulcis* and *Oryza sativa*.



The number of *S.innotata* larvae emerged on *E.dulcis* in different months.

The months (Chi square=19.730, d f=4, $p<0.00005$) had a significant impact on the number of *S.innotata* larvae emerged on *E.dulcis*. The highest range of emerged larva was observed in September, and followed by August, October, July and June (Fig.4.6).

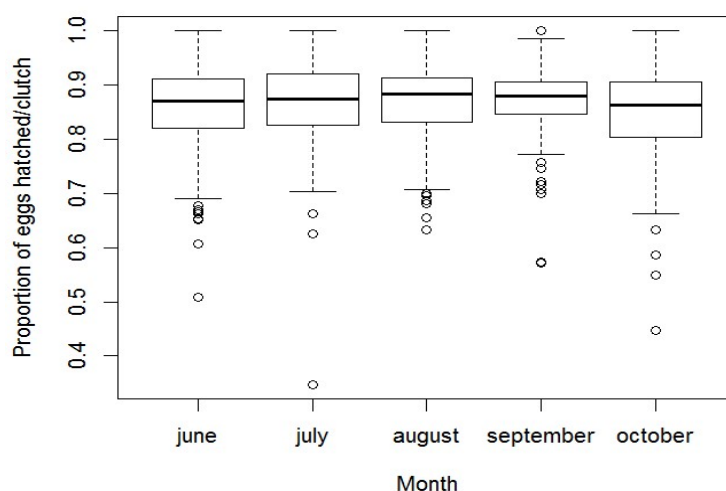
Fig.4.6: The abundance of *Scirpophaga innotata* larvae emerged on *Eleocharis dulcis* in different months.



The proportion of eggs hatched in *E. dulcis* during different months

The relationship between the proportion of eggs hatched and months did not show any significant difference (Chi square=0.43, d f=4, $p=0.9$) (Fig. 4.7).

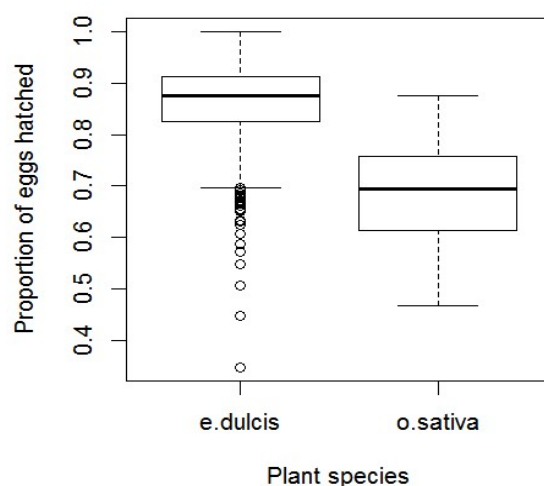
Fig.4.7: The proportion of *Scirpophaga innotata* eggs hatched/clutch on *Eleocharis dulcis* during different months.



The proportion of *S. innotata* eggs hatched in *E. dulcis* and *O. sativa*

The proportion of eggs hatched/larvae emerged on *E.dulcis* and *O.sativa* was significantly different ($p=0.000108$ ***). The range of proportion of eggs hatched was higher in *E.dulcis* than *O.sativa* (Fig.4.8).

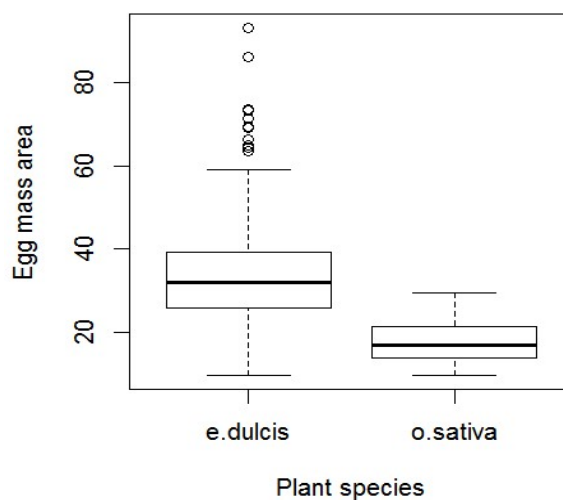
Fig. 4.8: The proportion of *Scirpophaga innotata* eggs hatched on *Eleocharis dulcis* and *Oryza sativa*.



The egg clutch area of *S. innotata* in *E. dulcis* and *O. sativa*.

The area of *S.innotata* egg clutch in *E.dulcis* and *O.sativa* were different, and the difference was significant ($t = 23.162$, $df = 288.38$, $p = < 2.2e-16$) (Fig.4.9).

Fig.4.9: The egg clutch area of *Scirpophaga innotata* on *Eleocharis dulcis* and *Oryza sativa*.



DISCUSSION

Sirpophaga innotata is a major pest of rice in rice-growing parts of Asia. Like other stem borers around the globe, IPM has been prescribed to manage *S. innotata* in rice (Zhu et al., 2002). Although it has been suggested to find trap plants to manage this pest and it is known that *S. innotata* use *E. dulcis* for oviposition, no studies have so far quantified its fitness benefits for using *E. dulcis* for oviposition.

In the present study, we quantified pest incidence, egg functional traits, and egg parasitism in egg clutches sampled on rice plants and *E. dulcis* with the aim that *E. dulcis* can be used as a potential trap plant to manage *S. innotata* in rice fields. We found the following: 1) female moths and egg clutches are disproportionately abundant on *E. dulcis*; 2) functional traits of eggs, such as egg clutch size and number of eggs in egg clutches are high in egg masses sampled on *E. dulcis*; 3) egg parasitism is confined only in egg clutches sampled on rice plants; 4) the proportion of eggs hatching into neonate caterpillars is high in egg masses sampled on *E. dulcis*; and 5) no neonates reared on *E. dulcis* survived. *E. dulcis* has only a green pseudostem, which may not be edible for the larvae. We had observed that dead hearts and white ear heads on rice cultivated in the Kaipad fields are negligible, which indicates that damage by *S. innotata* on *O. sativa* is minimal (personal observation). The preference of *S. innotata* for *E. dulcis* over *O. sativa* for oviposition may be reducing the number of egg masses on *O. sativa*, resulting in reduced damage to the plant.

Although studies (Ranganath et al., 2002; Gazalil and Ilhamiyah, 2012) noticed egg clutches of *S. innotata* on *E. dulcis*, they have not studied, why *E. dulcis* was preferred for oviposition, despite the primary food resource – rice – being abundant in the fields. The results suggest three likely reasons for *S. innotata*'s preference for *E. dulcis* for oviposition. First, *E. dulcis* pseudostems offer space for depositing large egg clutches and a greater number of eggs. Second, egg clutches in *E. dulcis* have better survival probability as parasitoid emergence was negligible. Third, the plant volatiles emanating from *E. dulcis* may be serving as an oviposition

attractant over *O. sativa*. We need further investigations to throw more lights on the last hypothesis.

It is not rare that herbivores, particularly the pests in agro-ecosystems use niches or plants that they do not eat, for oviposition (Wiklund, 1977; Sinu et al., 2013). The importance of cultural control of *Hyposidra talaca* in tea plantations through managing its oviposition sites has been highlighted by Sinu et al., (2013). The neonate *H. talaca*'s primary food in tea plantation is the two and a bud (the pluckable leaves) of tea leaves (*Camelia sinensis*) and the mature caterpillars (3rd instar onwards) prefer eating the maintenance foliage (mature leaves) of tea plants (Roy et al., 2017). However, the moth hardly oviposit on tea plants, but oviposit at a height above the tea layers on the barks of shade trees (Sinu et al., 2013). Once the eggs hatch, the neonates reach the two and a bud of tea leaves (the pluckable leaves) in no time through wind and salivary suspension threads. It was reported that the *S. innotata* can be dispersed by wind and ballooning for 200 – 280 cm. We suspect this sort of interaction between *E. dulcis* and *S. innotata* in rice fields, which however, needs an in-depth investigation.

In this study, we have for the first time quantified and illustrated the preference of *S. innotata* for *E. dulcis*. Although *S. innotata* eggs hatched on *E. dulcis*, they did not complete their development on the lab-reared plants. Although *S. innotata* died on *E. dulcis* in the lab, they may be migrating to rice to complete their development in the field. Cohen et al. (2000) have observed that the neonates of *S. innotata* may disperse up to a distance of 200-280 cm by ballooning. Therefore, destroying the eggs of *S. innotata* on *E. dulcis* may reduce the population of *S. innotata* in rice. Using trap host plants to control cereal pests is attaining popularity these days. Hui et al., (2019) used vetiver grass, *Vetiveria zizanioides* as a dead-end trap plant for managing *Chilo suppressalis*, another major pest of rice. They also showed that *C. suppressalis*, despite hatching on *V. zizanioides* could not complete their life cycle on it. From the second week of July itself, *S. innotata* starts laying eggs on *E. dulcis* (Trap crop) than on *O. sativa* (Main crop). Hence, removing egg clutches of *S. innotata* from *E. dulcis* may prevent subsequent spread of *S. innotata*

larva to rice after emergence as has been recommended in other studies (Anonymous, 2011; Sinu et al., 2013). There are two advantages for using trap crops for pest management, given that the trap crop is used by the pest as a food plant. First, once a female selects a suitable host plant for egg-laying, it does rarely explore other plants in the neighborhood, unless its population is spilled over and it is polyphagous (Ellgardt, 2008). Therefore, an egg-laying female landing on the trap crop is less likely to move to the main crop later in the season. Nissinen et al., (2000) has also confirmed this stationary behaviour in carrot psyllids, where most of females laid eggs in only one of the plants offered in the multi choice bioassay and did not move to other plants in the vicinity. The second advantage is that pest attack is normally high in field boundaries. So trap crops can be raised on field boundaries. Nissinen et al., (2008) recommended that a perimeter trap crop can save main crop from pests. In the present study, *E. dulcis* is growing naturally as a perimeter crop in rice fields. But the larvae are not using it as a food plant. A good trap plant in order to function as a primary sink must attract and restrict the pest on it (Hilje et al., 2001; Holden et al., 2012). Although it is predicted that the adult moths prefer a food plant for ovipositing in order to secure food for their hatching neonates (Cunningham et al., 2001), recent studies suggest that the moths can select a non-food plant or substrate for oviposition and plausible spread to food plants (Sinu et al., 2013). The fitness and survival traits of *S. innotata* on *E. dulcis* suggest such a case. In this context, studies may also be needed to decipher the chemical interaction between the trap plant *E. dulcis* and the pest, *S. innotata* for a large-scale application of trap cropping and stem borer control using *E. duclis* (Asikindan and Thamrin, 2011).

CHAPTER 5

THE CORRELATION BETWEEN ATMOSPHERIC PARAMETERS, INSECT PESTS AND PARASITIDS IN CONVENTIONAL AND KAIPAD RICE FIELDS

DATA ANALYSIS

The Linear r (Pearson) correlation matrix between atmospheric parameters Vs abundance of pest and parasitoids, Leaf parameters Vs Abundance of Insect pests; and Abundance Insect pests Vs Abundance of their Parasitoids were prepared using the statistical software PAST 3.22 version (Paleontological Statistics software package for education and data analysis) (Hammer et al., 2001). The Correlation between Atmospheric parameters, Insect pests and parasitoids in Conventional rice fields.

RESULTS

Atmospheric temperature showed negative correlation with Pest Egg stage ($r=-0.2219$, $p=0.3761$), Pest larval stage ($r=-0.4354$, $p=0.0708$), Pest pupal stage ($r=-0.0751$, $p=0.7670$), Pest adult stage ($r=-0.3398$, $p=0.1676$), leaf defoliators ($r=-0.2533$, $p=0.3104$), leaf folders ($r=-0.2568$, $p=0.3035$), leaf gall midges ($r=-0.0604$, $p=0.8116$), sap feeders ($r=-0.4566$, $p=0.0568$), stem borers ($r=-0.1020$, $p=0.6869$), overall pests ($r=-0.2645$, $p=0.2888$), egg parasitoids ($r=-0.0384$, $p=0.8796$), larval parasitoids ($r=-0.0237$, $p=0.925$), pupal parasitoids ($r=-0.2906$, $p=0.2419$) and total parasitoids ($r=-0.1131$, $p=0.6549$). The incidence of leaf case makers ($r=0.0853$, $p=0.7364$) and grain sap feeders ($r=0.0940$, $p=0.7104$) is positively correlated with atmospheric temperature.

The abundance of pest egg stages ($r=0.1761$, $p=0.48450$), pest larval stages ($r=0.0454$, $p=0.8578$), pest adult stages ($r=0.4393$, $p=0.0681$), leaf defoliators ($r=0.1352$, $p=0.5924$), leaf folders ($r=0.1230$, $p=0.6266$), sap feeders ($r=0.1887$,

p=0.4532), grain sap feeders ($r=0.2347$, $p=0.3485$), stem borers ($r=0.1214$, $p=0.6313$) and overall pests ($r=0.2126$, $p=0.3968$) increases with increase in atmospheric humidity. While the abundance of pest pupal stages ($r=-0.0954$, $p=0.7062$), leaf case makers ($r=-0.1459$, $p=0.5635$), leaf gall midges ($r=-0.0228$, $p=0.9281$), egg parasitoids ($r=-0.1039$, $p=0.6818$), larval parasitoids ($r=-0.383$, $p=0.1167$), pupal parasitoids ($r=-0.1503$, $p=0.5514$) and total parasitoids ($r=-0.2401$, $p=0.3370$) decreases with the increase of atmospheric humidity.

The Correlation between Leaf parameters and Insect pests in Conventional rice fields.

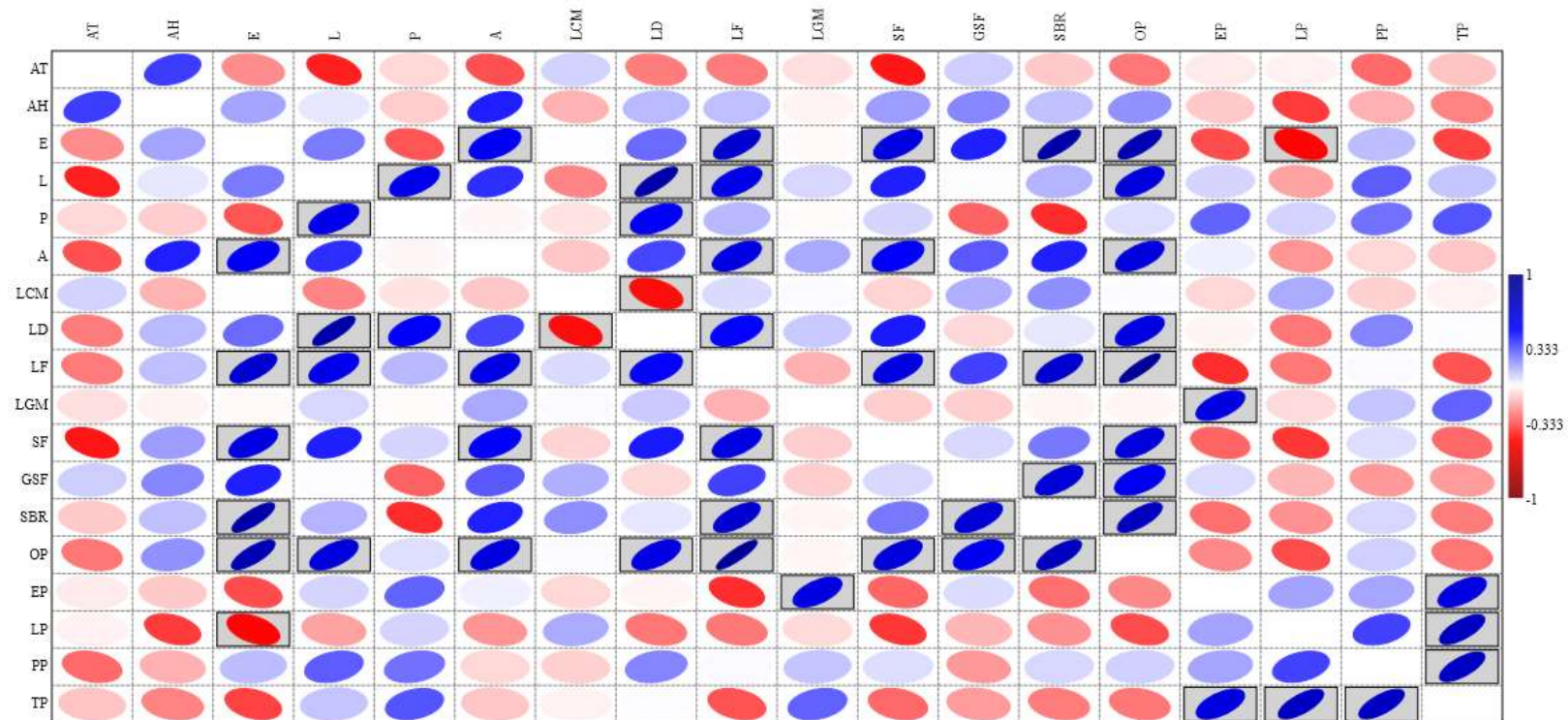
In Conventional rice fields, significant positive correlation was noted between leaf gall midges abundance and leaf copper ($r=0.8429$, $p=0.0350$), stem borer abundance and leaf magnesium ($r=0.9007$, $p=0.0142$), and pest egg stage abundance and leaf magnesium ($r=0.8486$, $p=0.0326$). While adult insect pest abundance and leaf boron ($r=-0.9631$, $p=0.0020$) was significantly negatively correlated (Figure 2)(Table 2 and 4).

The correlation between Insect pests and their parasitoids in Conventional rice fields.

In Conventional rice fields, the abundance of leaf defoliators is significantly positively correlated with abundance of their pupal parasitoids ($r=0.9338$, $p=1.5E-08$) and the abundance of their larval parasitoids was also positively correlated but without any significant difference ($r=0.2680$, $p=0.2823$). The abundance of leaf gall midges also showed significant positive correlation with the abundance of their egg parasitoids ($r=0.8347$, $p=1.64E-05$), larval parasitoids ($r=0.8811$, $p=1.37E-06$) and pupal parasitoids ($r=0.5855$, $p=0.0107$). Significant positive correlation was also noted between the abundance of grain sap feeders and the abundance of their egg parasitoids ($r=0.6682$, $p=0.0024$). The abundance of stem borers was significantly positively correlated with the abundance of their egg parasitoids ($r=0.6087$, $p=0.0073$) and larval parasitoids ($r=0.8305$, $p=1.98E-05$), but significant negative correlation was seen in the abundance of their pupal parasitoids ($r=-0.6125$,

p=0.0069). While, the abundance of leaf folders was significantly negatively correlated with the abundance of their egg parasitoids ($r=-0.5388$, $p=0.0211$) and larval parasitoids ($r=-0.6131$, $p=0.0068$), their abundance showed non-significant negative correlation with the abundance of their pupal parasitoids ($r=-0.4127$, $p=0.0888$). Significant negative correlation is also seen between the abundance of leaf defoliators and the abundance of their egg parasitoids ($r=-0.4684$, $p=0.04991$). The abundance of sap feeders also showed significant negative correlation with their egg parasitoids ($r=-0.4992$, $p=0.0349$) and larval parasitoids ($r=-0.4959$, $p=0.0363$). The abundance of stem borer was also significantly negatively correlated with the abundance of their pupal parasitoids ($r=-0.6125$, $p=0.0069$) (Figure 3)(Table 5 and 6).

Figure 5.1. The Correlation matrix between Atmospheric parameters, Insect pests and Parasitoids in Conventional rice fields.



AT- Atmospheric temperature,AH- Atmospheric Humidity, E- Pest egg stage, L- Pest larval stage, N- Pest nymphal stage, P- Pest pupal stage, A-Pest adult stage LCM-Leaf case maker, LD- Leaf defoliator, LF- Leaf folder, LGM- Leaf gall midge, SF- Sap feeder, GSF- Grain sap feeder, SBR- Stem borer, OP- Overall pests, EP- Egg parasitoids, LP- Larval parasitoids, PP- Pupal parasitoids,TP- Total Parasitoids. (Towards dark red: Negative correlation increase, Towards dark blue: Positive correlation increases, Eclipse area increases: Correlation decreases, Eclipse area decreases : Correlation increases, $p < 0.05$ boxed= significant.).

Table 5.1. The Correlation coefficient values between Atmospheric parameters, Insect pests and parasitoids in Conventional rice fields.

Correlation coefficient	Atmospheric Temperature (°C)	Atmospheric Humidity (%)
E	-0.2219	0.1761
L	-0.4354	0.0454
P	-0.0751	-0.0954
A	-0.3398	0.4393
LCM	0.0853	-0.1459
LD	-0.2533	0.1352
LF	-0.2568	0.1230
LGM	-0.0604	-0.0228
SF	-0.4566	0.1887
GSF	0.0940	0.2347
SBR	-0.1020	0.1214
OP	-0.2645	0.2126
EP	-0.0384	-0.1039
LP	-0.0237	-0.383
PP	-0.2906	-0.1503
TP	-0.1131	-0.2401

Table 5.2. The P values of Correlation between Atmospheric parameters, Insect pests and Parasitoids in Conventional rice fields.

