INSECT POLLINATION

IN SELECTED

CUCURBITACEOUS CROPS

THESIS SUBMITTED

TO THE FACULTY OF SCIENCE, UNIVERSITY OF CALICUT

IN PARTIAL FULFILMENT OF THE REQUIREMENTS

FOR THE DEGREE OF

DOCTOR OF PHILOSOPHY IN ZOOLOGY

BY

LEENA. P. T.

DEPARTMENT OF ZOOLOGY

UNIVERSITY OF CALICUT

KERALA

INDIA

2007

Department of Zoology

UNIVERSITY OF CALICUT

Dr. M.NASSER, Ph.D.
SENIOR LECTURER.

Division of Entomology
Department of Zoology
University of Calicut
Kerala, India-673635
Tel: +91-4942401144
Mobile: 91-9447446375
e-mail: drnasher@gmail.com

CERTIFICATE

This is to certify that the thesis entitled "**Insect Pollination in Selected Cucurbitaceous Crops**" *is an authentic record of the bonafide research work carried out by* **Leena. P. T.** *from 2002 to 2005 under my supervision and guidance and that no report of this work has been presented before for any other degree or diploma.*

It is further certified that the candidate has passed the M.Phil. degree examination of Kerala University held in 2000.

Date: **M. Nasser**

DECLARATION

I do hereby declare that the present thesis entitled "**Insect Pollination in Selected Cucurbitaceous Crops**" is original work done by me under the supervision and guidance of Dr. M. Nasser, Senior Lecturer, Department of Zoology, University of Calicut. I also declare that no report of this work has been published or submitted in part or full for any degree or diploma.

Date :   **Leena. P.T.**

Dedicated With Love

To

My Parents

Acknowledgements

It is with great pleasure I express my profound sense of gratitude to my revered guide Dr.M. Nasser, Senior Lecturer, Department of Zoology, University of Calicut, for suggesting the topic of the research and for his valuable guidance and constant encouragement for the completion of this research work.

I am greatly thankful to Dr.K.P.Janardanan, Professor and Head of the Department of Zoology, University of Calicut, for the timely help rendered whenever necessary.

I express my gratitude to Dr.T.C.Narendran, Professor Emeritus, for his ardent interest, constant support and valuable suggestion which has helped a lot to complete this work.

I am thankful to all the teachers of Department of Zoology and Dr.Jayaram of Department of Botany, University of Calicut, for their valuable suggestions and for various helps.

I extremely indebted to Dr.Sreekumar, Dr.Madhu, Dr.Pradeep of Kerala Agricultural University and Dr.Rajagopal of IIHR, Bangalore, for their encouragement, generosity and kindness which inspired me in fulfilling this work.

I place on record my gratitude to Dr.Prathap of Kerala Agricultural University and Dr. Jaffer Palot of ZSI, for helping me with the identification of the specimens.

I have debt of gratitude to Dr.Fareed, Mrs.Rejula, Miss.Dilsha and Mr.Jabir for analysing the data.

I record my sincere thanks to librarian and office staff of the Department of Zoology for the timely assistance with the Department facilities.

A special thanks is due to the favour shown by Mr.Kunhiraman Master for providing facilities and basic ideas to carry out this work. I also acknowledge the farmers of Madayi for permitting me to work in the farm. Special thanks are due to Mr.Prashanth, Mr.Prabhakaran, Mr.Rajeev and Miss.Sheeja for the logistic support in the field.

I am grateful to Mr.Sony Dingo and Mr. Anju Mahendra for the timely help in photography. My deep sense of gratitude are also due to my friends who have contributed in one way or other to complete this work.

Besides I would like to extend my gratitude to all research scholars of Department of Zoology especially Mr.Santhosh, Miss.Seena and Miss.Bindu for their kind co-operation and support in completion of this work.

I also remember with gratitude the authorities of the Calicut University for permitting me to register with Calicut University for the Ph.D programme.

I record my sincere thanks to Mr.Sajeev of Datamatics Computers and Mr.Mohanan of Malabar Printers for their support and co-operation in timely completion of thesis work.