P-value	E	L	P	A	LCM	LD	LF	LGM	SF	GSF	SBR	OP	EP	LP	PP	TP
AT	0.3761	0.0708	0.7670	0.1676	0.7364	0.3104	0.3035	0.8116	0.0568	0.7104	0.6869	0.2888	0.8796	0.925	0.2419	0.6549
AH	0.4845	0.8578	0.7062	0.0681	0.5635	0.5924	0.6266	0.9281	0.4532	0.3485	0.6313	0.3968	0.6818	0.1167	0.5514	0.3370

Figure 5.2. The Correlation matrix between Leaf parameters and Insect pests in Conventional rice fields.

L.N- Leaf Nitrogen, L.P- Leaf Phosphorus, L.K- Leaf Potassium, L.Ca- Leaf Calcium, L.Mg- Leaf Magnesium, L.S- Leaf Sulfur, L.Fe- Leaf Iron,, L.Mn- Leaf Manganese, L.Zn- Leaf Zinc, L.Cu – Leaf Copper, L.B- Leaf Boron, LCM-Leaf case maker, LD- Leaf defoliator , LF- Leaf folder, LGM- Leaf gall midge, SF- Sap feeder, GSF- Grain sap feeder, SBR- Stem borer, E- Pest egg stage, L- Pest larval stage, N- Pest nymphal stage, P- Pest pupal stage, A-Pest adult stage. (Towards dark red: Negative correlation increase, Towards dark blue: Positive correlation increases, Eclipse area increases: Correlation decreases, Eclipse area decreases: Correlation increases, $p < 0.05$ boxed= significant.).

Table 5.3. The Correlation coefficient values between Leaf parameters and Insect pests in Conventional rice fields.

Correlation	L.N	L.P	L.K	L.Ca	L.Mg	L.S	L.Fe	L.Mn	L.Zn	L.Cu	L.B
LCM	-0.2836	0.5457	-0.5585	0.3012	0.2945	0.3011	-0.0813	0.3631	-0.4555	-0.4050	0.5092
LD	0.4929	-0.4483	-0.1593	-0.3579	0.0545	-0.3446	-0.0949	-0.1573	-0.1699	-0.1508	-0.7129
LF	0.4445	-0.5095	0.0025	-0.5181	0.5188	-0.3402	-0.0925	-0.1052	-0.1686	-0.0144	-0.4709
LGM	-0.2291	-0.3526	0.6645	0.0290	-0.4385	-0.7403	0.5156	0.2811	0.5087	0.8429	0.5037
SF	0.5276	-0.3158	-0.4082	-0.2633	-0.1060	-0.2360	-0.2203	-0.1465	-0.3996	-0.3261	-0.6928
GSF	-0.485	0.648	-0.1158	0.4756	0.2494	0.6846	0.2223	-0.0596	0.5848	-0.5572	-0.4210
SBR	0.0935	0.0744	0.1121	-0.2861	0.9007	0.6826	-0.3042	-0.4203	0.0991	-0.3112	-0.3756
A	0.2474	-0.0816	-0.1510	-0.1434	0.2659	0.1918	-0.0634	-0.3121	0.1742	-0.4597	-0.9631
E	0.0860	0.0771	0.0936	-0.2455	0.8486	0.6520	-0.2339	-0.4256	0.1997	-0.3706	-0.5467
L	0.4591	-0.3813	-0.2569	-0.3795	0.3204	-0.2927	-0.1148	-0.0795	-0.2704	-0.2435	-0.6333
N	0.4350	-0.3890	0.0160	-0.5268	0.7117	0.0114	-0.2130	-0.2961	-0.0913	-0.1833	-0.6410
P	0.1630	-0.1580	-0.4215	-0.1501	0.4019	-0.4622	0.1172	0.3384	-0.3329	-0.2417	-0.1938

Table 5.4. The P values of Correlation between Leaf parameters and Insect pests in Conventional rice fields.

P value	LCM	LD	LF	LGM	SF	GSF	SBR	A	E	L	N	P
L.N	0.5858	0.3205	0.3770	0.6622	0.2820	0.3295	0.8600	0.6364	0.8712	0.3596	0.3885	0.7576
L.P	0.2626	0.3725	0.3018	0.4929	0.5419	0.1640	0.8885	0.8778	0.8845	0.4556	0.4458	0.7649
L.K	0.2493	0.7630	0.9961	0.1499	0.4216	0.8270	0.8325	0.7751	0.8599	0.6230	0.9759	0.4051
L.Ca	0.5618	0.4860	0.2923	0.9564	0.6141	0.3402	0.5825	0.7862	0.6391	0.458	0.2828	0.7765
L.Mg	0.5709	0.9182	0.2915	0.3844	0.8415	0.6336	0.0142	0.6105	0.0326	0.5357	0.1126	0.4295
L.S	0.5619	0.5034	0.5093	0.0924	0.6524	0.1334	0.1350	0.7157	0.1605	0.5733	0.9828	0.3560
L.Fe	0.8782	0.858	0.8616	0.2951	0.6747	0.672	0.5576	0.9050	0.6555	0.8284	0.6852	0.8249
L.Mn	0.4791	0.7659	0.8426	0.5894	0.7816	0.9106	0.4065	0.5470	0.4001	0.8809	0.5687	0.5117
L.Zn	0.3639	0.7475	0.7493	0.3027	0.4323	0.2227	0.8517	0.7412	0.7043	0.6042	0.8633	0.5190
L.Cu	0.4256	0.7754	0.9782	0.0350	0.5281	0.2506	0.5482	0.3590	0.4695	0.6419	0.7281	0.6444
L.B	0.3022	0.1117	0.3457	0.3083	0.127	0.4057	0.4629	0.0020	0.2615	0.1770	0.1701	0.7128

Figure 5.3. The Correlation matrix between Pests and their Parasitoids in Conventional rice fields.

LD- Leaf defoliator , LF- Leaf folder, LGM- Leaf gall midge, SF- Sap feeder, GSF- Grain sap feeder, SBR- Stem borer, LDEP- Leaf Defoliator Egg parasitoids, LDLP- Leaf Defoliator Larval parasitoids, LDPP- Leaf Defoliator Pupal parasitoids, LFEP- Leaf Folder Egg parasitoids, LFLP- Leaf Folder Larval parasitoids, LFPP- Leaf Folder Pupal parasitoids, LGMEP- Leaf Gall Midges Egg parasitoids, LGMLP- Leaf Gall Midges Larval parasitoids, LGMPP- Leaf Gall Midges Pupal parasitoids, SFEP- Sap Feeder Egg parasitoids, SFLP- Sap Feeder Larval parasitoids, GSFEP- Grain Sap Feeder Egg parasitoids, SBREP- Stem Borer Egg parasitoids, SBRLP- Stem Borer Larval parasitoids, SBRPP- Stem Borer Pupal parasitoids. (Towards dark red: Negative correlation increase, Towards dark blue: Positive correlation increases, Eclipse area increases: Correlation decreases, Eclipse area decreases: Correlation increases, $p < 0.05$ boxed= significant.).

Table 5.5. The Correlation coefficient values between Pests and their Parasitoids in Conventional rice fields.

	LD	LF	LGM	SF	GSF	SBR
LDEP	-0.4684	-0.6490	0.2595	-0.4345	-0.2136	-0.2313
LDLP	0.2680	-0.2138	0.2431	-0.0232	-0.3490	-0.4556
LDPP	0.9338	0.4000	0.0159	0.4206	-0.1504	-0.0280
LFEP	-0.4299	-0.5388	0.3668	-0.4174	-0.0539	-0.0433
LFLP	-0.5642	-0.6131	0.1859	-0.5194	-0.1904	-0.3602
LFPP	-0.0473	-0.4127	0.2593	-0.1497	-0.3489	-0.2789
LGMEP	0.2453	-0.0304	0.8347	0.2117	0.1675	0.0879
LGMLP	-0.0181	-0.1483	0.8811	-0.1990	-0.1926	0.0124
LGMPP	-0.1036	-0.0310	0.5855	-0.1854	0.3477	0.3565
SFEP	-0.1837	-0.1508	0.2798	-0.4992	-0.1711	-0.1065
SFLP	-0.5429	-0.7172	0.2407	-0.4959	-0.0841	-0.4338
GSFEP	-0.3373	-0.0336	-0.1308	-0.1242	0.6682	0.0522
SBREP	0.1006	0.3428	0.3109	0.1251	0.5681	0.6087
SBRLP	-0.0217	0.6234	-0.2030	0.2185	0.5063	0.8305
SBRPP	-0.1786	-0.3857	0.0029	-0.1863	-0.5216	-0.6125

Table 5.6. The P Values of Correlation between Pests and their Parasitoids in Conventional rice field.

	LDEP	LDLP	LDPP	LFEP	LFLP	LFPP	LGMEP	LGMLP	LGMPP	SFEP	SFLP	GSFEP	SBREP	SBRLP	SBRPP
LD	0.0499	0.2823	1.5E-08	0.0750	0.0147	0.8523	0.3265	0.9431	0.6824	0.4655	0.0199	0.1710	0.6914	0.9318	0.4783
LF	0.0035	0.3944	0.1000	0.0211	0.0068	0.0888	0.9047	0.5571	0.9027	0.5502	0.0008	0.8946	0.1637	0.0057	0.1139
LGM	0.2984	0.3310	0.9502	0.1343	0.4602	0.2988	1.64E-05	1.37E-06	0.0107	0.2609	0.3360	0.6050	0.2093	0.4192	0.9908
SF	0.0715	0.9271	0.0822	0.0848	0.0272	0.5532	0.3992	0.4287	0.4615	0.0349	0.0363	0.6233	0.6210	0.3837	0.4593
GSF	0.3946	0.1558	0.5513	0.8317	0.4492	0.1559	0.5065	0.4440	0.1574	0.4974	0.7401	0.0024	0.0139	0.0320	0.0264
SBR	0.3556	0.0574	0.9121	0.8645	0.1420	0.2624	0.7289	0.9612	0.1464	0.6742	0.0721	0.8372	0.0073	1.98E-05	0.0069

Correlation between Atmospheric parameters, Insect Pests and their Parasitoids in Kaipad rice fields.

The atmospheric temperature and the abundance of pupal parasitoids only showed significant negative correlation ($r=-0.5107$, $p=0.03033$). The atmospheric temperature discourages the incidence of pest larval stages ($r=-0.4150$, $p=0.08677$), pest pupal stages ($r=-0.4015$, $p=0.0985$), leaf case makers ($r=-0.166$, $p=0.5103$), leaf defoliators ($r=-0.2279$, $p=0.363$), leaf folders ($r=-0.1189$, $p=0.6383$), leaf gall midges ($r=-0.1897$, $p=0.4508$), egg parasitoids ($r=-0.1052$, $p=0.6777$), larval parasitoids ($r=-0.3852$, $p=0.1143$) and total parasitoids ($r=-0.2459$, $p=0.3252$). While, the abundance of pest egg stages ($r=0.1398$, $p=0.5800$), pest adults stages ($r=0.0278$, $p=0.9125$), sap feeders ($r=0.2432$, $p=0.3307$), grain sap feeders ($r=0.3186$, $p=0.1975$), stem borers ($r=0.1344$, $p=0.5948$) and overall pests ($r=0.1594$, $p=0.5273$) non-significant positive correlation with atmospheric temperature.

The atmospheric humidity favours the incidence of pest larval stages ($r=0.0214$, $p=0.9326$), leaf folders ($r=0.1373$, $p=0.5866$), sap feeders ($r=0.4134$, $p=0.0881$), egg parasitoids ($r=0.2321$, $p=0.3539$) and total parasitoids ($r=0.0526$, $p=0.8356$). While increase in atmospheric humidity causes decrease in the incidence of pest egg stages ($r=-0.2137$, $p=0.3944$), pest pupal stages ($r=-0.2180$, $p=0.3846$), pest adult stages ($r=-0.048$, $p=0.8499$), leaf case makers ($r=-0.1345$, $p=0.5944$), leaf defoliators ($r=-0.1017$, $p=0.6878$), leaf gall midges ($r=-0.1911$, $p=0.447$), grain sap feeders ($r=-0.1225$, $p=0.6281$), stem borers ($r=-0.2687$, $p=0.2809$), overall pests ($r=-0.2914$, $p=0.2407$), larval parasitoids ($r=-0.3490$, $p=0.1557$) and pupal parasitoids ($r=-0.4192$, $p=0.0832$).

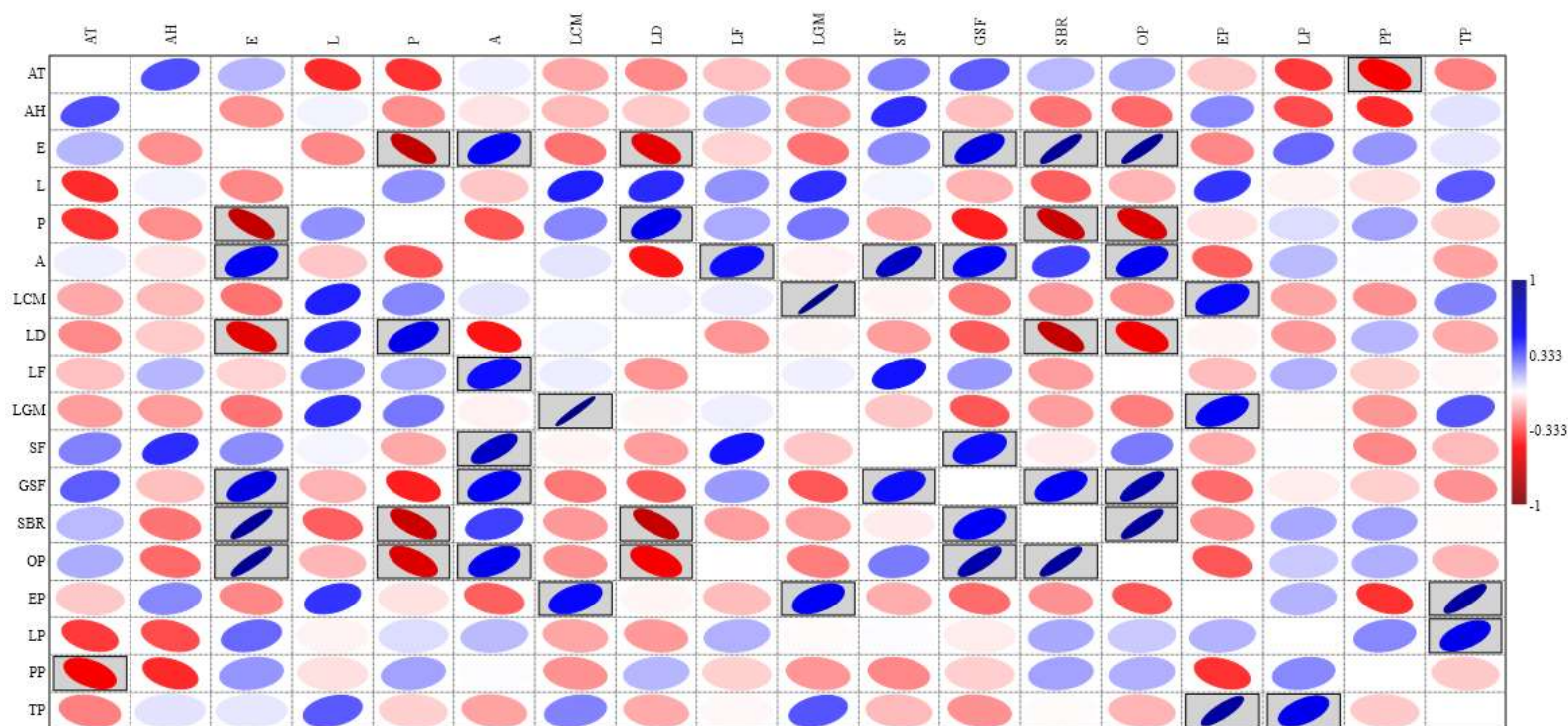
The Correlation between Leaf parameters and insect pests in Kaipad rice fields.

In Kaipad rice fields, the abundance of grain sap feeders ($r=-0.9054$, $p=0.0129$), stem borers ($r=-0.8199$, $p=0.0457$), adult insect pests ($r=-0.8384$, $p=0.0370$) and eggs of pests ($r=-0.8225$, $p=0.0444$) was significantly negatively correlated with leaf zinc. While the abundance of pest pupal stage ($r=0.8334$, $p=0.0393$) was significantly positively correlated with leaf zinc. The abundance of grain sap feeders ($r=-0.9089$, $p=0.0120$) and adult pest stage ($r=-0.8889$, $p=0.0178$) showed negatively significant correlation with leaf boron. A significant negative correlation was also noted between the abundance of sap feeders and leaf sulfur ($r=-0.8988$, $p=0.0148$), but the abundance of pest nymphal stage and leaf potassium showed significant positive correlation ($r=0.8910$, $p=0.0171$) (Fig.10)(Table 9 and 10). The correlation between leaf parameters and insect pests are given in the Figure 5 and Tables 9 & 10.

The Correlation between Pests and their parasitoids in Kaipad rice fields.

In Kaipad rice fields, the abundance of leaf defoliators was significantly positively correlated with the abundance of their egg parasitoids ($r=0.9530$, $p=1.04E-09$), larval parasitoids ($r=0.9027$, $p=2.97E-07$) and pupal parasitoids ($r=0.8823$, $p=1.27E-06$). Significant positive correlation was also observed between the abundance of leaf folders and their egg parasitoids ($r=0.9617$, $p=2.06E-10$), larval parasitoids ($r=0.9926$, $p=4.48E-16$), and pupal parasitoids ($r=0.9896$, $p=6.51E-15$). The abundance of leaf gall midges was also significantly positively correlated with the abundance of their larval parasitoids ($r=0.9971$, $p=1.98E-19$) and pupal parasitoids ($r=0.99113$, $p=1.88E-15$). But the abundance of leaf gall midges was non significantly positively correlated with the abundance of their egg parasitoids. The abundance of sap feeding ($r=0.6120$, $p=0.0070$) and grain sap feeding ($r=0.5036$, $p=0.0331$) pests were significantly positively correlated with the abundance of their egg parasitoids. In the case of stem borers also, their abundance is significantly positively correlated with their egg parasitoids ($r=0.9994$, $p=1.36E-24$), larval parasitoids ($r=0.9963$, $p=1.60E-18$) and pupal parasitoids ($r=0.9973$, $p=1.52E-19$)(Figure 6 and Tables 11 & 12.).

Figure 5.4. The Correlation matrix between Atmospheric parameters, Insect pests and Parasitoids in Kaipad rice fields.



AT- Atmospheric temperature, AH- Atmospheric Humidity, E- Pest egg stage, L- Pest larval stage, N- Pest nymphal stage, P- Pest pupal stage, A- Pest adult stage LCM- Leaf case maker, LD- Leaf defoliator, LF- Leaf folder, LGM- Leaf gall midge, SF- Sap feeder, GSF- Grain sap feeder, SBR- Stem borer, OP- Overall pests, EP- Egg parasitoids, LP- Larval parasitoids, PP- Pupal parasitoids, TP- Total Parasitoids. (Towards dark red: Negative correlation increase, Towards dark blue: Positive correlation increases, Eclipse area increases: Correlation decreases, Eclipse area decreases: Correlation increases, $p < 0.05$ boxed= significant.).

Table 5.7. The Correlation coefficient values between Atmospheric parameters, Insect pests and Parasitoids in Kaipad rice fields.

Correlation coefficient	Atmospheric Temperature (°C)	Atmospheric Humidity (%)
E	0.1398	-0.2137
L	-0.4150	0.0214
P	-0.4015	-0.2180
A	0.0278	-0.048
LCM	-0.166	-0.1345
LD	-0.2279	-0.1017
LF	-0.1189	0.1373
LGM	-0.1897	-0.1911
SF	0.2432	0.4134
GSF	0.3186	-0.1225
SBR	0.1344	-0.2687
OP	0.1594	-0.2914
EP	-0.1052	0.2321
LP	-0.3852	-0.3490
PP	-0.5107	-0.4192
TP	-0.2459	0.0526

Table 5.8. The P values of Correlation between Atmospheric parameters, Insect pests and Parasitoids in Kaipad rice fields.

P-value	E	L	P	A	LCM	LD	LF	LGM	SF	GSF	SBR	OP	EP	LP	PP	TP
AT	0.5800	0.08677	0.0985	0.9125	0.5103	0.363	0.6383	0.4508	0.3307	0.1975	0.5948	0.5273	0.6777	0.1143	0.03033	0.3252
AH	0.3944	0.9326	0.3846	0.8499	0.5944	0.6878	0.5866	0.447	0.0881	0.6281	0.2809	0.2407	0.3539	0.1557	0.0832	0.8356

Figure 5.5. The Correlation matrix between Leaf parameters and Insect pests in Kaipad rice fields.

L.N- Leaf Nitrogen, L.P- Leaf Phosphorus, L.K- Leaf Potassium, L.Ca- Leaf Calcium, L.Mg- Leaf Magnesium, L.S- Leaf Sulfur, L.Fe- Leaf Iron,, L.Mn- Leaf Manganese, L.Zn- Leaf Zinc, L.Cu – Leaf Copper, L.B- Leaf Boron, LCM-Leaf case maker, LD- Leaf defoliator , LF- Leaf folder, LGM- Leaf gall midge, SF- Sap feeder, GSF- Grain sap feeder, SBR- Stem borer, E- Pest egg stage, L- Pest larval stage, N- Pest nymphal stage, P- Pest pupal stage, A-Pest adult stage. (Towards dark red: Negative correlation increase, Towards dark blue: Positive correlation increases, Eclipse area increases: Correlation decreases, Eclipse area decreases: Correlation increases, $p < 0.05$ boxed= significant.).