My heartful gratitude is extended to my parents, brother, sister and all other family members who have been a perpectual source of inspiration and love which strengthened me during this period of study.

Above all, I thank God almighty for granting me the patience determination and knowledge throughout the study.

LIST OF FIGURES

LIST OF TABLES

LIST OF PLATES

INDEX

CHAPTER 1

INTRODUCTION

1.1. Overview

Pollination is the process of transfer of pollen from the anther of one flower to the stigma of another or the same flower. Pollination can be either self-pollination or cross-pollination. The simplest of these is self-ollination, whereby pollen from a flower pollinates and fertilizes the ovules of the same flower, but this limits them to inbreeding. Sometimes, self-pollinated plants do not require any outside assistance from wind or bees for complete pollination. But in other self-pollinated plants, these agents are needed to move the pollen about. In cross-pollination, the pollen is transferred from one flower on a plant to another flower on the same plant or it is the transfer of pollen among different plants or varieties of the same species. Cross-pollination is better than self-pollination as it helps to maintain a wider gene pool. Most species rely upon some kind of agent to accomplish the transfer of pollen grains from the anther of a stamen to the stigma of a carpel, which are well known as pollination vectors or pollinators.

Pollination is achieved by abiotic and biotic means. Abiotic pollination occurs mainly by wind (anemophily) and water (hydrophily). Biotic pollination includes mainly vertebrate pollination (zoophily) and insect pollination (Entomophily).

1.2. Insect Pollination

Insects have far more advantage in pollination than other animal vectors. The diverse groups of the class Insecta have evolved apt features for this specialized act of pollination in different flower types. Many flowers offer sugary liquid nectar as an added enticement for these pollinating insects. Insect pollinated plants produce large pollen grains but usually in smaller numbers. Insect pollinated flowers are usually showy, having evolved from the need to attract insect pollinators. However, many wind pollinated flowers such as maple, oak and corn are visited by bees collecting pollen.

Among insect pollinators, bees are especially efficient because they can operate in complicated flowers, attracted to sweet odours and use nectar guides. They eat pollen and nectar exclusively, visit many flowers of the same species during a single trip, and have hairy bodies, which easily pick up pollen grains. Of all the types of bees, honeybees have several advantages as pollinators. They are relatively abundant and manageable. Bees from a colony will visit a large number of plants over a large area, collecting pollen and nectar, with individual bees visiting one species of flowers in the same location until the supply of nectar or pollen is exhausted. This loyalty or constancy is not found in some other social bees, which visit different plant species during the same trip in the fields that reduces the effectiveness of these bee species as pollinators because the pollens are mixed. Being clumsy fliers with hard exoskeleton beetles are inefficient pollinators. Moths are nocturnal or crepuscular hoverers, feed upon flowers using their long proboscis. Butterflies are attracted to brightly coloured flowers, which usually pollinate the flowers that are facing upward to allow them to land. Flies are the most variable of all. Carrion or dung flies are attracted to flowers that look and smell like carrion. Wasps are mostly predaceous, but some (e.g., yellow jackets) can drink nectar from simple flowers.

Pollination by insects is largely unique to the angiosperms, and diversification of pollination systems has been one of the most important factors in the radiation and abundant success of this group of plants (Regal, 1977; Crepet, 1984; Willemstein, 1987).

1.3. Pollination Ecology

The value of insect pollination, the only type of pollination upon which man can exert much influence, is not limited to the cultivated crops. Baker and Hurd (1968) recognized this important ecological relationship, for they stated that "insect pollination is extremely important among the fortes of the grasslands, in the shrub and herb layer of the temperate forest and in the desert. It remains undiminished in the tropics.” In many parts of the country, fruit and vegetable growers are concerned about declining numbers of wild bees as human activities destroy bee habitat and forage. Bohart (1972) pointed out that the most drastic effect of the absence of pollinating insects would be in uncultivated areas, where, as a result, most soil-holding and soil-enriching plants would die out.

A simultaneous warning of disaster was issued because of our disregard of the importance of pollination. According to Abelson (1971) monoculture and the use of limited strains of plants makes the food supply vulnerable to plant enemies. Harlan (1971) reminded that the post-modern era has seen spectacular increases in yield, and a virtual genetic wipe-out, with whole continents planted with one or a few related populations. These narrow genetic bases and loss of gene pools are invitations to disaster. Cross-pollination can be one means of preventing such a disaster.

The seed yields of insect-pollinated crops may often be lower than they need be, not because of climate, soil, or cultural factors, but simply because the population of certain insects is low. In many parts of the world, the very change in land use, which now seems to be bringing about the end of beekeeping, may lead to its recognition as an essential part of agriculture, because of its importance for crop production (Crane, 1972). Bruner (1966) studied the purely business aspect of vegetable production in northwest Mexico. He considered the lack of proper "saturation-pollination" by bees and protection of beneficial insects from pesticides to be two major reasons for low agricultural production in certain areas. Some larger operations in our country tend to fall into a similar category. The plants and their pollinators are so intricately interdependent that the disappearance of pollinators will have catastrophic effect on the ecosystem.

1.4. Influence of Pollination on Agriculture

Worldwide, more than 3,000 plant species have been used as food, only 300 of which are now widely grown, and only 12 of which furnish nearly 90 percent of the world's food. These 12 include the grains[rice, wheat, maize (corn), sorghums, millets, rye, and barley], potatoes, sweet potatoes, cassavas or maniocs, bananas, and coconuts (Thurston, 1969). The grains are wind-pollinated or self-pollinated, coconuts are partially wind-pollinated and partially insect pollinated, and the others are propagated asexually. However, more than two-thirds of the world's population is in Southeast Asia where the staple diet is rice. It appears that insect pollination has little effect on the world's food supply, possibly no more than 1 percent. But it is pointed out that crops, valued at several million, are dependent upon insect pollination, primarily by honeybees.

More than half of the world's diet of fats and oils comes from oilseeds such as coconuts, cotton, oil palm, olives, peanuts, soybeans, and sunflower (Guidry, 1964). Many of these plants are dependent upon or benefitted by insect pollination. When these sources, the animal and plant products, are considered, one-third of our total diet is dependent, directly or indirectly, upon insect-pollinated plants. In addition, the insect-pollinated legumes have the ability to collect nitrogen from the air, store it in the roots, and ultimately leave it to enrich the soil for other plants. Without this beneficial effect, soils not fertilized by processed minerals would soon be depleted and become economically unproductive. Another value of pollination lies in its effect on quality and efficiency of crop production. The value of pollination on the succeeding generation of crops is also frequently overlooked. The value of hybrid seed lies in its earliness of development, plant health, and greater production of fruit or seed. Inadequate pollination can result not only in reduced yields but also in delayed yield and a high percentage of inferior fruits.

1.5. Economics of Crop Pollination

Crops dependent upon insect pollination were valued by Levin (1967) at $1 billion, with additional crops benefited by bee pollination valued at approximately $6 billion. The honey and beeswax produced were valued at about $45 million. In other words, honey bee colonies are worth roughly 100 times as much to the community as they are to the beekeeper.

The aesthetic value of pollination to ornamentals, wild flowers, and forest and range plants in terms of beauty of the landscape is recognized for specific plants (Alcorn *et al.* 1962, Grant and Grant 1965 and McGregor *et al.* 1962) and in general (Knuth, 1906-09), but it cannot be measured. Nor can we measure the related ecological value in terms of seeds, fruits, and nuts produced, which are used as food for various forms of wildlife, but this value, too, is doubtless considerable.

Pollinators other than honeybees are also extremely valuable although their value is difficult to estimate. Bohart (1972) estimated that the value of the wild bee industry was well over $1 million per year in terms of expenditures and benefits. He dealt largely with the gregarious leafcutter bee (*Megachile pacifica* Panzer) and the equally gregarious alkali bee (*Nomia melanderi* Cockerell). No doubt numerous other unmanaged and generally unrecognized wild bees exceed Bohart's estimate. Bumble bees are excellent, although generally unmanageable, pollinators (Holm, 1966). Unfortunately, in many intensively cultivated areas, they have largely been eliminated.