Table 5.9. The Correlation coefficient values between Leaf Parameters and Insect pests in Kaipad rice fields.

Correlation	L.N	L.P	L.K	L.Ca	L.Mg	L.S	L.Fe	L.Mn	L.Zn	L.Cu	L.B
LCM	0.0678	-0.6535	-0.0076	-0.2047	-0.1950	0.1178	-0.4209	-0.0615	0.2265	0.4360	0.6757
LD	0.8067	0.4268	-0.1141	-0.4511	0.1389	0.3421	0.6109	0.6731	0.7885	-0.0155	0.4094
LF	-0.6136	-0.7826	-0.0244	0.7448	-0.3835	-0.1612	-0.0157	-0.1516	-0.3898	0.5666	-0.1052
LGM	0.0201	-0.6664	-0.0002	-0.1681	-0.1546	0.1084	-0.4930	-0.0890	0.1580	0.4229	0.6221
SF	-0.3023	-0.1509	-0.6931	0.1189	-0.3247	-0.8988	0.0617	-0.7819	-0.1950	0.5933	-0.1823
GSF	-0.6751	-0.1517	-0.4824	0.6679	0.4195	-0.6752	-0.6282	-0.6188	-0.9054	0.3148	-0.9089
SBR	-0.6080	-0.0575	0.0184	0.4688	0.3590	-0.2521	-0.6522	-0.4154	-0.8199	-0.1510	-0.7226
A	-0.5492	-0.0319	-0.4632	0.5520	0.5469	-0.5949	-0.6704	-0.5350	-0.8384	0.2174	-0.8889
E	-0.6063	-0.0469	0.0301	0.4843	0.3702	-0.2349	-0.6376	-0.3902	-0.8225	-0.1634	-0.7379
L	0.0085	-0.4823	-0.1959	0.1633	-0.4293	-0.0802	0.3441	0.0726	0.2672	0.5932	0.3772
N	-0.3997	-0.1037	0.8910	0.2463	-0.2946	0.5482	0.0433	0.1901	-0.2874	-0.6548	-0.0644
P	0.6728	0.0080	0.0032	-0.4462	-0.1982	0.3830	0.5300	0.5647	0.8334	0.1735	0.7444

Table 5.10.The P Values of Correlation between Leaf Parameters and Insect pests in Kaipad rice fields.

P Value	LCM	LD	LF	LGM	SF	GSF	SBR	A	E	L	N	P
L.N	0.8983	0.0523	0.1951	0.9697	0.5603	0.1411	0.2003	0.259	0.2019	0.9871	0.4322	0.1430
L.P	0.1592	0.3985	0.0657	0.1483	0.7752	0.7741	0.9137	0.9520	0.9295	0.3325	0.8449	0.9879
L.K	0.9885	0.8295	0.9632	0.9996	0.1268	0.3325	0.9723	0.3547	0.9548	0.7098	0.0171	0.9951
L.Ca	0.6972	0.3691	0.0893	0.7501	0.8224	0.1470	0.3482	0.2560	0.3302	0.7571	0.6379	0.3750
L.Mg	0.7111	0.7928	0.4528	0.7698	0.5299	0.4076	0.4845	0.2613	0.4700	0.3955	0.5707	0.7065
L.S	0.8240	0.5068	0.7601	0.8379	0.0148	0.1410	0.6298	0.2129	0.6541	0.8799	0.2599	0.4535
L.Fe	0.4059	0.1975	0.9763	0.3204	0.9075	0.1816	0.1604	0.1449	0.1731	0.5041	0.9349	0.2793
L.Mn	0.9078	0.1427	0.7743	0.8667	0.0661	0.1902	0.4126	0.2740	0.4444	0.8912	0.7182	0.2429
L.Zn	0.6659	0.0623	0.4448	0.7649	0.7111	0.0129	0.0457	0.0370	0.0444	0.6087	0.5806	0.0393
L.Cu	0.3874	0.9767	0.2410	0.4033	0.2144	0.5433	0.7750	0.6790	0.7569	0.2145	0.1581	0.7423
L.B	0.1407	0.4201	0.8426	0.1871	0.7295	0.0120	0.1047	0.0178	0.0940	0.461	0.9034	0.0896

Figure 5.6. The Correlation matrix between Pests and their Parasitoids in Kaipad rice fields.

(LCM-Leaf case maker, LD- Leaf defoliator , LF- Leaf folder, LGM- Leaf gall midge, SF- Sap feeder, GSF- Grain sap feeder, SBR- Stem borer, LCMPP-Leaf Case Maker Pupal Parasitoids, LDEP- Leaf Defoliator Egg parasitoids, LDLP- Leaf Defoliator Larval parasitoids, LDPP- Leaf Defoliator Pupal parasitoids, LFEP- Leaf Folder Egg parasitoids, LFLP- Leaf Folder Larval parasitoids, LFPP- Leaf Folder Pupal parasitoids, LGMEP- Leaf Gall Midges Egg parasitoids, LGMLP- Leaf Gall Midges Larval parasitoids, LGMPP- Leaf Gall Midges Pupal parasitoids, SFEP- Sap Feeder Egg parasitoids, SFLP- Sap Feeder Larval parasitoids, GSFEP- Grain Sap Feeder Egg parasitoids, SBREP- Stem Borer Egg parasitoids, SBRLP- Stem Borer Larval parasitoids, SBRPP- Stem Borer Pupal parasitoids). (Towards dark red: Negative correlation increase, Towards dark blue: Positive correlation increases, Eclipse area increases: Correlation decreases, Eclipse area decreases: Correlation increases, $p < 0.05$ boxed= significant.).

Table 5.11. The Correlation coefficient values between Pest and their Parasitoids in Kaipad rice fields.

	LCM	LD	LF	LGM	SF	GSF	SBR
LCMPP	-0.1576	0.0185	-0.0995	-0.1921	-0.0958	-0.4115	-0.2279
LDEP	0.0329	0.9530	-0.1913	0.0212	-0.2202	-0.2229	-0.6105
LDLP	-0.0080	0.9027	-0.2644	-0.0210	-0.1102	-0.2870	-0.6598
LDPP	-0.0705	0.8823	-0.0759	-0.1466	-0.1570	-0.2825	-0.7006
LFEP	-0.0852	-0.1630	0.9617	-0.1270	0.4983	0.2951	-0.1528
LFLP	-0.0454	-0.2515	0.9926	-0.0454	0.4726	0.2227	-0.1484
LFPP	-0.0109	-0.2502	0.9896	-0.0057	0.4210	0.1652	-0.1705
LGMEP	-0.0297	-0.0137	-0.0130	0.0125	0.1616	0.1038	-0.0508
LGMLP	0.9714	-0.0416	0.0664	0.9971	-0.0872	-0.2836	-0.1736
LGMPP	0.9653	0.0288	-0.0057	0.9911	-0.1078	-0.3111	-0.2115
GSFEP	-0.1802	-0.1505	0.6030	-0.2774	0.6120	0.2357	-0.1131
SFLP	-0.2091	0.1046	0.3559	-0.3069	0.7402	0.2325	-0.2916
GSFEP	-0.0943	-0.1341	-0.5092	-0.071	-0.0015	0.5036	0.3783
SBREP	-0.2047	-0.7186	-0.1992	-0.1947	-0.0481	0.5278	0.9994
SBRLP	-0.2230	-0.7017	-0.2291	-0.2111	-0.0790	0.5113	0.9963
SBRPP	-0.1858	-0.7116	-0.2357	-0.1678	-0.0642	0.4849	0.9973

Table 5.12.The P Values of Correlation between Pest and their Parasitoids in Conventional rice.

	LCMPP	LDEP	LDLP	LDPP	LFEP	LFLP	LFPP	LGMEP	LGMLP	LGMPP	SFEP	SFLP	GSFEP	SBREP	SBRLP	SBRPP
LCM	0.5323	0.897	0.9749	0.7811	0.7369	0.8581	0.9656	0.9070	2.07E-11	9.49E-11	0.4744	0.4049	0.7097	0.4152	0.3739	0.4603
LD	0.9419	1.04E-09	2.97E-07	1.27E-06	0.5182	0.3141	0.3166	0.9569	0.8699	0.9098	0.5511	0.6796	0.5958	0.0008	0.0012	0.0009
LF	0.6944	0.4469	0.2891	0.7646	2.06E-10	4.48E-16	6.51E-15	0.9591	0.7934	0.9821	0.0081	0.1473	0.0309	0.4280	0.3605	0.3465
LGM	0.4449	0.9333	0.9340	0.5616	0.6155	0.8580	0.9819	0.9605	1.98E-19	1.88E-15	0.2650	0.2154	0.7795	0.4387	0.4004	0.5055
SF	0.7054	0.3799	0.6634	0.5337	0.0353	0.0476	0.0819	0.5218	0.7309	0.6703	0.0070	0.0004	0.9953	0.8498	0.7553	0.8004
GSF	0.0898	0.3740	0.2482	0.2561	0.2346	0.3745	0.5124	0.6819	0.2541	0.2089	0.3465	0.3532	0.0331	0.0244	0.0301	0.0414
SBR	0.3631	0.0071	0.0029	0.0012	0.5449	0.5566	0.4988	0.8414	0.4910	0.3996	0.6551	0.2404	0.1217	1.36E-24	1.60E-18	1.52E-19

DISCUSSION

The overall relation between atmospheric parameters, leaf parameters, pest incidence and parasitoid incidence showed significant and non-significant positive and negative correlation. Insect abundance and distribution are regulated by several biotic and abiotic factors and their interactions. Among abiotic factors, temperature and humidity are the most important ones constraining abundance and distribution of insects (Soultani et al., 2012).

Temperature and abundance of insect pest stages

The abundance of insect pest stages and insect pest guilds are influenced by the atmospheric temperature and humidity. The present study observed that the incidence of larval and pupal stages of insect pests are negatively correlated (non significant) with the atmospheric temperature. Xiao et al., (2017) also noticed that warm temperatures decreased the survival of the rice stem borer larvae, and are negatively correlated. They also observed that warmer temperatures also resulted in declines in pupation rate, pupal weight and post-diapause reproductive potential.

The incidence of egg, larval, pupal and adult stages showed non-significant negative correlation with atmospheric temperature in Conventional rice fields. In Kaipad rice fields, the atmospheric temperature showed non-significant positive correlation with the incidence of egg and adult, while it showed non significant negative correlation with the incidence of larval and pupal stages of insect pests.

Temperature and abundance of insect pest guilds

During the present study in the conventional rice fields, the atmospheric temperature showed non significant negative correlation with abundance of Pest Egg stage, Pest larval stage, Pest pupal stage, Pest adult stage, leaf defoliators, leaf folders, leaf gall midges, sap feeders, stem borers and overall pests. In Kaipad rice fields also, the atmospheric temperature showed non significant negative correlation with the incidence of pest larval stages, pest pupal stages, leaf case makers, leaf defoliators, leaf folders and leaf gall midges. Insects being poikilotherms, temperature is the single most significant environmental factor influencing their

behaviour, distribution, development, survival, and reproduction (Petzoldt and Seaman, 2010). Reproduction, oviposition period and longevity of insects were reduced with increase in temperature (Zhang et al., 2014; Overgaard and Sorenson, 2008; Finlay and Walter, 2012). In the present study temperature showed a negative significant impact on the population of *S. incertulas* which is similar to the observation of Morshed et al., (2020a).

During the present study, stem borers and Sap feeders are positively correlated (non significant) with temperature in Kaipad rice fields. Sawai and Kothikar (2019) documented that yellow stem borer, brown plant hopper, white backed plant hopper, green leaf hopper and leaf folder positively correlated with maximum and minimum temperature. Sulagitti et al., (2017) and Ahmed et al., (2013) also noticed that brown plant hopper (sap feeder) showed a positive non-significant correlation with temperature.

During the present study, temperature showed positive correlation (non significant) with stem borers and sap feeders in Kaipad rice fields only. While temperature showed negative correlation (non significant) with the leaf folder incidence in both categories of rice fields. Madhuri et al., (2017a) also revealed that the temperature favors stem borer, leaf folder, green leaf hopper, brown plant hopper and white backed plant hopper.

In Kaipad rice fields, the stem borer incidence and temperature are positively correlated (non significant). According to Manikandan et al., (2013) and Singh et al., (2020) also the yellow stem borer abundance is positively (significant) influenced by temperature. Ramprasad and Sandeep (2006) and Kalita et al., (2020) also recorded that rice stem borer showed positive correlation with minimum temperature and maximum temperature. In a study by Nag et al., (2018), they observed that population of *S. incertulas* showed non-significant positive correlation with maximum temperature, whereas, minimum temperature had a significant positive correlation. Contrary to these observations Morshed, et al., (2020a), Hugar et al., (2009), Patil et al., (2020) and Ali et al., (2020) have observed that the maximum

temperature showed a negative impact on the population of *S. incertulas* which is supported by the observation from Conventional fields of the present study.

Leaf folders showed negative correlation (non significant) with temperature in Conventional and Kaipad rice fields. Vidyawati Garg (2012) and Priya and Prasad (2021) also made similar observation. But several researchers have observed that leaf folder population density had a significantly positive correlation with temperature (Khan and Ramamurthy, 2004; Supawan and Wiboon 2017; Kalita et al., 2020; Jasrotia et al., 2019 and Patil et al., 2020). Ramprasad and Sandeep (2006) also recorded that leaf folder showed non-significant positive correlation with minimum temperature and maximum temperature.

During the present study, the temperature showed positive correlation (non significant) with the incidence of leaf case makers in Conventional rice fields, and negative correlation (non significant) in Kaipad rice fields. The earlier observation by Kalita et al., (2020) showed that the population build up of case worm was found positively correlated with maximum temperature, minimum temperature.

In Kaipad rice fields, the incidence of sap feeders showed positive correlation (non significant) with temperature. While in Conventional fields, the incidence of sap feeders are negatively correlated (non significant) with temperature. Ramprasad and Sandeep (2006) documented that, among sap feeders, the brown plant hoppers exhibit positive significant correlation with maximum temperature while green leaf hopper showed positive non-significant correlation. According to Sulagitti et al., (2017) also, the correlation of Brown plant hopper with temperature revealed a positive non-significant correlation. Singh et al., (2020) documented that Maximum temperature favours the sap feeders like, Green Hoppers, Green Leaf Hoppers.

During the present study, the incidence of grain sap feeders showed positive correlation (non significant) with the temperature in both categories of rice fields, similar observation is also documented by Singh et al., (2020) and Ramprasad and Sandeep (2006). In contrast, Sulagitti et al., (2017), Sharma et al., (2019b) and Raj Kumar et al., (2018) noted that grain sap feeders showed a negative correlation with

temperature. Kalita et al., (2020) also noted that maximum temperature and minimum temperature reduces the abundance of gundhi bugs (grain sap feeders).

The abundance of leaf defoliators showed negative correlation (non significant) with the temperature in Kaipad and Conventional rice fields. During a study by Raj Kumar et al., (2018), the rice hispa (leaf defoliator) showed positive correlation with minimum temperature, and Kalita et al., (2020) documented that rice hispa incidence was positively correlated to maximum and minimum temperatures. Devendra et al., (2018) also found positively significant correlation between rice hispa (Leaf defoliator) with maximum temperature. According to Chattopadhyay et al., (2004), a drop in the maximum and minimum temperatures under high humidity for a period of 3-4 days is favorable for the incidence of rice hispa.

Humidity and abundance of insect pests

Various insects respond to humidity in different ways, and it not only affect the behavior of insects but also disturb the physiological mechanism (Overgaard and Sorenson, 2008; Karl et al., (2011). The variation in humidity puts the insect under stress which in turn produce immune responses, and finally it affects mortality, fecundity, generation time, multiplication rate, sex ratio and sometimes lead to mutation (Khaliq et al., 2014).

In Conventional rice fields, the incidence of yellow stem borer showed a positive correlation (non significant) with average humidity, but in Kaipad rice fields, those parameters are negatively correlated (non significant). Observations by Sulagitti et al., (2017) matched with the results of the present study in Conventional rice fields, but findings of Jasrotia et al., (2019), Kalita et al., (2020) and Patil et al., (2020, 2021) supported the observations of the present study in Kaipad rice fields.

The incidence of gundhi bugs is positively correlated (non significant) to the atmospheric humidity in Conventional rice fields, while in Kaipad, it is negative (non significant). According to Sulagitti et al., (2017) and Kalita et al., (2020), Gundhi bug (grain sap feeder) showed a positive non-significant correlation

with relative humidity, which is also similar to the results from Conventional rice fields and contradictory to the observations from Kaipad rice fields. Raj Kumar et al., (2018) and Morshed et al., (2020b) found that gundhi bug has significant negative correlation with maximum RH, minimum RH, average RH which does not support the observations from Kaipad rice fields, because the relation is not significant in the present study.

During the present study, the abundance of sap feeders was positively correlated with atmospheric humidity although it was not significant, which agrees with the observation of Sulagitti et al., (2017), Ashrith et al., (2017), Madhuri et al., (2017a) and Singh et al. (2020) also noticed that among sap feeders, the abundance of Brown plant hopper, White backed plant hopper, green hoppers and green leaf hoppers are positively correlated with the relative humidity in rice ecosystems.

In Kaipad rice fields, the incidence of yellow stem borer showed non significant negative correlation with atmospheric humidity, and Sawai and Kothikar (2019) supported this finding. But in Conventional rice fields, the abundance of stem borers and atmospheric humidity showed non-significant positive correlation. Nag et al., (2018) noticed the significant positive correlation of abundance of *S. incertulas* with morning and evening relative humidity. Singh et al., (2020) also documented that abundance of Yellow stem borers is positively correlated with relative humidity.

During the present study, the incidence of leaf folders showed positive correlation (non significant) with atmospheric humidity in both categories of rice fields. Madhuri et al., (2017b) supported this study and recorded that, humidity favours leaf folder incidence. Khan and Ramamurthy (2004) also noted leaf folder population density had a significantly positive correlation with average relative humidity. Rasul et al., (2019), Boopathi et al., (2018), Chakraborty and Deb (2011), Singh et al., (2020) and Priya and Prasad (2021) recorded relative humidity has positive impact on incidence of *C. medinalis* (leaf folder). These studies support the present study but differing observations are recorded by Emura and Kojima (1974), i.e., negative impact of relative humidity on abundance of *C. medinalis* infestations.

During the present study, the abundance of grain sap feeders (*L.acuta*) showed non-significant negative correlation with atmospheric humidity in Kaipad rice fields, and non-significant positive relationship in Conventional rice fields. Sharma et al., (2019b) support the present study in Kaipad rice fields, i.e. non-significant negative correlation of rice ear head bug abundance with average relative humidity. While, Sulagitti et al., (2017), Singh et al., (2020) and Devendra et al., (2018) recorded that rice ear head bug (grain sap feeder) showed positive insignificant correlation with morning Relative Humidity, and which supports the results of the present study in Conventional rice fields.

Temperature and parasitism

Temperature was the most important single variable, explaining up to 75% of the variation in field parasitism (Kalyebi et al., 2006). The authors recorded that temperature played more critical role in developmental time and life table parameters of *Trichogramma* and *Trichogrammatoidea*. They also noted that the developmental time and generation time of parasitoid strains was inversely related to temperature.

The level of parasitization is influenced by temperature (Maulina et al., 2018). During the present study, the incidence of egg parasitoids, larval parasitoids, pupal parasitoids and total parasitoids showed non-significant negative correlation with the atmospheric temperature. According to Palumbo (2011), temperature is the driving force behind insect development, growth and behavior. Furlong and Zalucki (2017) reported that increasing global temperatures will produce a greater negative impact on parasitoid distribution. Zhang et al., (2019) also documented that the temperatures experienced during the pre-adult and adult stages significantly change immature development, adult longevity, host feeding and fecundity. Increase in temperature resulted in shorter development period for immature stages of the parasitoid, and decreasing the temperature during the adult stage increased reproduction and longevity. They also found that host-feeding events changed with temperature, and daily host-feeding ability of the parasitoid increased with increasing temperature at all temperatures except the stress temperature (34 °C).

The egg parasitoids abundance showed non- significant negative correlation with temperature in Kaipad and Conventional rice fields during the present study. Bari et al., (2015) observed that highest number of rice hispa eggs parasitized by egg parasitoids was at 26 °C and development duration and longevity decreased as temperature increased, while emergence rates decreased at both high and low temperatures. Hansen and Jensen (2002) also recorded that killing of the host eggs by egg parasitoid was highest at the lower temperature, which agrees with the observations made during the present study.

The abundance of egg parasitoids, larval parasitoids, pupal and total parasitoids showed negative correlation (non significant) with the atmospheric humidity in Conventional rice fields during the present study. In Kaipad rice fields, the abundance of larval and pupal parasitoids showed negative correlation (non significant) with atmospheric humidity; and the incidence of egg and total parasitoids showed non significant positive correlation with atmospheric humidity. Maulina et al., (2018) have observed that the level of parasitization is influenced by relative humidity.

Humidity and parasitism

During the present study, the egg – larval- pupal and total parasitoids abundance showed non-significant negative correlation with atmospheric humidity in Conventional rice fields. In Kaipad rice fields, the incidence of larval and pupal parasitoids showed non significant negative correlation with atmospheric humidity. Contrary to this the incidence of egg parasitoids and total parasitoids showed positive correlation (non-significant) with atmospheric humidity in Kaipad rice fields. Kalyebi et al., (2006) recorded that humidity affected developmental time and life table parameters of *Trichogramma* and *Trichogrammatoidea*. There was a significant negative relationship between the mean relative humidity and the parasitism in the field (Bourchier and Smith, 1996).