If the need for insect pollination is increasing, one would assume that the number of colonies of honey bees should also be increasing to help meet this demand. Such is not the case. The number of colonies in farms has been decreasing steadily (Tyler and Haseman, 1915). They have either shifted to the suburbs, where they are operated by hobbyists. This situation has disturbed the more or less even distribution of pollinators across the countryside, and even created a serious deficiency in some areas. A population of bees necessary for maximum set of fruit or seeds on the crop, may be far greater than the location, will support for honey production or colony maintenance. There appears to be a potential market for many more properly maintained and managed colonies of honey bees for pollination of present and anticipated crops than can be mobilized.

We should be aware of the shrinking number of pollinators and gauge ways to measure the decline and find ways to halt it. A disaster could possibly happen if we don't start to take care of the precious pollinators of our crops. A global shortage of bees and other insects that pollinate plants is destroying crops around the world and could lead to far higher prices for fruits and vegetables. Pollinator populations have been hit hard by increased pesticide use in recent years, and much of their natural habitat, such as dead trees and old fence posts, have been destroyed to make room for more farmland.

According to Kevan and Phillips (2001), pollination systems in many agricultural areas today are threatened by an inadequate number or complete lack of sustainably managed pollinators, either indigenous or imported. Although, concerns about pollinator shortages date back to biblical times, their report is the first one to quantify the effects in economic terms. Their research does not pinpoint exactly how high food prices will rise, but rather presents a model for assessing the economic ramifications if birds, bees and other pollinators continue to disappear. Their economic analysis indicates that consumers of a commodity affected by a pollinator deficit may suffer since the commodity will likely cost more and become less available. At the same time, producers of affected commodities may experience crop declines but may also experience economic gains resulting from higher prices. The amount gained or lost by producers depends on the supply and demand curves. Their research states that there is ample evidence to suggest the existence of pollinator declines and those declines are affecting agricultural productivity. The authors conclude that the adverse economic effects of pollinator deficits on food prices must follow from on-farm considerations, but that the effects could be much broader. Although there is little data to work with, they state that security, trade and the global food supply could be in serious jeopardy if pollinator abundance, diversity, and availability are not reversed. So the pollinator conservation is an important issue in the global context of agricultural and natural sustainable productivity. Conservation concerns for pollination have started to take on a greater profile than ever before (Kevan 1974; Kevan *et al.*, 1990 a, 1990 b; Torchio, 1991, 1994).

1.6. Scope of the Investigation

This study aims to investigate influence of insect pollination in the selected cucurbitaceous crops viz. Musk melon (*Cucumis melo*), Cucumber (*Cucumis sativus* L.), Bittergourd (*Momordica charantia*), Ashgourd (*Benincasa hispida* Thunb. and Cogn.), and Pumpkin (*Cucurbita moschata* L.) along with the phenological, palynological and pomological aspects of the crops, in Madayi, Kerala.

CHAPTER 2

LITERATURE REVIEW

Several studies have been conducted on different aspects of pollination till date. Among them pollination by insects is the most effective and cheapest method of increasing yield.

According to Abrol (1991a), who conducted studies on conservation of pollinators for promotion of agricultural production in India, pollination of crops by insects is an essential feature for enhancing agricultural productivity.

Kevan and Phillips (2001) conducted studies on the economic impacts of pollinator declines and found that pollinator shortages adversely affect crop production and commodity markets.

Lehrer (1997) observed honeybee's use of spatial parameters (natural flower display, e.g., contrast, spatial frequency, geometry, symmetry, size, depth, edges, orientation of contours, and position in the visual field) for flower discrimination and concluded that bees use each of these parameters for learning and recognizing the food source.

Minckley *et al.* (1999) studied spatial predictability and resource specialization of bees at a superabundant, widespread resource and found that species composition and relative abundance of floral visitors vary dramatically at all spatial and temporal scales.

Foraging strategies of insects for gathering nectar and pollen, and implications for plant ecology and evolution were elucidated by Goulson (1999). He found that the behaviour of its pollinators was likely to vary according to the rewards offered, the size and complexity of floral displays used to advertise their location and the abundance and behaviour of other flower visitors.

According Iwasa *et al.* (1995) plants can manipulate the number of flowers visited per pollinator approach by adjusting attractiveness of flowers so as to maximize pollen export. The length of the visitation sequence decreases with pollen deposition rate, pollen uptake rate, and the number of pollinator approaches to the plant, but increases with the total number of flowers.

Goulson (2000) studied why pollinators visit proportionally fewer flowers in large patches and found that visiting a declining proportion of inflorescences as patch size increases is an optimal strategy.

Rademaker and Jong (1998) studied the effects of flower number on estimated pollen transfer in natural populations of three hermaphroditic species and found that there is no difference in total pollen transfer between small and large individuals.

Studies on the variety of visitation patterns among pollinators in relation to floral display and floral design in a generalist pollination system were conducted by Thompson (2001). In general, the number of visits were positively related to the number of open flowers in a patch, but analyses by insect type showed that this was only true for bees, flies and butterflies. The significant differences between different insect types in patterns of visitation rates in response to floral design and display may act to diversify selection on floral traits and thereby constrain specialization of the plant to particular pollinators.

A model to predict the influence of insect flower constancy on interspecific competition between insect pollinated plants was put forward by Goulson (1994). The model predicts that scarce plant species will receive no pollinators below a threshold density of reward, and that scarce plants must provide a relatively huge reward per flower to achieve pollination. The threshold is lowered at high insect densities when the reward offered by the more common species becomes depleted.

Kunin and Iwasa (1996) studied the pollinator strategies in mixed floral arrays and found that where floral resources are scarce, pollinators should behave as generalists, whereas when resources are superabundant, specialization on the single most profitable flower type is favoured. Rare flowers are at a reproductive disadvantage in all cases, but their relative success is highest where their pollinators are constant.

Wilson and Stine (1996) conducted studies on floral constancy in bumble bees and they could observe that individual bees often prefer flowers of the same species that they are already foraging on. They suggested that constancy is due to some form of perceptual conditioning whereby individual bees become temporarily sensitized to one or a few floral cues.

Slaa *et al.* (1998) conducted studies on floral constancy in *Trigona*, stingless bees foraging on artificial flower patches and found that the degree of flower constancy in the stingless bee species was lower than that reported for European honeybees (*Apis mellifera*), but comparable with that reported for Asian honeybees (*Apis cerana*). They hypothesize that bees of tropical climates will be generally less constant than bees of temperate climates, due to different (environmentally imposed) optimal foraging strategies.

White (2001) tested the flower constancy of the stingless bee *Trigona carbonaria* Smith by examining the composition of the pollen loads of individual foragers over time and found that 88% of the samples comprised of pure pollen loads (97% or more of one pollen type). The pattern is consistent with that of highly social bees. It enhances the pollinator efficacy of these insects by increasing the chances of pollen being transferred to stigmas of the same plant species. This increases the ecological importance of these bees and their value in crop pollination.

Fritz and Nilsson (1994) studied how pollinator mediated mating varies with population size in plants. According to them as the amount of pollen removed from plants by insects (either absolute or proportional) increased, so did the number of pollinations and fruit set, whereas the proportions of plants with different pollinator-designated functional sex (male, female, hermaphrodite) depended primarily on the ratio between the amount of fruit set and pollen removed within populations. The results empirically verified the basic importance of population size for the mating structure of outcrossing plants and indicated that the selection for female sexual traits was reinforced when population size was smaller while selection for male sexual traits was reinforced when population size was larger.

Moller (2000) studied developmental stability and pollination and found that insect preferences for symmetric flowers increase reproductive success of both pollen donors and recipients by affecting seed set and embryo abortion.