Leaf Nutrients and abundance of insect pests

The results of the present study indicates that different nutrients do have positive and negative correlation with abundance of insect pests. Earlier, Listinger (1993) noted that the plants with sufficient nutrients are stronger, healthier and able to compensate for pest damage than those under nutritional deficiencies. Since the plants provide nutrients to insect pests, an increase in the nutrient content of the plant is likely to increase its acceptability to pests (Scriber, 1984). According to Sarwar (2011), the nutrient status is an indicator of host plant quality, which plays an important role in the population dynamics of many insect pests. Invertebrate herbivore abundance increased with nutrient additions. As per La Pierre and Smith (2016), addition of nutrient induced shifts in plant biomass and leaf nutrient content, altered invertebrate abundance and feeding rate.

Leaf Nitrogen and abundance of insect pests

Nitrogen is one of the most significant nutrients influencing the performance of herbivores (Douglas, 1993), and they can normally increase herbivore feeding preference, food consumption, survival, growth, reproduction, and population density, and it affect the reproduction, longevity and overall fitness of certain pests (Jahn, 2004).

During the present study, the abundance of leaf defoliators, leaf folders, sap feeders, stem borers showed positive correlation (non significant) with leaf nitrogen content, and negative correlation (non significant) with leaf case makers, leaf gall makers and grain sap feeders in Conventional rice fields. In Kaipad rice fields, leaf case makers, leaf defoliators and leaf gall midges showed positive correlation (non significant) with leaf nitrogen content, but leaf folders, sap feeders, grain sap feeders and stem borers showed negative correlation (non significant) with leaf nitrogen content. Pramanick et al., (1995) and Xian et al., (2007) supported the present study, and they noted that the incidence of green leafhoppers, yellow stem borers and leaf folders was significantly greater in fields that received high rates of nitrogen. Similarly, Subbaih and Morachan, (1974) also recorded high level of nitrogen increase during leaf folder infestation. Wu et al., (2017) revealed that high N

fertilization level significantly decreased rice resistance to Brown plant hoppers. These studies support the trend observed during the present study in Conventional rice fields.

During the present study, the correlation between leaf nitrogen and abundance of leaf folder, stem borer and sap feeders in Conventional rice fields are positive (non significant). Similar observation was noted by Bala et al., (2018), Pandey (2003) and Randhawa and Aulakh (2014) i.e. the incidence of leaf folder and stem borer increased with an increase in nitrogen level. Ramzan et al, (2007) also recorded the highest infestation of stem borers, leaf folders and white backed planthopper with the dose increase of nitrogen fertilizer application. Aziz et al., (2018) also documented that, the application of nitrogen fertilizer in plants can increase herbivore's feeding preference, food consumption, survival, growth, reproduction, and population density, they also added that higher nitrogen doses is a reason for higher incidence of sucking pests.

The impact of higher nitrogen levels in plants can be manifold and may influence top -down and bottom-up effects as observed in conventional and Kaipad rice fields. Zhu et al., (2020) documented that herbivores got double benefit from N applications. Host plant nutritional quality was improved by high rates of N and this allowed them to accumulate more protein and fat and produce larger eggs, besides producing more eggs (Lu et al., 2004). Second, the herbivore may be subjected to lower risk of attack by parasitoids because the plants upon which they feed were less attractive to gravid female parasitoids. Finally, as per Chen et al., (2010) and Winter and Rostás (2010), nitrogen can also exert an array of bottom-up effects on herbivore populations and their natural enemies.

Leaf Phosphorus and abundance of insect pests

In the present study, the abundance of leaf case makers, leaf folders, leaf gall midges, sap feeders, grain sap feeders and stem borers was negatively (non-significant) correlated with the leaf phosphorus content in Kaipad rice fields. Non-significant negative correlation is also recorded between the abundance of leaf

defoliators, leaf folders, leaf gall midges, sap feeders and leaf phosphorus content in Conventional rice fields. But studies by Aziz et al., (2018) and Kulagod et al., (2011) have opined that Phosphorus is not considered as important or limiting as nitrogen for phytophagous insects. Bala et al., (2018) revealed that Phosphorus decreases the host suitability to various insect pests. Few studies have also showed that phosphorus can affect survivorship (Ayres et al., 2000), fecundity (Popp et al., 1989), oviposition preference (Skinner and Cohen, 1994); growth rate (Perkins et al., 2004), and population density (Schade et al., 2003). Rashid et al., (2016) also observed reduced abundance of sap feeders (brown plant hopper) on plant with more phosphorus content, which supports the observation of the present study.

Leaf Potassium and abundance of insect pests

It is observed that the concentration of leaf potassium and abundance of sap feeders are negatively correlated (non significant) in Conventional and Kaipad rice fields. Potassium considered as the key component of plant nutrition that significantly influences crop growth and protection against pests. It provides resistance against most common insect pests (stem borer, leaf folder, whorl maggot and gundhi bug) in rice (Mohapatra et al., 2017; Bala et al., 2018; Aziz et al., 2018).

Sarwar (2012) found that K fertilizer significantly reduced the rate of rice borers' infestation. Salim (2002) recorded that the deficiency of K in rice plant increased intake and assimilation of food, growth index, adult longevity and population build up of *S. furcifera*. But high dose of K to rice plants decreased adult life and population build up of the insects, and is negatively correlated. Several studies noted that the Potassium is negatively associated with occurrence of leafhoppers (Parihar and Upadhyay, 2001; Raju et al., 1996), white-backed plant hopper (El-Zahi et al., 2012), and other sucking insects (Walter and DiFonzo, 2007).

During the present study, the abundance of sap feeders, leaf folders and grain sap feeders showed non significant negative correlation with leaf potassium in Kaipad rice fields; and sap feeders and grain sap feeders in Conventional rice fields.

Bala et al., (2018) supported this finding in Kaipad and observed that surviving larvae and population of rice leaf folder decreased due to high potassium application. Similarly, Pramanick et al., (1995), Narayansamy et al., (1976) and Venugopal (1987) also recorded that, the incidence of green leafhoppers, yellow stem borer, leaf folder and ear head bug was significantly lower in fields that received high rates of potash. Samiayyan and Janarthanan (1988) revealed that the application of potassium enhances the protein synthesis and thus, reducing amino acid content in the sap there by making the plant less favorable for the reproduction of sucking pests. This may be the reason for lower incidence of sap feeders in the present study also. In contrast, Rashid et al., (2017a and b) noted that potassium fertilizers had no significant effect on Brown plant hopper.

Micronutrients and abundance of insect pests

Besides primary macronutrients some secondary macronutrients and micronutrients also influence the pest population. The incidence of leaf defoliators, leaf folders, sap feeders, and stem borers showed non significant negative correlation with the amount of leaf calcium in Conventional rice fields. In the Kaipad fields also, the incidence of leaf case worm, leaf defoliators, leaf gall midges are negatively (non significant) correlated with the leaf calcium content. The incidence of leaf defoliators, leaf folders, leaf gall midges, sap feeders, pest larval stage and pest pupal stage showed non significant negative correlation with leaf sulfur content in Conventional rice fields. The abundance of leaf folders, sap feeders (significant), grain sap feeders, stem borers, pest egg stage, pest larval stage and pest adult stage showed negative correlation with the leaf Sulfur in Kaipad rice fields. Bala et al., (2018) has observed that secondary macronutrients and micronutrients like Calcium, Zinc and Sulfur also reduce the pest populations.

Leaf Manganese and abundance of insect pests

The abundance of leaf defoliators, leaf folders, sap feeders, grain sap feeders, and stem borers showed non significant negative correlation with leaf manganese content in Conventional rice fields of the present study, while the abundance of leaf case makers, leaf folders, leaf gall maker, sap feeders, grain sap feeders, stem borers

are negatively correlated (non significant) with leaf manganese content in Kaipad rice fields. These results are supported by Shahar (2018), i.e., chronic exposures to Mn, even at below toxic level, cause negative impact on abundance, behavior and foraging activity of insects.

Leaf Zinc and abundance of insect pests

The results of the present study shows that the incidence of leaf case maker, leaf defoliators, leaf folders, and sap feeders showed non significant negative correlation with leaf zinc in Conventional rice fields. While the abundance of leaf gall maker, grain sap feeder, and stem borer are positively correlated (non significant) with leaf zinc. In Kaipad rice fields, the incidence of leaf folders, sap feeders, grain sap feeders, stem borers, showed significant negative correlation with leaf zinc. While leaf case maker, leaf gall maker, and leaf defoliator showed significant positive correlation with the amount of leaf zinc in Kaipad rice fields. Bala et al, (2018) and Sarwar (2011) also observed that the brown plant hopper (sap feeder) and stem borer population decreased with increase in leaf Zinc content, and which is similar to the present study. Shu et al., (2009) also noticed that, in *Spodoptera litura*, the oviposition rate, fecundity and hatchability of female adults treated with high amount of Zn/kg were significantly lower.

Leaf Copper and abundance of insect pests

In the present study, the abundance of pest larval stages and nymphal stages showed non significant negative correlation with leaf Copper in Conventional rice fields. Kozlov et al., (2000) reported that larval weight and feeding efficiency leaf mining larvae of *Eriocrania semipurpurella* decreased with an increase in foliar concentrations of Copper, i.e. negatively correlated, and which support the present findings in Conventional rice fields.

Leaf Boron and abundance of insect pests

In Conventional rice fields, the abundance of leaf defoliators, leaf folders, sap feeders, grain sap feeders, and stem borers are negatively correlated with leaf boron. In Kaipad fields also, the abundance of different developmental stages of leaf folders, sap feeders, grain sap feeders, and stem borers, pest adults are significantly negatively correlated with the leaf boron content. Margaret and Grace (2006) has

also noted that although boron is an essential nutrient, it can be toxic at higher concentrations reducing the abundance of insect pests.

The abundance of Pest and parasitoids

The abundance of parasitoids on plants that harbor their herbivorous host often correlates with host numbers.

In the present study in conventional and Kaipad rice fields, the abundance of larval and pupal parasitoids showed significant and non significant positive correlation with the abundance of their hosts, viz. leaf defoliators, leaf gall midges, grain sap feeders and stem borers. Kishinevsky et al., (2017) documented that the abundance of three parasitoid species showed significant and positive correlation with the abundance of *B. tabaci* on plants. Lane et al., (1999) revealed that the parasitoids with higher fecundity will provide better control of their hosts, and will thus be better biological control agents. The fecundity of parasitoids is correlated positively with their ability to suppress host population.

In Conventional rice fields, the abundance of stem borers showed significant positive correlation with egg parasitoids and larval parasitoid. Their abundance showed significant positive correlation with egg-larval-pupal parasitoids in Kaipad rice fields. Parasappa et al., (2017) also recorded positive correlation between stem borers and hymenopterans with significant difference. They also reported sap feeders (white backed plant hopper) and leaf defoliators (skipper, caseworm, rice hispa and grass hopper) showed positive non-significant correlation with parasitoids, which is similar to the observations in the present study in Kaipad rice fields, i.e., the abundance of leaf defoliators and sap feeders are positively correlated with their egg and larval parasitoids. The abundance of leaf defoliators showed significant positive relation with the pupal parasitoids in Conventional rice fields.

The present study indicates that physico-chemical parameters of soil, water and leaf does influence the incidence of insect pests thereby influencing the species richness and abundance of parasitoids. It is also recommended that following good cultivation practices in conventional and Kaipad rice fields with addition of optimal amount of plant nutrients may help in ensuring better plant health and lower level of pest attack resulting in enhanced crop yield.

CONCLUSION

- Atmospheric maximum temperature, Surface water temperature, Bottom water temperature, Water salinity, Water EC, Water COD, Water K, Water Ca, and Water S, showed significant difference between months in Kaipad and Conventional rice fields.
- Water Total hardness, Water Mg, Soil Fe, Leaf Fe and Leaf B was significantly different between months in Kaipad rice fields only.
- Water pH, Water Turbidity, Water N, and Water P showed significant difference between months in Conventional rice fields only.
- Among water parameters, Salinity, EC, COD, Hardness, Turbidity, Nitrate, Potassium, Calcium, Magnesium and Sulfate are significantly different between Kaipad and Conventional rice fields.
- Among Soil parameters, EC, Nitrogen, Phosphorus, Calcium, Magnesium, Sulfur and Boron showed significant difference between Kaipad and Conventional rice fields.
- Iron, Manganese, Zinc, Copper and Boron in leaves showed significant difference between Kaipad and Conventional rice fields.
- The studies on this aspect is lacking in Kaipad rice fields, and the findings will help farmers in improving the yield by input and reduction of various nutrients which are recorded to be below or above the acceptable limit needed for normal rice growth.
- As no adverse effect on growth of rice varieties in Kaipad rice fields due to deficiency/excess concentration of nutrients are noted, further studies need to be taken up to understand the adaptability of these rice varieties and mode of cultivation in helping the rice plants to maintain healthy plant growth and yield.
- 22 species of insect pests were recorded during the present study. The pests *Cofana spectra*, *Nilaparvata lugens*, *Psalis pennatula*, *Recilia dorsalis*, *Sogatella frucifera* and *Stenchaetothrips biformis* are recorded from Conventional fields only.

- In every month, the adult stage is dominant than other immature stages in both categories of rice fields.
- In Conventional and Kaipad rice fields, leaf defoliators are dominant. They are predominant during the study period in both categories of rice fields.
- The abundance of leaf case makers, leaf defoliators, leaf folders, leaf gall midges, sap feeders, grain sap feeders are significantly different, but stem borers abundance did not show any significant difference between Kaipad and Conventional rice fields.
- The pests, *Hieroglyphus banian*, *Leptocorisa acuta*, *Marasmia patnalis*, *Melanitis leda*, *Nephotettix nigopictus*, *Orseolia oryzae*, *Paraponyx stagnalis*, *Pelopidas mathias*, *Scirpophaga incertulas*, *Scirpophaga innotata*, *Scotinophara coarctata*, and *Spodoptera mauritia* showed significant difference in their abundance between Kaipad and Conventional rice fields.
- The present study provides the baseline data of various pests infesting rice at different stages of rice growth, when cultivated conventionally and in Kaipad. This will help farmers, researchers, Krishibhavadans to formulate proper methods of pest control before the specific pest establishes in the field.
- Study reports that the abundance and diversity of insect pests are lower in Kaipad rice fields than in Conventional one.
- 171 species of parasitoid are recorded during the present study in Conventional and Kaipad rice fields.
- The abundance of Egg parasitoids, larval parasitoids, Pupal parasitoids are significantly different between Kaipad and Conventional rice fields.
- There is variation in the species richness and abundance of parasitoids across years and months.
- The lower abundance and diversity of insect pests in Kaipad rice fields may be the reason for lower abundance and diversity of hymenopteran parasitoids in Kaipad rice fields.
- The study reiterates the need to opt trap cropping for managing rice stem borer, *S. innotata*. The possibility of using the *E. dulcis* as a trap plant in conventional rice fields also needs to be explored.

- Atmospheric temperature showed negative correlation with egg, larva, pupa, adult, leaf defoliators, leaf folders, leaf gall midges, sap feeders, stem borers, overall pests, egg parasitoids, larval parasitoids, pupal parasitoids and overall parasitoids. While incidence of leaf case maker and grain sap feeder are positively correlated with atmospheric temperature in conventional rice fields.
- Atmospheric temperature was negatively correlated with the incidence of larva, pupa, leaf case maker, leaf defoliators, leaf folders, leaf gall midges, egg parasitoids, and larval parasitoids. While the abundance of egg, adult, sap feeders, grain sap feeders, and stem borers showed non-significant positive correlation with atmospheric temperature in Kaipad rice fields.
- Significant and non significant positive correlation was observed between different leaf parameters and pest abundance in Conventional and Kaipad rice fields.
- Significant positive correlation was noted between the abundance of stem borers and the abundance of their egg, larval and pupal parasitoids.
- The present study sheds light on the pest and parasitoid diversity in conventional and Kaipad rice fields and their possible relationship with physico-chemical parameters. These observations may help farmers to develop better crop management strategies.

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**വടക്കൻ കേരളത്തിലെ തിരഞ്ഞെടുത്ത പരമ്പരാഗത,
കൈപ്പാട്നെൽവയലുകളിലെ ഭൗതിക -രാസപരമായഘടകങ്ങൾ, കീടങ്ങൾ,
പരന്നഭോജികൾ എന്നിവയുടെ വൈവിധ്യം**

വികസ്വരരാജ്യങ്ങളിൽ കൃഷി ചെയ്യുന്ന നെല്ല് ഏഷ്യയിലെയും ആഫ്രിക്കയിലെയും 100 ദശലക്ഷത്തിലധികം കുടുംബങ്ങളുടെ പ്രാഥമികവരുമാനവും തൊഴിലവസരവുമാണ്. സംസ്ഥാനത്തെ ഏറ്റവും പ്രധാനപ്പെട്ട ഏകധാന്യമായ നെല്ല്, കേരളത്തിലുടനീളമുള്ള വ്യത്യസ്ത കാർഷിക ആവാസവ്യവസ്ഥകളിൽ കൃഷിചെയ്യുന്നു.

കോഴിക്കോട്, കണ്ണൂർ, കാസർകോട് ജില്ലകളിലായി വ്യാപിച്ചു കിടക്കുന്ന വടക്കൻ കേരളത്തിലെ ലവണാംശം ബാധിച്ച പ്രകൃതിദത്തമായ ജൈവഉൽപ്പാദനകേന്ദ്രമായ കൈപ്പാട് ഒരു അതുല്യമായ തീരദേശ തണ്ണീർത്തട നെല്ല്പാദന സംവിധാനമാണ്. ജൈവപദാർത്ഥങ്ങളാൽ സമ്പന്നമായ തീരദേശ ഉപ്പുവെള്ള ചതുപ്പനിലങ്ങളിൽ നെൽക്കൃഷിയും അക്വാകൾച്ചറും ഒരുമിച്ച്പോകുന്നു. “കായൽപാടം” എന്നതിന്റെ ചുരുക്ക രൂപമാണുകൈപ്പാട്. ‘കായൽ’, ‘പാടം’ എന്നിവ യഥാക്രമം ‘ഉപ്പുവെള്ളപ്രദേശം’, ‘നെൽവയൽ’ എന്നീ രണ്ട് മലയാള പദങ്ങളാണ്. കൈപ്പാട് പ്രദേശത്തിന്റെ വിസ്തീർണ്ണം ഏകദേശം 4100 ഹെക്ടറാണ്.

വേലിയേറ്റവും വേലിയിറക്കവും ദിവസത്തിൽ രണ്ടുതവണ കൈപ്പാടിനെ ബാധിക്കുന്നു, ജൂൺ മുതൽ ഒക്ടോബർ വരെയുള്ള കാലയളവിൽ ഉൽപ്പാദനചക്രത്തിന്റെ കുറഞ്ഞ മുതൽ ഇടത്തരം ഉപ്പുവെള്ളഘട്ടത്തിൽ പ്രത്യേകരീതിയിൽ നടത്തുകയും ഒക്ടോബർ അവസാനത്തോടെ വിളവെടുപ്പ് നടത്തുകയും ചെയ്യുന്നു. പിന്നീടുള്ള മാസങ്ങളിൽ, അതായത് നവംബർ മുതൽ ഏപ്രിൽ വരെയുള്ള മാസങ്ങളിൽ, ഉയർന്നലവണാംശമുള്ള ഘട്ടത്തിൽ പരമ്പരാഗത മത്സ്യബന്ധനം നടക്കുന്നു. ആനുകാലികമായ വേലിയേറ്റവും സമീപമലയോരങ്ങളിൽ നിന്ന് ഒഴുകുന്ന മഴവെള്ളവും ജൈവവസ്തുക്കളാൽ നിറഞ്ഞതും കൂടാതെ നെൽക്കമ്പികളുടെയും മത്സ്യവിസർജ്ജ്യങ്ങളുടെയും അവശിഷ്ടങ്ങൾ ദ്രവിച്ചും ഭൂമിയുടെ ഫലഭൂയിഷ്ഠത്വ സ്വാഭാവികമായി നിലനിർത്തുന്നു.

കുതിര്, ഓർകഴമ എന്നീ രണ്ട് പരമ്പരാഗത നെല്ല്പിനങ്ങളാണ് ഇവിടെ കൃഷിചെയ്യുന്നത്. കൈപ്പാട് നെല്പ്പാടങ്ങളിൽ മുന്പ് ഉപയോഗിച്ചിരുന്ന മറ്റ് ഇനങ്ങൾ ഓർത്തടിയൻ, മുണ്ടോൺ, കട്ടുസൻ തുടങ്ങിയവയാണ്. ഏഴോം 1, ഏഴോം 2, ഏഴോം

3, ഏഴോ 4 എന്നിവ കേരളകാർഷിക സർവകലാശാല വികസിപ്പിച്ചെടുത്ത പുതിയ ഇനങ്ങളാണ്.

വടക്കൻ കേരളത്തിലെ സാധാരണ നെൽകൃഷിയും കൈപ്പാട് നെൽകൃഷിയും തമ്മിലുള്ള ഒരു താരതമ്യ പഠനമാണിത്. പ്രധാനമായും കീടങ്ങളെയും അവയുടെ മിത്രകീടങ്ങളെയും കേന്ദ്രീകരിച്ചിട്ടുള്ള പഠനം. സാധാരണ നെൽകൃഷിയുമായി ബന്ധപ്പെട്ട പഠനത്തിനായി കൈവേലി, മുണ്ടേരിമൊട്ട, കീഴറ, പെരിയാട്, കുതിരപ്പുറം, മംഗലശ്ശേരി എന്നീസ്ഥലങ്ങളും കൈപ്പാട്നെൽകൃഷിപഠനം നടത്താൻ ഏഴോ, മുണ്ടേരിക്കടവ്, കൈത്തിൽ, വെള്ളിക്കീൽ, മുളളൂൽ, പട്ടുവം എന്നീ സ്ഥലങ്ങളും തിരഞ്ഞെടുത്തു. 2015 ജൂൺ മുതൽ 2017 ഒക്ടോബർ വരെ ആയിരുന്നു ഫീൽഡ് പഠനം. 2014 മുതൽ പ്രാഥമികപഠനം നടത്തിയിരുന്നു.

ഒന്നാമത്തെ അദ്ധ്യായത്തിൽ രണ്ടുതരം കൃഷിസ്ഥലത്തെയും ജലം, മണ്ണ്, സസ്യം എന്നിവ പരിശോധിച്ചു. ജൂൺ മുതൽ ഒക്ടോബർ വരെ ഉള്ള മാസങ്ങളിലായി മൂന്നുവർഷം അത് ആവർത്തിച്ചു. ജലോപരിതല ഊഷ്മാവ്, അന്തർജ്ജല ഊഷ്മാവ്, പിഎച്, ഉപ്പിന്റെ അംശം, ഇലക്ട്രോണുകളുടെ ചാലകത, അലിഞ്ഞുചേർന്ന ഓക്സിജൻ, രാസ ഓക്സിജൻ ആവശ്യകത, ആകെ കാഠിന്യം, ജലപ്രതിരൂപം, നൈട്രേറ്റ്, ഫോസ്ഫേറ്റ്, പൊട്ടാസിയം, കാൽസ്യം, മഗ്നീഷ്യം, സൾഫേറ്റ് എന്നീ കാര്യങ്ങൾ ജലത്തിൽ പരിശോധിച്ചു. പിഎച്, ഇലക്ട്രോണുകളുടെ ചാലകത, ലഭ്യമായ നൈട്രജൻ, ഫോസ്ഫറസ്, പൊട്ടാസ്യം, കാൽസ്യം, മഗ്നീഷ്യം, സൾഫർ, അയേൺ, മാങ്കനീസ്, സിങ്ക്, കോപ്പർ, ബോറോൺ എന്നീ ഘടകങ്ങൾ മണ്ണിലും പരിശോധിച്ചു. ഇലയിൽ അടങ്ങിയിട്ടുള്ള ആകെയുള്ള നൈട്രജൻ, ഫോസ്ഫറസ്, പൊട്ടാസ്യം, കാൽസ്യം, മഗ്നീഷ്യം, സൾഫർ, അയേൺ, മാങ്കനീസ്, സിങ്ക്, കോപ്പർ, ബോറോൺ എന്നീ ഘടകങ്ങളും പരിശോധിച്ചു. അന്തരീക്ഷ താപനില, അന്തരീക്ഷ ഈർപ്പം എന്നീ ഘടകങ്ങളും ഈ കാലയളവിൽ ശേഖരിച്ചിരുന്നു.

രണ്ടാമത്തെ അദ്ധ്യായത്തിൽ പ്രധാനമായും പ്രാണികീടങ്ങളുടെ നിരീക്ഷണം ആയിരുന്നു. അവയുടെ മുട്ട, പൂഴ്, പൂപ്പ, അഡൽറ്റ് വിഭാഗത്തിൽപ്പെട്ടവ ഏതൊക്കെ ഉണ്ടെന്നും എത്ര എണ്ണം ഉണ്ടെന്നും ജൂൺ മുതൽ ഒക്ടോബർ ഉള്ള കാലയളവിൽ (നെൽകൃഷി നടത്തുന്ന മാസങ്ങൾ) രണ്ടുതരത്തിലുള്ള കൃഷിസ്ഥലങ്ങളിലും മൂന്നുവർഷം പരിശോധിക്കുക ഉണ്ടായി കോഡറേറ്റ്സാംപ്ലിങ് പ്രീതിയാണ് സാധാരണ നെൽകൃഷി ചെയ്യുന്നിടത്തും കൈപ്പാടും ഉപയോഗിച്ചത്. കീടങ്ങളെ വിദഗ്ദ്ധരുടെ സഹായത്തോടെ തിരിച്ചറിഞ്ഞു.

സാധാരണ നെൽക്കൃഷിയിലും കൈപ്പാട്നെൽക്കൃഷിയിലും മിത്ര കീടങ്ങളുടെ വൈവിധ്യം എത്രമാത്രം വ്യത്യാസം ഉണ്ട് എന്നാണുനാമത്തെ അധ്യായത്തിൽ പരിശോധിച്ചത്.

മൂന്നുവർഷങ്ങളിൽ നെൽകൃഷി ചെയ്യുന്ന ജൂൺ മുതൽ ഒക്ടോബർ വരെയുള്ള മാസങ്ങളിൽ പരിശോധന നടത്തി. "സ്പീഷേറ്റിങ് " രീതിയാണത്രെ കീടങ്ങളെ ശേഖരിക്കാൻ ഉപയോഗിച്ചത് ..ശേഖരിച്ചവയെ വിദഗ്ദ്ധരുടെ സഹായത്തോടെ തിരിച്ചറിഞ്ഞു.

കൈപ്പാട്മുണ്ടേരിക്കടവ് മേഖലയിലെ ചില കൃഷിയിടങ്ങളിൽ നടത്തിയ കെണിവിള സംബന്ധിച്ച പഠനമായിരുന്നു നാലാമത്തെ അധ്യായം. പ്രാഥമിക പഠനസമയത്ത് അവിചാരിതമായി ശ്രദ്ധയിൽപെട്ട ഒരു സസ്യമാണ് "എലിയോചാരിസ്ഡാൽഷിസ്". നെൽപ്പാടങ്ങളിൽ കൂടുതലായി കണ്ടുവരുന്ന വെളുത്തതണ്ടുതുരപ്പൻ കീടങ്ങളെ ഈസസ്യങ്ങളിൽ നെല്ലിൽ കാണുന്നതിനേക്കാൾ കൂടുതൽ എന്നതിൽ കാണപ്പെട്ടു.

ഈ ഒരു നിരീക്ഷണത്തിന്റെ അടിസ്ഥാനത്തിൽ ഈ ഒരു കെണിവിളയെക്കുറിച്ച് കൂടുതൽ പഠനം നടത്തി. പ്രധാന വിളയായ നെല്ലിലും കെണിവിളയായ എലിയോചാരിസ്ഡാൽഷിസ് എന്ന സസ്യത്തിലും വെളുത്ത തണ്ടുതുരപ്പൻ കീടത്തിന്റെ മുട്ട, അഡൽറ്റ് എന്നിവയുടെ എണ്ണം, ഓരോ മാസത്തിൽ ഇവയുടെ എണ്ണത്തിലുള്ള വ്യത്യാസം, ഇടുന്ന മുട്ടയുടെ എണ്ണത്തിൽ ഉള്ള വ്യത്യാസം, മുട്ടയിൽ നിന്നും വരുന്ന പുഴുക്കളുടെ എണ്ണത്തിലുള്ള വ്യത്യാസം, മുട്ടവിരിയുന്ന അനുപാതത്തിലുള്ള വ്യത്യാസം, മുട്ടപിണ്ഡത്തിന്റെ ഏരിയ വ്യത്യാസം എന്നിവ വിശദമായി പഠിച്ചു.

അന്തരീക്ഷ ഘടകങ്ങൾ കീടങ്ങളുടെയും മിത്രകീടങ്ങളുടെയും സാന്നിധ്യത്തെ എങ്ങനെ ബാധിക്കുന്നു, സസ്യഘടകങ്ങൾ കീടങ്ങളുടെ സാന്നിധ്യത്തെ എങ്ങനെ ബാധിക്കുന്നു, കീടങ്ങളുടെ സാന്നിധ്യവും മിത്രകീടങ്ങളുടെ എണ്ണവും തമ്മിലുള്ള ബന്ധം എന്നിവ അഞ്ചാമത്തെ അധ്യായത്തിൽ പ്രതിപാദിക്കുന്നു.

ഈവശം സംബന്ധിച്ച പഠനങ്ങൾ കൈപ്പാട്നെൽവയലുകളിൽ കുറവാണ്, കൂടാതെ സാധാരണ നെല്ലുളർച്ചയ്ക്ക് ആവശ്യമായ സ്വീകാര്യമായ പരിധിക്ക് താഴെയോ അതിൽ കൂടുതലോ രേഖപ്പെടുത്തിയിട്ടുള്ള വിവിധ പോഷകങ്ങളുടെ കൂടുതൽ ഉപയോഗം , ഉപയോഗം കുറയ്ക്കൽ എന്നിവയിലൂടെ വിളവ് മെച്ചപ്പെടുത്തുന്നതിന് ഈ കണ്ടെത്തലുകൾ കർഷകരെ സഹായിക്കും. കൈപ്പാട്നെൽവയലുകളിൽ പോഷകങ്ങളുടെ കുറവ്/അധികസാന്ദ്രതകാരണം നെല്ലിന്റെ വളർച്ചയെ പ്രതികൂലമായി ബാധിക്കാത്തതിനാൽ, നെൽച്ചെടികളെ പരിപാലിക്കാൻ സഹായിക്കുന്ന ഈ

നെല്ലിനങ്ങളുടെ അനുയോജ്യതയും കൃഷിരീതിയും മനസ്സിലാക്കാൻ കൂടുതൽ പഠനങ്ങൾ ആവശ്യമാണ്.

കൈപ്പാട്നെൽവയലുകളിൽ പ്രാണികീടങ്ങളുടെ സമൃദ്ധിയും വൈവിധ്യവും പരമ്പരാഗത നെൽവയലുകളേക്കാൾ കുറവായെന്നു പറയാൻ റിപ്പോർട്ട്. 22 ഇനം പ്രാണികളുടെ കീടങ്ങളാണ് ഈ പഠനത്തിൽ രേഖപ്പെടുത്തിയിരിക്കുന്നത്. കോഫാന സ്പെക്ട്ര, നിലപർവ്വത ല്യൂജൻസ്, സാലിസ്പെനാറ്റ, റെസിലിയ ഡോർസാലിസ്, സൊഗറേല്ല പ്രൂസിഫെറ, സ്റ്റേൻചാറ്റോത്രിപ്റ്റ്ബൈഫോർമിസ് എന്നീ കീടങ്ങൾ പരമ്പരാഗത വയലുകളിൽ നിന്ന് മാത്രം രേഖപ്പെടുത്തിയിട്ടുണ്ട്. എല്ലാ മാസത്തിലും, രണ്ടിടാഗങ്ങളിലെ നെൽവയലുകളിലും പ്രായപൂർത്തിയായ ഘട്ടം മറ്റ് പക്വതയില്ലാത്ത ഘട്ടങ്ങളെ അപേക്ഷിച്ച് പ്രബലമാണ്. പരമ്പരാഗത നെൽവയലുകളിലും കൈപ്പാട്നെൽവയലുകളിലും ഇല ഭക്ഷിക്കുന്ന കീടങ്ങൾ കൂടുതലായി കാണപ്പെടുന്നത്.

സർവ്വേ നടത്തിയ മൂന്നു വർഷങ്ങളിലും ജൂൺ മുതൽ ഒക്ടോബർ വരെയുള്ള മാസങ്ങളിലും നെൽവയലുകളുടെ രണ്ടിടാഗങ്ങളിലും ഇവ പ്രബലമാണ്. കീട ഇനങ്ങളിൽ, ലീഫ്ഫോൾഡിംഗ് കറുപ്പുകൾ, ലീഫ് ഡിഫോളിയേറ്റുകൾ, ലീഫ് ഫോൾ ഡറുകൾ, ലീഫ് ഗാൾമിഡ്ജുകൾ, ബ്രൂം തീറ്റുകൾ, ധാന്യബ്രൂം തീറ്റുകൾ എന്നിവ പരമ്പരാഗത, കൈപ്പാട്നെൽ വയലുകളിൽ കാര്യമായ വ്യത്യാസമുണ്ട്. എന്നാൽ തണ്ടുതൂപ്പന്മാർ കാര്യമായ വ്യത്യാസം കാണിച്ചില്ല. കീടങ്ങളിൽ, ഹൈറോഗ്ലിഫസ് ബനിയൻ, ലെപ്റ്റോകോറിസ അക്വട്ട, മരസ്സിയ പട്നാലിസ്, മെലാനിറ്റിസ്സെഡ, നെഫോട്ടെറ്റിക്സ് ഗ്രോപിക്ലസ്, ഓർസിയോലിയ ഒറിസെ, പാരാപോണിക്സ് റ്റാഗാലിസ്, പെലോപിഡാ സൂത്തിയാസ്, സിർപ്പൊഫഗാ ഇൻസെർട്ടാസ്, സിർപ്പൊഫഗാ ഇനോടേറ്റ, സ്കോട്ടിനോഫറാ കോയർക്ലേറ്റ, സ്പോടോപ്റ്റെ റൗറിഷ്യ എന്നിവയും, മൊത്തത്തിലുള്ള കീടങ്ങളുടെ എണ്ണവും പരമ്പരാഗതമായ നെൽക്കൃഷിയിലും, കൈപ്പാട്കൃഷിയിലും തമ്മിൽ കാര്യമായ വ്യത്യാസം കാണിക്കുന്നുണ്ട്.

പരമ്പരാഗത രീതിയിലും കൈപ്പാടിയിലും കൃഷിചെയ്യുമ്പോൾ, നെല്ലിന്റെ വളർച്ചയുടെ വിവിധ ഘട്ടങ്ങളിൽ നെല്ലിനെ ബാധിക്കുന്ന വിവിധ കീടങ്ങളുടെ അടിസ്ഥാനവിവരങ്ങൾ നിലവിലെ പഠനം നൽകുന്നു. കർഷകർ, ഗവേഷകർ, കൃഷിഭവനങ്ങൾ എന്നിവരെ കൃഷിയിടത്തിൽ പ്രത്യേക കീടങ്ങൾ സ്ഥാപിക്കുന്നതിനുവേണ്ടി കീടനിയന്ത്രണത്തിനുള്ള ശരിയായ രീതികൾ രൂപപ്പെടുത്താൻ ഇത് സഹായിക്കും.

പരമ്പരാഗത, കൈപ്പാട്നെൽവയലുകളിൽ 171 ഇനം മിത്രകീടങ്ങൾ ഈ പഠനത്തിൽ രേഖപ്പെടുത്തിയിട്ടുണ്ട്. മുട്ട പരാനഭോജികൾ, ലാർവ പരാനഭോജികൾ,

പൂപ്പൽ പരാനഭോജികൾ, മൊത്തത്തിലുള്ള പരാനഭോജികൾ എന്നിവയുടെ സമൃദ്ധിയിൽ കൈപ്പാടും പരമ്പരാഗതനെൽവയലുകളും തമ്മിൽ കാര്യമായ വ്യത്യാസമുണ്ട്. വർഷങ്ങളിലും മാസങ്ങളിലും പരാനഭോജികളുടെ സമൃദ്ധിയിലും സമൃദ്ധിയിലും വ്യത്യാസമുണ്ട്. കൈപ്പാട്നെൽവയലുകളിൽ പ്രാണികീടങ്ങളുടെ എണ്ണവും വൈവിധ്യവും കുറവായതുകൊണ്ടായിരിക്കാം അവിടെ പരാനഭോജികളുടെ സമൃദ്ധിക്കും വൈവിധ്യത്തിനും കുറവുരാൻ കാരണം.

തണ്ടുതുരപ്പൻ കീടത്തെ നിയന്ത്രിക്കുന്നതിനുകെണിവിള തിരഞ്ഞെടുക്കേണ്ടതിന്റെ ആവശ്യകത അനിവാര്യമാണ് അക്കാര്യാത്തിൽ ഒരുപാട്ഭാവിപാതം ആവശ്യമാണ്. പരമ്പരാഗത നെൽവയലുകളിൽ കെണിവിളയായി എലിയോചാരിസ്ഡൽസിസ് ഉപയോഗിക്കുന്നതിനുള്ള സാധ്യതയും അന്വേഷിക്കേണ്ടതുണ്ട്.

പ്രകൃതിദത്ത ശത്രുക്കളുടെ (പാരസൈറ്റോയ്ഡ്സ്) വൈവിധ്യത്തിന്റെയും സമൃദ്ധിയുടെയും അടിസ്ഥാനത്തിൽ നൽകിയിരിക്കുന്ന വിവരങ്ങൾവെച്ച് പ്രകൃതിദത്ത ശത്രുക്കൾ പരിസ്ഥിതിയോട് എത്രത്തോളം സൗഹൃദപരമായ ഒന്നാണെന്നും അവ എത്രത്തോളം പ്രോയോജനപ്രദമാണെന്നും വിലയിരുത്താൻ ഇപ്പോഴത്തെ പഠനത്തിനുകഴിയുന്നു. ജൈവവൈവിധ്യനിരീക്ഷണം സമയവും അധ്വാനവും ആവശ്യമുള്ളതിനാൽ, ജൈവവൈവിധ്യത്തിന്റെ നിലവാരവും പരിസ്ഥിതികമായ പ്രവർത്തനരീതികളും പ്രതിഫലിപ്പിക്കുന്ന സൂചകസ്പീഷീസുകളെ തിരിച്ചറിയുന്നത് അഭികാമ്യമാണ്.

ABSTRACT

This is a comparative study of physico-chemical parameters, pest incidence and parasitoid diversity between Conventional and Kaipad rice cultivation in North Kerala. Kaipad is a salinity-affected natural organic production tract in northern Kerala spread over Kozhikode, Kannur and Kasargode districts where cultivation and aquaculture go hand in hand.

In the first chapter, the physico-chemical parameters of water and soil, chemical parameters of leaves of both types of rice fields were examined. It was done for three years in the months from June to October i.e. the rice cultivation period. Atmospheric temperature and atmospheric humidity were also checked during this period. Atmospheric maximum temperature, Surface water temperature, Bottom water temperature, Water salinity, Water EC, Water COD, Water K, Water Ca, and Water S, showed significant difference between months in Kaipad and Conventional rice fields. Water Total hardness, Water Mg, Soil Fe, Leaf Fe and Leaf B was significantly different between months in Kaipad rice fields only. Water pH, Water Turbidity, Water N, and Water P showed significant difference between months in Conventional rice fields only. Among water parameters, Salinity, EC, COD, Hardness, Turbidity, Nitrate, Potassium, Calcium, Magnesium and Sulfate are significantly different between Kaipad and Conventional rice fields. Among Soil parameters, EC, Nitrogen, Phosphorus, Calcium, Magnesium, Sulfur and Boron showed significant difference between Kaipad and Conventional rice fields. Studies related to this aspect are less in Kaipad rice fields and these findings will help the farmers to improve the yield by increasing and reducing the use of various nutrients that are below or above the acceptable limit required for normal rice growth. As no adverse effect on growth of rice varieties in Kaipad rice fields due to deficiency/excess concentration of nutrients are noted, further studies need to be taken up to understand the adaptability of these rice varieties and mode of cultivation in helping the rice plants to maintain healthy plant growth and yield.

In the second chapter, the egg, larva, pupa and adult stages of insect pests were checked in the period from June to October (the months of rice cultivation) for three years in two types of rice cultivation areas. Study reports that the abundance and diversity of insect pests are lower in Kaipad rice fields than in Conventional one. Leaf-feeding pests were more common in Conventional rice fields and Kaipad rice fields. Among the pest species, the abundance of leaf casemakers, leaf defoliators, leaf folders, leaf gall midges, sap feeders and grain sap feeders differed significantly between conventional and Kaipad rice fields. But stem borers abundance was not significantly different. The present study provides basic information on various pests affecting rice at different stages of its growth under both Kaipad and Conventional rice cultivation. It will help farmers, researchers and other officials to develop proper methods of pest control before establishing specific pests in the field.

In the third chapter, the diversity of parasitoids in Conventional and Kaipad rice cultivation was analysed. 171 species of parasitoid are recorded during the present study in Conventional and Kaipad rice fields. The abundance of Egg parasitoids, larval parasitoids, Pupal parasitoids and Total parasitoids are significantly different between Kaipad and Conventional rice fields. There is variation in the species richness and abundance of parasitoids across years and months. The lower abundance and diversity of insect pests in Kaipad rice fields may be the reason for lower abundance and diversity of hymenopteran parasitoids in Kaipad rice fields.

The fourth chapter was a study about a trap crop, *Eleocharis dulcis* which is seen in Munderikkadavu region of Kaipad. The white stem borer, which is more common in rice fields, was found in these plants more than in rice. The number of white stem borer eggs and adults in the main crop rice and the trap crop *Eleocharis dulcis*, the difference in their number in each month, the difference in the number of eggs laid, the difference in hatching time, and the area of the egg masses were studied in detail. The study reiterates the need to opt trap cropping for managing rice

stem borer, *S. innotata*. The possibility of using the *E. dulcis* as a trap plant in conventional rice fields also need to be explored.

Chapter five describes how atmospheric factors affect the presence of pests and parasitoids, how plant factors affect the presence of pests, and the relationship between the presence of pests and the number of their parasitoids. The present study indicates that physico-chemical parameters of soil, water and leaf does influence the incidence of insect pests thereby influencing the species richness and abundance of parasitoids. It is also recommended that following good cultivation practices in conventional and Kaipad rice fields with addition of optimal amount of plant nutrients may help in ensuring better plant health and lower level of pest attack resulting in enhanced crop yield.

The present study emphasizes the maintenance of a healthy agroecosystem with adequate plant growth nutrients, parasitoids and management practices for human wellbeing.

RESEARCH PUBLICATIONS



Eleocharis dulcis (Burm.f) as a promising trap plant for the biocontrol of rice white stem borer, *Scirpophaga innotata* (Walker)

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HIGHLIGHTS

- The rice stem borer's use of trap plant, *Eleocharis dulcis* is examined.
- The trap plants had 20 times more egg clutches of stem borer than on rice plants.
- Egg functional traits and hatch rate are high in eggs on trap plants.
- Egg parasitism was low for eggs deposited on rice plant.
- No eggs hatched on the trap plants survived.

GRAPHICAL ABSTRACT



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ABSTRACT

The rice white stem borer, *Scirpophaga innotata* Walker (Family: Crambidae) is a major lepidopteran pest of rice from seedling to ear setting stage. Due to their hidden life style, no satisfactory means of control other than systemic pesticide application, habitat management, and egg parasitism have been prescribed yet. It is observed that *S. innotata* use a plant, the Chinese water chestnut (*Eleocharis dulcis* (Burm. F.)) (Family: Cyperaceae) for oviposition. We investigated why and how *S. innotata* is benefited by using *E. dulcis* for oviposition to prescribe it as a trap plant for managing the pest. We surveyed moths and egg clutches, and studied functional traits of eggs, egg hatching, and egg parasitism in eggs deposited on rice and the chestnut for three years in Kaipad rice fields of peninsular India. We observed 20 times more egg clutches on the chestnut than on rice. The egg density in clutches and hatching rate were high in eggs deposited on the chestnut. Egg parasitism was meager and restricted only to the eggs deposited on rice. However, no larvae hatched on the chestnut in the lab survived. The results suggest that *E. dulcis* could be a dead-end trap plant for biological control of *S. innotata*. We do not rule out the probability of the moth using *E. dulcis* for oviposition, escaping from egg parasitoids, and most importantly for rapid spread of neonates to rice. We recommend using *E. dulcis* as a trap plant to trap the eggs and removing them to manage this pest in rice fields.

1. Introduction

Habitat management has been suggested as an important strategy in integrated pest management (IPM) programs during late 1990s,

particularly in less biodiverse industrial countries and in monoculture systems of developing countries (Landis et al., 2000). After about 2 decades, habitat management is still considered a viable environment-friendly practice for management of pests and conservation of natural

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biological control, as the ecosystem service is outweighed by the ecosystem dis-service they render (Chang et al., 2019), such as when pests benefit from flowers or when plant species that are added to enhance natural biological diversity become weeds (Gillespie and Wratten, 2017). One important tool of habitat management specific for a pest species is finding and using trap plants in agroecosystems (Chang et al., 2019; Wan et al., 2016; Badenes-Perez, 2018; Sarkar et al., 2018). Trap cropping involves the use of alternative host plants to attract, intercept, and or retain targeted insect pests for the purpose of reducing damage to a main crop and is a method designed to reduce the impact of pest attack on the main crop (Shelton and Badenes-Perez, 2006; Grundy et al., 2004). The aim of trap cropping is not only to divert the pest away from the crop, but also to provide ecosystem services including shelter, nectar, alternative hosts, and pollen for the natural enemies (Gurrett et al., 2017), which can improve conservation biological control.

The use of trap cropping in agricultural systems can significantly reduce the amount of pesticides and crop damage (Cavanagh et al., 2009; Lu et al., 2009; Ulmer et al., 2020). Sharma et al. (2019) has reviewed the studies done on trap cropping in various cereal crops and has concluded that trap crops remain an important tool of integrated pest management. They recommend that future studies should work in a direction to find and promote alternate or trap host plants for managing key pests for cost-efficient and environmental-friendly cereal production, which at present rely predominantly on chemical pesticides. The

most important task in this is to find a trap crop that can attract the pest species for foraging or ovipositing. The second major task is to assess its suitability in existing agricultural practices of the crop, by examining whether they compete for space and resources with the main crop and so on. Differences in attractiveness could be based on a more attractive plant species or cultivar and/or a more preferred development stage of the same plant species (Hokkanen, 1991).

The stem borer, *Scirpophaga innotata* (Crambidae) is a major pest of rice in rice-growing Asian countries. It attacks the rice throughout the growing stages i.e., from seedling to ear setting stages. Its damage is assessed by symptoms of dead heart and white head (Banwo, 2002). In rice plants, *S. innotata* lays egg masses mostly on leaf blades and protect them with a mat of body hair. Within a day of emergence, stem borer larvae tunnel into rice tillers where they complete their development, and protected from most natural enemies (Khan et al., 1991). Around the world, the stem borers have been controlled by integrated pest management practices suitable for each species, but including the following basic outlay: 1) selection of an appropriate crop planting technique or scheme; 2) using insect pest resistant plants (Baloch and Abdullah, 2011); and 3) using natural enemies. Insecticides have less efficacy for controlling the notorious stem borers, including the white-stem borer of rice because chemicals are effective only during the very short period between egg-hatch and plant penetration (Nesbitt et al., 1975; Beevor et al., 1990; Howse et al., 1998). Van der Goot (1948)

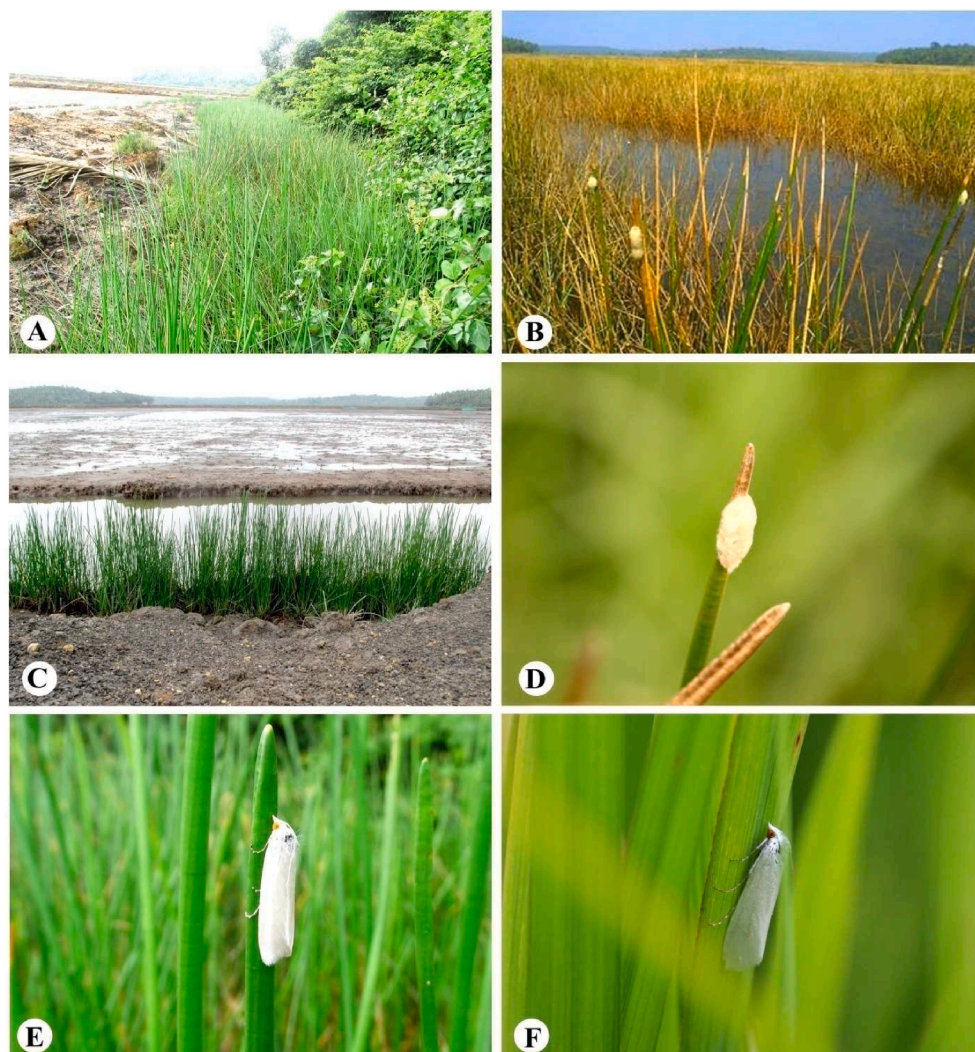


Fig. 1. The *Eleocharis dulcis* in the fallow rice field (A & C), The *E. dulcis* along with *Oryza sativa* in the field (B), The *Scirpophaga innotata* egg mass on *E. dulcis* (D), The *S. innotata* adult on *E. dulcis* (E), The *S. innotata* adult on *O. sativa*.

recorded three hymenopteran parasitoids, viz. *Telenomus rowani* (Gahan) (Scelionidae), *Tetrastichus schoenobii* Ferriere (Eulophidae), and *Trichogramma japonicum* Ashmead (Trichogrammatidae) as egg parasitoids of *S. innotata*.

Eleocharis dulcis (Cyperaceae) – the Chinese water chestnut – grows abundantly during the period of rice cultivation. It is a grass-like sedge that grows in marshes and has a stem-like, tubular pseudostem that grows to about 1.5 m (Fig. 1). *Scirpophaga innotata*, however, is attracted and oviposits on *E. dulcis* in rice fields of southern Andaman Islands (Ranganath et al., 2002). Gazalil and Ilhamiyah (2012) also noted its egg clutches on *E. dulcis* in Indonesian rice fields. However, both these studies have not assessed its use as a trap plant or quantified the fitness traits of the stem borer on *E. dulcis*. This study, through a quantitative assessment of the preference of *S. innotata* for *E. dulcis* as a potential oviposition site, inquires whether *E. dulcis* can be a potential trap crop to manage this pest in rice fields. We asked: 1) what is the abundance of adults and egg clutches of *S. innotata* on *O. sativa* and *E. dulcis*? 2) What is the egg- and larval fitness of *S. innotata* reared on *E. dulcis* and on *O. sativa* plants? 3) Whether the egg parasitism differed in egg clutches sampled from *O. sativa* and *E. dulcis*? We investigated this in the Kaipad rice cultivation system in peninsular India.

2. Material and methods

2.1. Kaipad rice cultivation system

It is a unique, coastal brackish wetland rice production system which is naturally organic (Vanaja, 2013). In Kaipad fields, rice is cultivated during low salinity phase (June - October) and shrimp/fish is cultivated in the high salinity phase (November - April) (Vanaja et al., 2009a, 2009b). Due to this peculiar agricultural practice, Kaipad farming is considered as a good model for sustainable integrated rice and fish cultivation. Agricultural activities begin by April by draining out saline water completely from the Kaipad field, later left to dry for a period of one month. After that, small mounds of mud approximately 45 cm diameter and 60 cm height are prepared for planting the rice. The mounds are prepared to minimize the salinity effect on germinated seeds.

The soil type of Kaipad area is saline hydromorphic (Swarajalakshmi et al., 2003), and the rich microflora in the soil helps in the rapid degradation of the biomass carried to the Kaipad region by rivulets and water currents (Nambiar and Raveendran, 2009). The environment created by shift in salinity of water, agriculture-aquaculture cycle, and drying makes Kaipad fields an inhospitable habitat for many conventional rice pests (Rajesh and Nasser personal observation). Kaipad rice fields covers ca. 4100 ha in north Malabar region of Kerala, i.e., Kasaragod, Kannur and Kozhikode in peninsular India.

The major Kaipad areas seen in North Malabar are Chengottukkavu (11.426 N, 75.726 E), Ulleri (11.436 N, 75.738E), Koyilandi (11.448 N, 75.724E), Pilicode (12.188 N, 75.152E), Padanna (12.178 N, 75.140E), Thrikkariapur (12.148 N, 75.155E), Udma (12.445 N, 75.015E), Kumbala (12.601 N, 74.943E), and Manjeswar (12.711 N, 74.888E).

2.2. Study area

We selected four Kaipad plots of Munderi Kadavu region in Kannur district, Kerala (11° 93' 7.137" N; 75° 42' 9.402" E) for the present study. The source of saline water in Kaipad fields of this region is Munderi Kadavu backwaters. The farmers here do cultivate rice in cent per cent organic mode with no chemical inputs either in the form of pesticide or in the form of fertilizer. Kaipad cultivation is practiced here for last several decades. *Kuthiru* and *Orkayama* are the traditional varieties of rice cultivated in the study area (Vanaja et al., 2009a, 2009b). Because the cultivars are native, pest incidence is low, except for the rice white stem borer, *S. innotata*. The Kaipad fields in this region covers 10 ha area, and it produces approximately 35–40 tons of rice annually. Fish

cultivation was not active during our survey period in this area. The nearest conventional rice fields are approximately 2 km away and hence, the agricultural practice followed in conventional field is unlikely to have an impact on the Kaipad fields. Cohen et al. (2000) have observed that the maximum distance moved by the neonate larvae of *S. innotata* by ballooning was 200–280 cm and hence, there is negligible chance of larvae moving in from the conventional rice fields. Our study spanned across three cultivation years – 2015, 2016 and 2017. Rice cultivation in Kaipad fields begins at the onset of southwest monsoon. The monsoon rainfall reduces salinity of water in Kaipad fields. During the study period, *Kuthiru* was the rice cultivar used in the study area.

Eleocharis dulcis grows abundantly in Munderi Kadavu field. They are seen in linear strips/clusters adjacent to the rice crop on two sides of the bund submerged in approximately 10 cm of water. The presence of *E. dulcis* is observed throughout the year but grow more densely during the rice cultivation season. Stem leaves are bladeless sheaths (Fig. 1). Plants produce horizontal rhizomes that terminate in rounded tubers. Each tuber produces a dense clump of erect, branchless, green stems, many of which are topped by a cylindrical, straw-brown, hermaphrodite inconspicuous flower spikelet (upto 2" long).

2.3. Sampling

We sampled the pest – adults and egg clutches – every month of the rice cultivating season – June–October, because it infests rice throughout its vegetative and productive phases. For counting egg mass and adult, quadrat sampling method was followed in the main crop (*O. sativa*) and trap crop (*E. dulcis*). Quadrates measuring 2 × 2 sq m were laid out in the four corners of the field for sampling both from rice and the trap plants. The quadrates had 25 paddy hills which consists of approximately 375 plants. In the case of *E. dulcis* approximately 350–400 plants are counted in one quadrat which, however, are not growing on mounds. Some quadrates were maintained throughout the five months in a year for the survey.

We sampled both the egg clutches and adults on main crop and trap crop in all sampling units. In *O. sativa*, the moth laid eggs on leaves only; in *E. dulcis*, the eggs were laid on the pseudostem (Fig. 1). Egg masses (along with the plant part) were brought to the laboratory in air-filled labeled zip lock covers, and length of the egg mass, width of the egg mass, area of the egg mass, and number of eggs present per clutch were recorded, and reared under laboratory conditions. The collected egg masses were enclosed in glass tubes individually and plugged with cotton balls and maintained at room temperature (Max. 29 ± 1 °C and Min. 23 ± 0.5 °C and Average RH 65%) for studying hatching rate. The number of larvae emerged and number of parasitized eggs per egg clutch were recorded using Stereo zoom microscope, Leica M205A with DMC2900 camera. We reared a total of 253,053 eggs in 691 egg clutches sampled from rice (N = 10,995 eggs in 91 clutches) and *E. dulcis* (N = 242,058 eggs in 600 clutches) to study egg parasitism and hatching rate.

2.4. Data analysis

Together, we had 240 sampling units each for *E. dulcis* and *O. sativa*. When the number of egg clutches and adult moths were response variables, the numbers per plant was the unit in the statistical models. When the clutch traits, such as number of eggs, number of hatchlings, egg mass size, and the proportion of parasitized eggs/clutch were the response variables, the egg clutch was the unit in the analyses. To study the effect of plant species on the abundance of egg clutches and adult moths collected on plants, we constructed two generalized linear mixed effect models by fitting the abundances as the response variables, plant species as the fixed effect, and years, months, and plant ID in a nested fashion as the random effects. We studied the effect of plant species on the number of eggs in clutches, the size of egg clutch, larval hatching rate, and parasitism rate by fitting these response variables on separate generalized linear mixed effect models with plant species as fixed effect and

months nested in years as random effect. When number or abundance were the response variables, negative binomial distribution was used as the error type, when size of egg clutch was the response variable, Gaussian distribution was used as the error type, and when the rates were the response variables, binomial distribution was used as the error type in the models.

3. Results

S. innotata was sampled approximately twenty times more in number on *E. dulcis* than on *O. sativa*. Both the number of egg clutches (-2.85 ± 0.11 , $z = -27.48$, $p < 0.00005$) and adult moths (-2.47 ± 0.12 , $z = -20.9$, $p < 0.00005$) on plants were significantly less on the primary host (rice) than on the trap crop, *E. dulcis*, suggesting that the moth preferred *E. dulcis* for oviposition (Fig. 2). The number of eggs/clutch (-1.19 ± 0.04 , $z = -27.4$, $p < 0.00005$), the size of egg clutches (-15.72 ± 1.15 , $t = -13.7$, $p < 0.00005$), and the proportion of enclosed eggs/clutch (-1.42 ± 0.05 , $z = -29.07$, $p < 0.00005$) were significantly lower for the egg clutches sampled on *O. sativa* than that were sampled on *E. dulcis*. On average, 86.03% ($\pm 10\%$ SD) and 63.27% ($\pm 10\%$ SD) of eggs per clutch sampled from *E. dulcis* and *O. sativa*, respectively hatched to larvae (Fig. 3).

In general, egg parasitism was very low for *S. innotata* in the Kaipad rice fields. Out of 253 053 eggs in 691 egg clutches reared, only 0.1% of total eggs and 3.5% of total egg clutches were parasitized. However, all parasitism happened in eggs of clutches sampled from rice; 26% ($N = 91$) of egg clutches had parasitized eggs (23.93 ± 0.03 , $z = 6695$, $p < 0.00005$). This suggests that the oviposition on plant species predicts egg parasitism for the egg clutches of *S. innotata*. No larvae emerged from the eggs deposited on the Chinese water chestnut survived in laboratory conditions, but 24 percent of the eggs deposited on rice survived.

4. Discussion

S. innotata is a major pest of rice in rice-growing parts of Asia. Like other stem borers around the globe, IPM has been prescribed to manage

S. innotata in rice (Zhu, 2007). Although it has been suggested to find trap plants to manage this pest and it is known that *S. innotata* use *E. dulcis* for oviposition, no studies have so far quantified its fitness benefits for using *E. dulcis* for oviposition.

In the present study, we quantified pest incidence, egg functional traits, and egg parasitism in egg clutches sampled on rice plants and *E. dulcis* with the aim that *E. dulcis* can be used as a potential trap plant to manage *S. innotata* in rice fields. We found the following: 1) female moths and egg clutches are disproportionately abundant on *E. dulcis*; 2) functional traits of eggs, such as egg clutch size and number of eggs in egg clutches are high in egg masses sampled on *E. dulcis*; 3) egg parasitism is confined only in egg clutches sampled on rice plants; 4) the proportion of eggs hatching into neonate caterpillars is high in egg masses sampled on *E. dulcis*; and 5) no neonates reared on *E. dulcis* survived. *E. dulcis* has only a green pseudostem, which may not be edible for the larvae. We had observed that dead hearts and white ear heads on rice cultivated in the Kaipad fields are negligible, which indicates that damage by *S. innotata* on *O. sativa* is minimal (personal observation). The preference of *S. innotata* for *E. dulcis* over *O. sativa* for oviposition may be reducing the number of egg masses on *O. sativa*, resulting in reduced damage to the plant.

Although studies (Ranganath et al., 2002; Gazalil and Ilhamiyah, 2012) noticed egg clutches of *S. innotata* on *E. dulcis*, they have not studied, why *E. dulcis* was preferred for oviposition, despite the primary food resource – rice – being abundant in the fields. The results suggest three likely reasons for *S. innotata*'s preference for *E. dulcis* for oviposition. First, *E. dulcis* pseudostems offer space for depositing large egg clutches and a greater number of eggs. Second, egg clutches in *E. dulcis* have better survival probability as parasitoid emergence was negligible. Third, the plant volatiles emanating from *E. dulcis* may be serving as an oviposition attractant over *O. sativa*. We need further investigations to throw more light on the last hypothesis.

It is not rare that herbivores, particularly the pests in agroecosystems use niches or plants that they do not eat, for oviposition (Wiklund, 1977; Sinu et al., 2013). The importance of cultural control of *Hyposidra talaca* in tea plantations through managing its oviposition sites has been highlighted by Sinu et al. (2013). The neonate *H. talaca*'s primary food in tea plantation is the two and a bud (the pluckable leaves) of tea plants (*Camelia sinensis*) and the mature caterpillars (3rd instar onwards) prefer eating the maintenance foliage (mature leaves) of tea plants (Roy et al., 2017). However, the moth hardly oviposits on tea plants, but oviposits at a height above the tea layers on the barks of shade trees (Sinu et al., 2013). Once the eggs hatch, the neonates reach the two and a bud of tea leaves (the pluckable leaves) in no time through wind and salivary suspension threads. It was reported that *S. innotata* can be dispersed by wind and ballooning for 200–280 cm (Cohen et al., 2000). We suspect this sort of interaction between *E. dulcis* and *S. innotata* in rice fields, which however, needs an in-depth investigation.

In this study, we have for the first time quantified and illustrated the preference of *S. innotata* for *E. dulcis*. Although *S. innotata* eggs hatched on *E. dulcis*, they did not complete their development on the lab-reared plants. Although *S. innotata* died on *E. dulcis* in the lab, they may be migrating to rice to complete their development in the field. Cohen et al. (2000) have observed that the neonates of *S. innotata* may disperse up to a distance of 200–280 cm by ballooning. Therefore, destroying the eggs of *S. innotata* on *E. dulcis* may reduce the population of *S. innotata* in rice. Using trap host plants to control cereal pests is attaining popularity these days. Hui et al. (2019) used vetiver grass, *Vetiveria zizanioides* as a dead-end trap plant for managing *Chilo suppressalis*, another major pest of rice. They also showed that *C. suppressalis*, despite hatching on *V. zizanioides* could not complete their life cycle on it. From the second week of July itself, *S. innotata* starts laying eggs on *E. dulcis* (Trap crop) than on *O. sativa* (Main crop). Hence, removing egg clutches of *S. innotata* from *E. dulcis* may prevent subsequent spread of *S. innotata* larva to rice after emergence as has been recommended in other studies (Anonymous, 2011; Sinu et al., 2013).

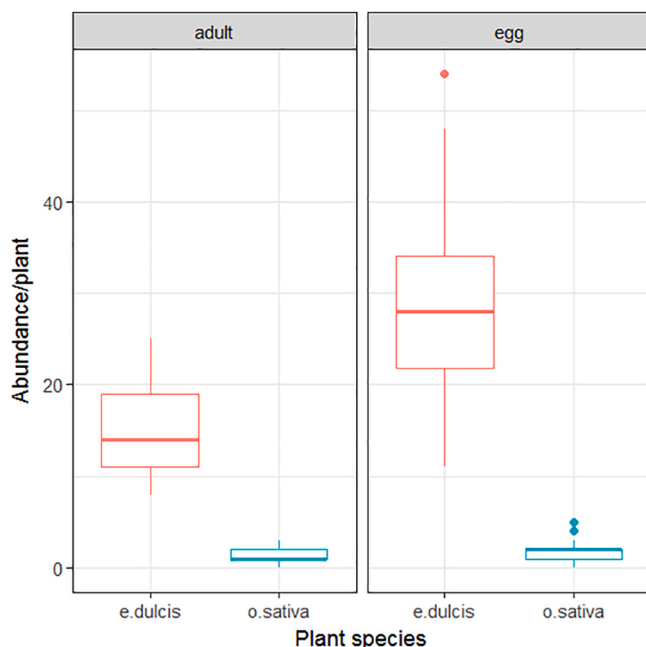


Fig. 2. Both adults ($p < 0.00005$) and egg clutches ($p < 0.00005$) of *Scirpophaga innotata* are sampled more on *Eleocharis dulcis* than on *Oryza sativa*. The middle line of box plot is median; the box is 25th and 75th percentile; the whiskers are 1.5x the inter-quartile range; the dots beyond whiskers are outliers.

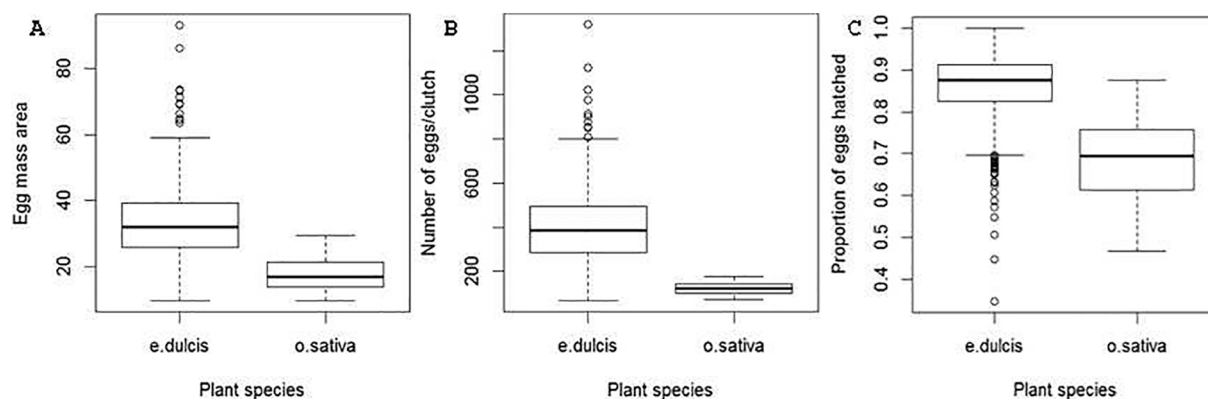


Fig. 3. The size of egg clutches ($p < 0.00005$), number of eggs/egg clutch ($p < 0.00005$), and eclosion rate of eggs ($p < 0.00005$) are significantly high in egg clutches sampled on *E. dulcis* than that sampled on *O. sativa*.

There are two advantages for using trap crops for pest management, given that the trap crop is used by the pest as a food plant. First, once a female selects a suitable host plant for egg-laying, it does rarely explore other plants in the neighborhood, unless its population is spilled over and it is polyphagous (Ellgardt, 2008). Therefore, an egg-laying female landing on the trap crop is less likely to move to the main crop later in the season. Nissinen et al. (2000) has also confirmed this stationary behaviour in carrot psyllids, where most of females laid eggs in only one of the plants offered in the multi choice bioassay and did not move to other plants in the vicinity. The second advantage is that pest attack is normally high in field boundaries. So, trap crops can be raised on field boundaries. Nissinen et al. (2008) recommended that a perimeter trap crop can save main crop from pests. In the present study, *E. dulcis* is growing naturally as a perimeter crop in rice fields.

A good trap plant in order to function as a primary sink must attract and restrict the pest on it (Hilje et al., 2001; Holden et al., 2012). Although it is predicted that the adult moths prefer a food plant for ovipositing in order to secure food for their hatching neonates (Cunningham et al., 2001), recent studies suggest that the moths can select a non-food plant or substrate for oviposition and plausible spread to food plants (Sinu et al., 2013). The fitness and survival traits of *S. innotata* on *E. dulcis* suggests such a case. In this context, studies may also be needed to decipher the chemical interaction between the trap plant, *E. dulcis* and the pest, *S. innotata* for a large-scale application of trap cropping and stem borer control using *E. dulcis* (Asikindan and Thamrin, 2011).

5. Conclusion

We have examined the rice stem borer's use of trap plant, *Eleocharis dulcis* for three years in Kaipad rice agro-ecosystem, a unique model of rice cultivation. In the present study, we quantified pest incidence, egg functional traits, and egg parasitism in egg clutches sampled on rice plants and *E. dulcis* with the aim that *E. dulcis* can be used as a potential trap plant to manage *S. innotata* in rice fields. We found the following: 1) female moths and egg clutches are disproportionately abundant on *E. dulcis*; 2) functional traits of eggs, such as egg clutch size (length, width, and area) and number of eggs in egg clutches are high in egg masses sampled on *E. dulcis*; 3) egg parasitism is confined only in egg clutches sampled on rice plants; 4) the proportion of eggs hatching into neonate caterpillars is high in egg masses sampled on *E. dulcis*; and 5) no neonates reared on *E. dulcis* survived. The study reiterates the need to opt trap cropping for managing rice stem borer, *S. innotata*. The possibility of using the *E. dulcis* as a trap plant in conventional rice fields also need to be explored.

Author contribution

Rajesh K.M. surveyed and documented the data, analysed the data

and wrote the manuscript. Sinu P. A. Statistically analysed the data and commented on the manuscript. Nasser M. guided and encouraged during the whole research work, wrote the manuscript.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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New distributional records of fairyflies (Hymenoptera: Chalcidoidea: Mymaridae) from rice–agroecosystems of Kerala

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Abstract

Gonatocerus aegyptiacus Soyka, 1950, *Gonatocerus shamimi* Subba Rao and Hayat, 1986 (Hymenoptera: Chalcidoidea: Mymaridae), *Anagrus* sp. are recorded from Kerala for the first time. Ten species of Mymarids are new distributional records from the rice-agroecosystems of Kerala. The samples were taken from the rice fields of Kerala using sweep net method during July 2013 - February 2015, and the collection comprises mymarids belonging to 10 species under 5 genera.

Keywords: *Mymaridae, New distribution, Rice-Agroecosystems, Kerala.*

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Introduction

The family Mymaridae (Hymenoptera: Chalcidoidea) is one of the most distinctive families of Chalcidoidea and includes the smallest known insects and are all parasitoids of eggs laid in concealed habitats (Huber *et al.*, 2009). The members are widely distributed with 117 genera known from two subfamilies, Gonatocerinae and Mymarinae (Noyes and Valentine, 1989). Majority of them attack Auchenorrhyncha hemipteran, but Coleoptera, Psocoptera, Diptera and Orthoptera are also attacked (Huber and Rajakulendran, 1988). Members can be identified by using a combination of characters; female antennae with distinct club, head with 'H' shaped mark, protibial spur often long and curved, tarsi with 4–5 tarsomeres and metasoma either broadly or narrowly attached with mesosoma.

Systematic and biological research on the Mymaridae up until 1984 has been reviewed by Huber and Rajakulendran (1988). The major taxonomic treatises on the group are those of Debauche (1948), and Peck (1963). Further studies which should be of interest are those of Enock (1909), Girault (1911, 1912), Soyka (1950), Hincks (1960), Sahad and Hirashima

(1984) and Matthews (1986).

To date 194 species under 38 genera are reported from India (Manickavasagam and Athithya, 2018). Taxonomic studies on Indian mymarids were mainly carried out by Verma (1980), Subba Rao and Hayat (1983), Hayat (1992), Zeya and Hayat (1995), Hayat and Anis (1999 a,b,c), Hayat and Singh (2001), Hayat *et al.* (2008), Rehmat *et al.* (2009), Zeya and Khan (2011), Rameshkumar *et al.* (2011 a,b) Manickavasagam and Rameshkumar (2011, 2012), and Manickavasagam *et al.* (2011). As per Noyes (2019) only 35 species in 14 genera were reported from Kerala.

The species like other chalcid families (Eulophidae, Trichogrammatidae) are most encountered parasitoids of pest species and have potential as biological control agents against different pests belonging to Cicadellidae, Miridae, Membracidae and Chrysomelidae in different crops or in their natural environment (Noyes, 2003). These parasitoids attack eggs of insects in a variety of habitats and crops, but its efficacy appears to vary with host plant species (Graham *et al.*, 1986). Little is known about the host parasitoid association as only about one

quarter of the genera have hosts reported for them.

Studies by Forster (1847), Enock (1909), Macgill (1934), Douth (1959), Anderson & Paschke (1968), Stoner and Surber (1969), Miura (1979), Sahad (1982), Graham *et al.* (1986), Huber and Rajakulendran (1988), Norton *et al.* (1992), Conti *et al.* (1996), De Moraes and Mescher (1999), Virla (2001) and Jones (2001) reveals the importance of mymarids as parasitoids of insect pests.

In this paper, we reviewed the distribution and abundance of mymarid genera and species in rice agro-ecosystems of Kerala, south India.

Materials and Methods

The survey of mymarid parasitoids of rice fields was carried out from July 2013 to February 2015 during the Kharif (July—November) and Rabi (December—March) seasons. The samples were taken from the rice fields of 10 districts (three plots per district) by sweep net method.

Sweeping was done 25 meter along the bunds of rice field and two meter inside from edges, swept once at each step in a figure of eight. The trapped insects were collected using an aspirator and transferred to labeled bottles containing 70% ethyl alcohol. The collected specimens were dried and card mounted. Hexamethyldisilazane (HMDS) was employed as the drying agent during mounting in order to avoid collapsing. Images of identified parasitoids were taken using Leica M205 A with DMC 2900 camera. Multiple images with different focal levels were combined into a single image using Leica Automontage Software V4.7. Images were edited in Adobe Photoshop to remove artifacts formed during stack processing. Distribution map was made with ArcGis software version 9.3 (ArcGIS 9.3 Improves Your Entire GIS Workflow: Enhanced Data Management, New Cartographic Tools, and More Efficient Information Sharing". *ESRI*. 2008-06-25. Archived from the original on 2008-06-30.).

Results

The aim of the present investigation is to study the species composition of Mymaridae

distributed in the rice–agro systems of Kerala. From the present survey 10 species of mymarids in five genera were collected, in which, *G. aegyptiacus* *G. shamimi* and *Anagrus* sp. are new distributional report from Kerala. Of the ten species of mymarids collected during the present study, eight of them with the exception of *Lymanon* species are new distributional records from rice fields of Kerala.

New distributional reports of Mymarid fauna of Rice-Agroecosystems from Kerala (Fig. 1)

1. *Gonatocerus aegyptiacus* Soyka, 1950 (Fig. 3B)

Specimen examined: INDIA: Kerala, Thrissur, Mullakkara, 22.iii.2013, sweep net, coll. Rajesh, K.M.; INDIA: Kerala, Alappuzha, Kainakari, 5.ii.2013, sweep net, coll. Ranjith, A.P.; INDIA: Kerala, Wayanad, Kambalakkad, 8.xi.2012, sweep net, coll. Ranjith, A.P.; INDIA: Kerala, Wayanad, Kambalakkad, 6.xii.2013, sweep net, coll. Ranjith, A.P.; INDIA: Kerala, Kannur, Nellikapalam, 28.xi.2013, sweep net coll. Rajesh, K.M.; INDIA: Kerala, Kannur, Maniyoore, 7.ii.2013, sweep net, coll. Ranjith, A.P.; INDIA: Kerala, Ernakulam, Thuruthikkara, 26.i.2013, sweep net, coll. Ranjith, A.P.; INDIA: Kerala, Ernakulam, Thuruthikkara, 7.iii.2014, sweep net, coll. Ranjith, A.P.; INDIA: Kerala, Kozhikode, Mundoth, 10.x.2013, sweep net, coll. Rajesh, K.M.; INDIA: Kerala, Malappuram, Kalachal, 22.iii.2013, sweep net, coll. Rajesh, K.M.; INDIA: Kerala, Thiruvananthapuram, Amaravila, 23.i.2013, sweep net, coll. Ranjith, A.P.

Distribution: India: Assam (Zeya and Hayat, 1995), Andhra Pradesh (Zeya and Hayat, 1995), Bihar (Zeya and Hayat, 1995), Jammu & Kashmir (Zeya and Hayat, 1995), Karnataka (Zeya and Hayat, 1995), Meghalaya (Zeya and Hayat, 1995), Tamil Nadu (Zeya and Hayat, 1995), Delhi (Anwar and Zeya, 2012), Himachal Pradesh (Anwar and Zeya, 2012), Odisha (Anwar and Zeya, 2012), Puducherry (Anwar and Zeya, 2012), Punjab (Anwar and Zeya, 2012), Uttarakhand (Anwar and Zeya, 2012), West Bengal (Anwar and Zeya, 2012), Andaman and Nicobar (Zeya *et al.*, 2014), Uttar Pradesh (Shamim and Shafee, 1984; Subba Rao and Hayat, 1986) and Kerala (Present study).

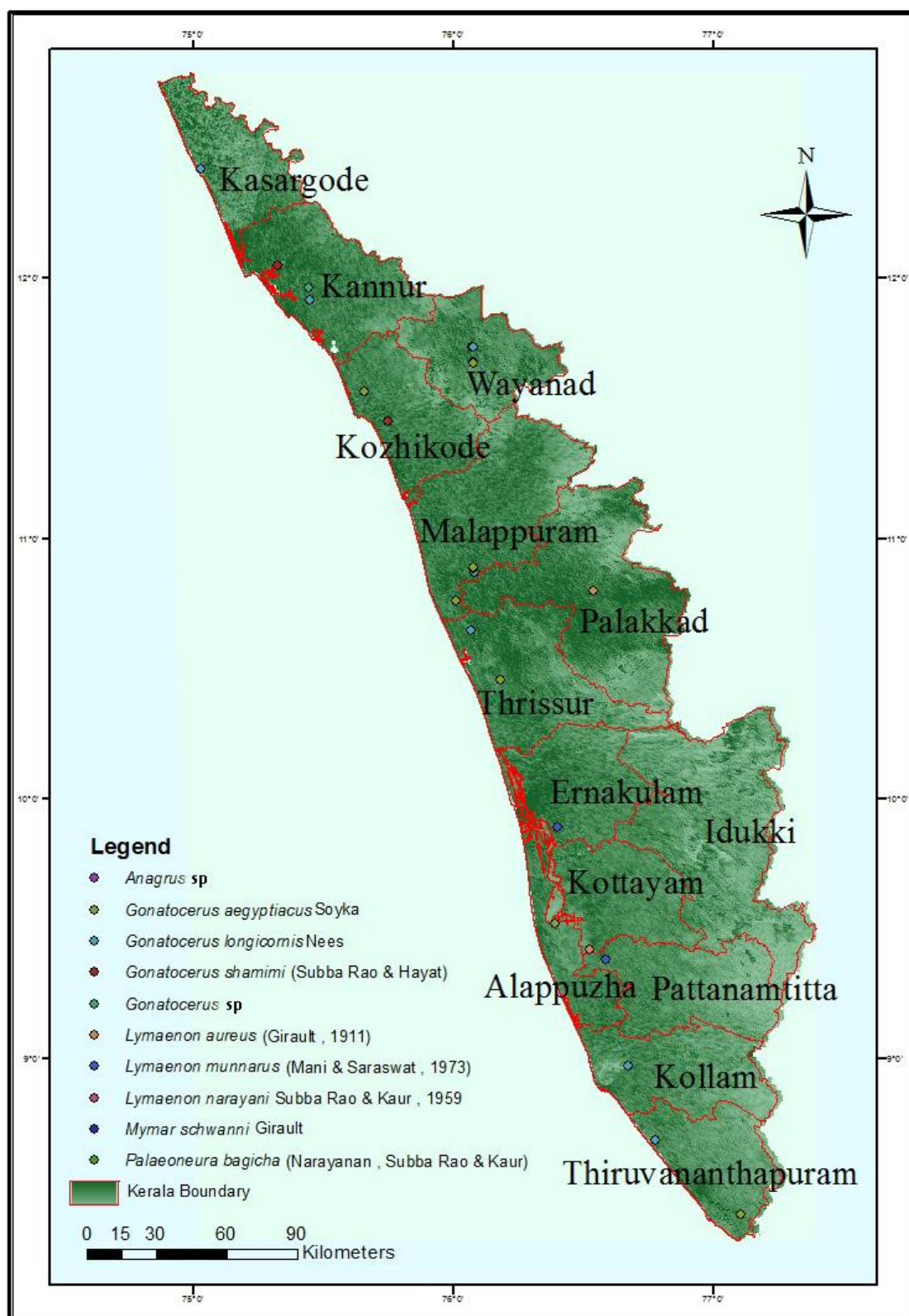


Figure 1: Distribution map of Mymaridae in Rice Agro-ecosystems of Kerala

Plant associates: Poaceae: *Oryza sativa* L. (Present study).

2. *Gonatocerus shamimi* Subba Rao and Hayat, 1986 (Fig. 3D)

Specimens examined: INDIA: Kerala, Palakkad, Thenur, 27.viii.2013, sweep net, coll. Rajesh, K.M.; INDIA: Kerala, Kozhikode, Mundoth, 10.x.2013, sweep net, coll. Rajesh, K.M.; INDIA: Kerala, Thiruvananthapuram, Amaravila, 23.1.2013, sweep net, coll. Ranjith, A.P.; INDIA: Kerala, Kannur, Kaively, 29.xi.2013, sweep net, coll. Rajesh, K.M.

Distribution: India: Bihar (Manickavasagam and Rameshkumar, 2011), Meghalaya (Zeya, 2015), Odisha (Zeya, 2015), Tamil Nadu (Manickavasagam and Rameshkumar, 2011) Uttar Pradesh (Shamim and Shafee, 1984), Andhra Pradesh (Rameshkumar and Manickavasagam, 2014), Jharkhand (Anwar and Zeya, 2012), West Bengal (Anwar and Zeya, 2012) and Kerala (Present study).

Plant associates: Poaceae: *Oryza sativa* L. (Present study).

3. *Lymaenon aureus* (Girault, 1911) (Fig. 3F)

Specimen examined: INDIA: Kerala, Kottayam, Changanassery, 25.1.2013, sweep net, coll. Rajesh, K.M.; INDIA: Kerala, Kannur, Nellikkapalam, 28.xi.2013, sweep net, coll. Rajesh, K.M.; INDIA: Kerala, Palakkad, Thenur 27.xii.2013, sweep net, coll. Rajesh, K.M.

Distribution: India: Jammu & Kashmir (Narayanan, 1961), Maharashtra (Mani *et al.*, 1973), Uttar Pradesh (Shamim and Shafee, 1984) Andhra Pradesh (Amer *et al.*, 2017), Assam (Amer *et al.*, 2017), Bihar (Amer *et al.*, 2017), Himachal Pradesh (Amer *et al.*, 2017), Jharkhand (Amer *et al.*, 2017), Karnataka (Amer *et al.*, 2017), Kerala (Amer *et al.*, 2017), Odisha (Amer *et al.*, 2017), Puducherry (Amer *et al.*, 2017), Punjab (Amer *et al.*, 2017), Sikkim (Amer *et al.*, 2017), Uttarakhand (Amer *et al.*, 2017), West Bengal (Amer *et al.*, 2017), Tamil Nadu (Zeya and Hayat, 1995) and Meghalaya (Ramesh Kumar *et al.*, 2015).

Plant associates: Fabaceae: *Medicago sativa*, Poaceae: *Oryza sativa* L. (Present study).

4. *Lymaenon narayani* Subba Rao and Kaur, 1959

Specimen examined: INDIA: Kerala, Kannur, Nellikkapalam, 28.xi.2013, sweep net, coll. Rajesh, K.M.

Distribution: India: Uttar Pradesh (Subba Rao and Hayat, 1986), Kerala (Amer *et al.*, 2017), Andaman & Nicobar (Amer *et al.*, 2017), Andhra Pradesh (Amer *et al.*, 2017), Bihar (Amer *et al.*, 2017), Delhi (Amer *et al.*, 2017), Himachal Pradesh (Amer *et al.*, 2017), Karnataka (Amer *et al.*, 2017), Odisha (Amer *et al.*, 2017), Puducherry (Amer *et al.*, 2017), Tamil Nadu (Amer *et al.*, 2017), Uttarakhand (Amer *et al.*, 2017), and West Bengal (Amer *et al.*, 2017).

Plant associates: Poaceae: *Oryza sativa* L. (Present study).

5. *Gonatocerus longicornis* Nees, 1834 (Fig. 3C)

Specimen examined: INDIA: Kerala, Kollam, Kundara, 23.i.2013, sweep net, coll. Rajesh, K.M.; INDIA: Kerala, Wayanad, Panamaram, 8.xi.2013, sweep net, coll. Ranjith, A.P.; INDIA: Kerala, Wayanad, Kambalakkad, 6.xii.2013, sweep net, coll. Ranjith, A.P.; INDIA: Kerala, Thiruvananthapuram, Amaravila, 23.i.2013, sweep net, coll. Rajesh, K.M.; INDIA: Kerala, Ernakulam, Thuruthikkara, 7.iii.2014, sweep net, coll. Ranjith, A.P.; INDIA: Kerala, Kozhikode, Mundoth, 12.iv.2013, sweep net, coll. Rajesh, K.M.; INDIA: Kerala, Thrissur, Ottappilavu, 12.v.2013, sweep net, coll. Ranjith, A.P.; INDIA: Kerala, Kannur, Kaively, 29.xi.2013, sweep net, coll. Rajesh, K.M.; INDIA: Kerala, Kannur, Kudukkimotta, 7.ii.2013, sweep net, coll. Ranjith, A.P.

Distribution: India: Kerala (Mani *et al.*, 1973), Karnataka (Subha Rao & Hayat, 1986), Tamil Nadu (Subha Rao & Hayat, 1986), Assam (Zeya and Hayat, 1995), Jammu & Kashmir (Zeya and Hayat, 1995), Madhya Pradesh (Zeya and Hayat, 1995), Odisha (Zeya and Hayat, 1995), Uttar Pradesh (Zeya and Hayat, 1995), Jharkhand (Anwar and Zeya, 2012), Uttarakhand (Anwar and Zeya, 2012), West Bengal (Anwar and Zeya, 2012) and Andaman & Nicobar (Zeya *et al.*, 2014).

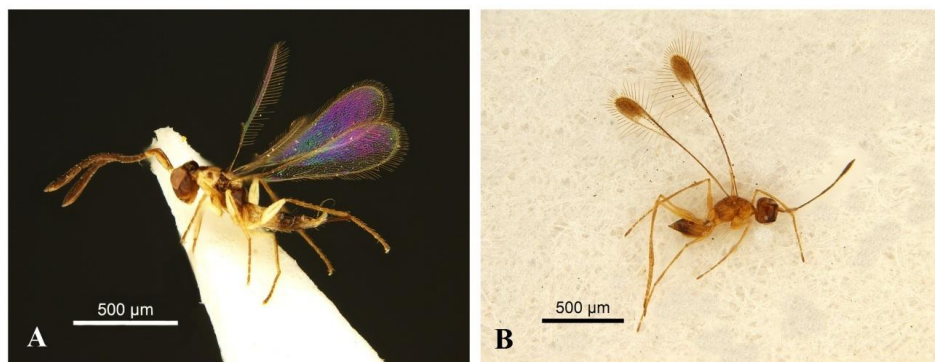
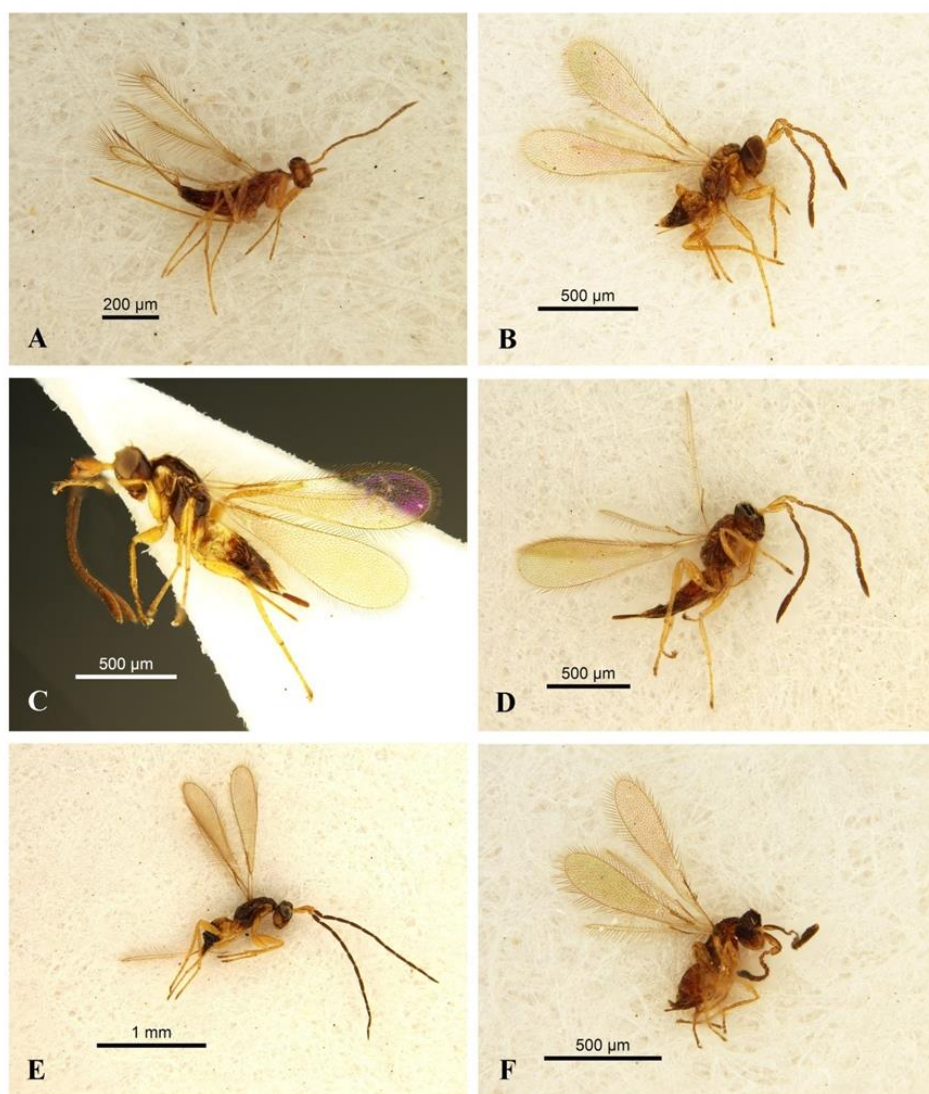


Figure 2: A. *Lymaenon munnarus* (Mani and Saraswat, 1973); B. *Mymar schwanni* Girault, 1912



Figures 3A-F: A. *Anagrus* sp.; B. *Gonatocerus aegyptiacus* Soyka, 1950; C. *Gonatocerus longicornis* Nees, 1834; D. *Gonatocerus shamimi* Subba Rao and Hayat, 1986; E. *Gonatocerus* sp.; F. *Lymaenon aureus* (Girault, 1911).

Plant associates: Betulaceae: *Corylus avellana* (Viggiani, 1974), Fabaceae: *Medicago sativa* (Pricop, 2009), Poaceae: *Oryza sativa* L. (Present study).

6. *Lymaenon munnarus* (Mani and Saraswat, 1973) (Fig. 2A)

Specimen examined: INDIA: Kerala, Pathanamthitta, Thiruvalla, 24.i.2013, sweep net, coll. Rajesh, K.M.; INDIA: Kerala, Thiruvananthapuram, Kadakkavoor, 23.i.2013, sweep net, coll. Rajesh, K.M.; INDIA: Kerala, Palakkad, Thenur, 27.viii.2013, sweep net, coll. Ranjith, A.P.; INDIA: Kerala, Wayanad, Kambalakkad, 6.xii.2013, sweep net, coll. Ranjith, A.P.; INDIA: Kerala, Thrissur, Ottapilavu, 12.v.2013, sweep net, coll. Ranjith, A.P.

Distribution: India: Andhra Pradesh (Manickavasagam *et al.*, 2011), Jammu & Kashmir (Manickavasagam *et al.*, 2011; Amer *et al.*, 2017), Karnataka (Manickavasagam *et al.*, 2011), Kerala (Manickavasagam *et al.*, 2011), Madhya Pradesh (Manickavasagam *et al.*, 2011), Maharashtra (Manickavasagam *et al.*, 2011), Tamil Nadu (Manickavasagam *et al.*, 2011), Uttar Pradesh (Manickavasagam *et al.*, 2011), Himachal Pradesh (Amer *et al.*, 2017), Jharkhand (Amer *et al.*, 2017), Odisha (Amer *et al.*, 2017) and West Bengal (Amer *et al.*, 2017).

Plant associates: *Oryza sativa* L. (Present study).

7. *Mymar schwanni* Girault, 1912 (Fig. 2B)

Specimens examined: INDIA: Kerala, Alappuzha, Kainakari, 5.ii.2013 sweep net, coll. Ranjith, A.P.; INDIA: Kerala, Ernakulam, Thuruthikkara, 7.iii.2014, sweep net, coll. Ranjith, A.P.

Distribution: India: Andhra Pradesh (Manickavasagam *et al.*, 2011), Karnataka (Manickavasagam *et al.*, 2011), Kerala (Manickavasagam *et al.*, 2011), Odisha (Manickavasagam *et al.*, 2011), Tamil Nadu (Manickavasagam *et al.*, 2011), Uttar Pradesh (Manickavasagam *et al.*, 2011), Uttarakhand (Manickavasagam and Rameshkumar, 2011) and Puducherry (Manickavasagam *et al.*, 2011).

Plant associates: Poaceae: *Oryza sativa* L. (Present study).

8. *Palaeoneura bagicha* (Narayanan, Subba Rao and Kaur, 1960)

Specimens examined: INDIA: Kerala, Kannur, Kaiveli, 29.xi.2013, sweep net, coll. Rajesh, K.M.

Distribution: Delhi (Huber, 2003), Himachal Pradesh (Manickavasagam *et al.*, 2011), Kerala (Manickavasagam *et al.*, 2011), Maharashtra (Subha Rao and Hayat, 1986), Punjab (Manickavasagam *et al.*, 2011), Tamil Nadu (Manickavasagam *et al.*, 2011), Uttar Pradesh (Hayat, 1992) Karnataka (Subha Rao, 1989), Meghalaya (Rameshkumar *et al.*, 2015), Uttarakhand (Joshi *et al.*, 2017) and Arunachal Pradesh (Amer and Zeya, 2018)..

Primary hosts: Hemiptera: Cicadelidae: *Sophonia rufofasciata* (Yang *et al.*, 2002).

Plant associates: Poaceae: *Oryza sativa* L. (Present study).

9. *Anagrus* sp. (Fig. 3A)

Specimens examined: INDIA: Kerala, Kannur, Nellikkapalam, 28.xi.2013, sweep net, coll. Rajesh, K.M.

10. *Gonatocerus* sp. (Fig. 3E)

Specimens examined: INDIA: Kerala, Kannur, Nellikkapalam, 28.xi.2013, sweep net, coll. Rajesh, K.M.; INDIA: Kerala, Alappuzha, Kainakari, 5.ii.2013, sweep net, coll. Ranjith, A.P.

Gonatocerus aegyptiacus is the numerically abundant mymarid species collected and distributed in nine districts viz: Kannur, Kozhikode, Wayanad, Malappuram, Palakkad, Thrissur, Ernakulam, Alappuzha and Thiruvananthapuram. *Gonatocerus longicornis* is the second dominant species recorded in 10 districts except Kottayam, Idukki, Pathanamthitta and Palakkad. Mymarid species richness in Kannur district was the highest with eight species viz: (*G. aegyptiacus*, *G. shamimi*, *G. longicornis*, *Lymaenon aureus*, *L. narayani*, *Palaeoneura bagicha* and *Gonatocerus* sp.),

Table 1. The distribution of Mymaridae in Rice-Agroecosystems of Kerala

SI. No	Species	Place
1.	<i>Gonatocerus longicornis</i> Nees, 1834	Kollam – Kundara : 8°58'05.6"N 76°40'24.3"E Malappuram – Valanchery : 10°53'08.4"N 76°04'41.4"E Ernakulam – Thuruthikkara : 9°53'17.0"N 76°24'13.1"E Panamaram–Wayanad : 11°44'09.7"N 76°04'38.4"E Wayanad – Kambalakkadu : 11°40'31.1"N 76°04'39.3"E Thiruvananthapuram – Amaravila : 8°23'50.0"N 77°06'26.1"E Thiruvananthapuram –Kadakkavoor : 8°41'02.1"N 76°46'43.8"E Ernakulam – Thuruthikkara : 9°53'17.0"N 76°24'13.1"E Thrissur– Ottapilavu : 10°38'36.0"N 76°04'13.5"E Kozhikode – Mundoth : 11°27'04.4"N 75°45'08.9"E Kannur – Kaiveli : 12°03'00.1"N 75°19'38.5"E Alappuzha – Kainakari : 9°30'58.5"N 76°23'31.8"E Kannur – Kudukkimotta : 11°54'57.0"N 75°26'55.8"E Kasaragode – Pallikkara : 12°25'17.7"N 75°01'57.3"E

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2.	<i>Gonatocerus aegyptiacus</i> Soyka, 1950	Thrissur– Mullakkara : 10°27'07.9"N 76°10'57.3"E Palakkad – Thenur : 10°47'42.5"N 76°32'26.7"E Ernakulam – Thuruthikkara : 9°53'17.0"N 76°24'13.1"E Kozhikode – Mundoth : 11°27'04.4"N 75°45'08.9"E Wayanad – Kambalakkad : 11°40'31.1"N 76°04'39.3"E Kannur – Nellikkapalam : 11°57'41.6"N 75°26'40.9"E Alappuzha – Kainakari : 9°30'58.5"N 76°23'31.8"E Thiruvananthapuram – Amaravila : 8°23'50.0"N 77°06'26.1"E Malappuram – Kalachal : 10°45'30.4"N 76°00'57.7"E Kannur – Maniyoor : 11°33'50.6"N 75°39'36.2"E Malappuram – Valanchery : 10°53'08.4"N 76°04'41.4"E
3.	<i>Gonatocerus shamimi</i> Subba Rao and Hayat, 1986	Malappuram – Valanchery : 10°53'08.4"N 76°04'41.4"E Palakkad – Thenur : 10°47'42.5"N 76°32'26.7"E Kozhikode – Mundoth : 11°27'04.4"N 75°45'08.9"E Thiruvananthapuram – Amaravila : 8°23'50.0"N 77°06'26.1"E Kannur – Kaiveli : 12°03'00.1"N 75°19'38.5"E
4.	<i>Lymaenon munnarus</i> (Mani and Saraswat, 1973)	Pathanamthitta – Thiruvalla : 9°22'43.9"N 76°35'18.6"E Thiruvananthapuram – Kadakkavoor : 8°41'02.1"N 76°46'43.8"E

		Palakkad – Thenur : 10°47'42.5"N 76°32'26.7"E Wayanad – Kambalakkadu : 11°40'31.1"N 76°04'39.3"E Malappuram – Valanchery : 10°53'08.4"N 76°04'41.4"E Thirissur – Ottapilavu : 10°38'36.0"N 76°04'13.5"E Ernakulam – Thuruthikkara : 9°53'17.0"N 76°24'13.1"E
5.	<i>Lymaenon aureus</i> (Girault, 1911)	Kottayam – Changanassery : 9°25'03.0"N 76°31'26.9"E Palakkad – Thenur : 10°47'42.5"N 76°32'26.7"E Kannur – Nellikkapalam : 11°57'41.6"N 75°26'40.9"E
6.	<i>Lymaenon narayani</i> Subba Rao and Kaur, 1959	Kannur – Nellikkapalam : 11°57'41.6"N 75°26'40.9"E
7.	<i>Palaeoneura bagicha</i> (Narayanan, Subba Rao and Kaur, 1960)	Kannur– Kaiveli : 12°03'00.1"N 75°19'38.5"E
8.	<i>Mymar schwanni</i> Girault, 1912	Alappuzha – Kainakari : 9°30'58.5"N 76°23'31.8"E Ernakulam – Thuruthikkara : 9°53'17.0"N 76°24'13.1"E
9.	<i>Gonatocerus</i> sp.	Kannur – Nellikkapalam : 11°57'41.6"N 75°26'40.9"E Alappuzha – Kainakari : 9°30'58.5"N 76°23'31.8"E
10.	<i>Anagrus</i> sp.	Kannur – Nellikkapalam : 11°57'41.6"N 75°26'40.9"E

followed by Alappuzha (*G. longicornis*, *G. aegyptiacus*, *Mymar schwanni*, *Anagrus* sp. and *Gonatocerus* sp.), species richness is least in Kottayam (*L. aureus* only) and Kollam (*G. longicornis* only) districts (Table 1).

Discussion

Out of the 1424 species reported from 103 genera worldwide, only 194 species under 38 genera are known from the Indian subcontinent that constitute 32.8 and 11.9 per cent of world genera and species respectively (Manickavasagam and Athithya, 2018). Manickavasagam and Athithya in 2018 constructed the very latest checklist of Indian mymarids, with five genera viz., *Allanagrus*, *Dorya*, *Platystethynium*, *Schizophragma* and *Stephanocampta* were newly recorded, four genera viz., *Cosmocomoidea*, *Lymaenon*, *Tanyxiphium* and *Zeyanus* were added during reclassification of *Gonatocerus*, 56 new species were described and 12 first reports of species were made from India. Seven species viz., *Acmopolynema shrawastianum*, *Erythmelus lygivorus*, *Gonatocerus sulphuripes*, *G. tarae*, *G. pahlgamensis*, *G. similis* and *Polynema huberi* were synonymized and one species misidentified.

Distribution status of the Mymaridae from Kerala is comparatively wider as 35 species under 14 genera were recorded earlier. Most of the mymarids were reported as solitary/gregarious egg parasitoids of the plant/leaf hoppers (Huber and Rajakulendran, 1988). Present study extended the distribution status of mymarids in the rice agroecosystems with the first report of species *G. aegyptiacus* from south India. The distribution of *G. aegyptiacus* is found to be very wide as it extended from Holarctic to the Oriental regions (Soyka, 1950; Sahad, 1982; Sahad and Hirashima, 1984; Subba Rao and Hayat, 1986; Donev, 2003).

The present study also portrays the distribution and abundance of fairyflies in the rice fields as ten species under five genera were reported exclusively from rice fields of Kerala.

Among the studied species, the speciose genus, *Gonatocerus* is numerically abundant with 26 specimens from four species. This result is well in line with the study of Rameshkumar *et al.* (2011b) as 13 species were already recorded

from the Kerala state. In addition to this the distribution of the species listed in the present study apparently confirms the biological association of the genus with the rice agroecosystems as the species *G. longicornis* and *G. shamimi* were already recorded from rice paddy ecosystems. Most of the *Gonatocerus* species are already reported from north Indian states but the extended distribution of *Gonatocerus* (*G. ater* Foerster, 1841, *G. bakrotus* Mani and Saraswat, 1973, *G. bashai* Zeya, 1995, *G. bouceki* Zeya, 1995, *G. delhiensis* (Narayanan and Subba Rao, 1961) and *G. shamimi*) indicates that the genus has a wider distribution status within the Indian subcontinent than reported earlier (Zeya and Hayat, 1995; Rameshkumar *et al.*, 2011a,b).

Despite the wide distribution of Indian *Gonatocerus*, some species are found to be endemic to south India like *G. berijamus* Mani and Saraswat, 1973 and *G. kodaianus* (Mani and Saraswat, 1973) (Rameshkumar *et al.*, 2011a, b). Similarly all the *Lymaenon* species collected during the present study were already recorded from the rice paddy ecosystems (Rameshkumar *et al.*, 2011b).

In 2017, Amer *et al.* conducted a survey on Indian mymarids, and they provided many new distribution reports from all over India.

As mentioned in the results the 10 species recorded in the present study from rice ecosystems of Kerala are distributed across many states of India. This study has recorded additional mymarid species as possible parasitoids of pests of rice. In addition to this *L. narayani* earlier recorded as a parasitoid of *Eucoccosterphus tuberculatus* (Hemiptera: Membracidae) (Zeya and Hayat, 1995) has now been collected from rice fields which opens up the possibility of an alternate host for the parasitoid species as membracids are usually not seen in rice fields. Additionally, more detailed survey with emphasis on host rearing will help in providing the host association of mymarids which will help to facilitate the adoption and designing of biocontrol strategies to control pests of rice using mymarids.

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