Elberling and Olesen (1999) studied the structure of a high latitude plant-flower visitor system and noted that the proportion of dipteran species of the total pollinator fauna increases with latitude but that the proportions of species of Diptera, Hymenoptera, and Lepidoptera do not vary significantly among high altitude systems.

Totland (1994) studied the influence of environmental factors (temperature, light intensity, wind speed, time of day and flowering season, and flower density) on flower visitation activity of insects. Visitation activity was highest early in the flowering season and decreased as the season progressed. Visitation was positively correlated with the daily mean flower density. The flower density of individual species also affected visitation activity. Visitation reached a maximum level at medium flower densities where after it stabilized.

Abrol (2005) found that the pollinators were highly selective in their floral visits and shown to choose those flowers which best meet their energetic needs. The energy needs and forging dynamics of pollinators were dependant upon prevailing weather conditions, which regulate the schedule of activities.

Studies on temperature and pollinating activity of social bees, conducted by Corbet *et al.* (1993) showed that thermal constraints on flight activity limit the pollinating effectiveness of bees.

Results of studies on quantity and seasonal variation of pollen types collected by honeybees, showed that there was no relationship between rainfall and the amounts of pollen collected (Arita and Fujii,1992).

Abrol (1987) studied the influence of thermal and energetic constraints on the pollination activity of carpenter bee *Xylocopa pubescens*. The bees exhibited bimodal pattern of activities. Its activities were negatively correlated with temperature and solar radiation and positively with caloric rewards. Maximum pollination was accomplished early in the morning and late afternoon. This type of behavioural pattern was related to the physiological adaptability and energy economy of the bees.

2.1. Pollination in Horticultural Crops

Pollination studies have been done specifically in many horticultural crops viz; fruit crops, seed crops, plantation crops, fodder crops, tuber crops, ornamental crops, and vegetable crops.

2.1.1. Fruit Crops

Studies on pollen sources for *Apis cerana* Fabr. and *Apis mellifera* L. bees by Suryanarayana *et al.* (1992) at Muzaffarpur, Bihar, India showed that each of the species had 13 anemophilous plant species as sources of pollen. Studies on the pollinator activities on mango inflorescence, indicated that *Apis florea* was the most frequent visitor followed by *Syrphis* spp.*, Ceratina viridissima, X. pubescens, Xylocopa fenestrata and Megachile aurgentata.* The activity of *Nomia thoracica*, *Tachina* spp. *and Musca* spp. was almost negligible. The pollinator's activity was synchronous with the flowering (Rehman *et al.*, 1990).

Singh (1984) conducted studies on the activity of some insect pollinators on jujube (*Zizyphus mauritiana* Lamk.) and found that honeybees were the more efficient pollinators while frequency of visits of houseflies to receptive flowers was more.

Verma and Dulta (1986) studied foraging behaviour of *Apis cerana indica* and *A. mellifera* in pollinating apple flowers. According to them *A. c. indica* began to forage earlier in the morning than *A. mellifera* and stopped later in the evening. In both species nectar collectors outnumbered pollen collectors. Peak foraging activity for *A. c. indica* occurred at 0900 h. -1130 h. when the temperature ranged between 15.5 and 21°C and 1100 h -1330 h. for *A. mellifera* when the temperature was 21 to 25°C.

Further studies on the behaviour of *A. cerana* and *A. mellifera* foraging on apple flowers by Verma and Rana (1994) showed that *A. mellifera* visited significantly more flowers than *A. cerana* during single foraging trips at each site. There was no significant difference between the two species for number of flowers visited per minute.

Dashad and Sharma (1994) studied foraging rate of insect visitors on blooms of various cultivars of apple (*Malus domestica* Borkh). According to them pollen gatherers had higher foraging rate as compared to nectar and nectar-pollen foragers among *Apis* spp. All three kinds of foragers of *Apis dorsata* had higher foraging rates as compared to their counterparts of *A. cerana* and *A. mellifera*. Dipteran flies had very low foraging rate as compared to honeybees.

Later Dashad *et al.* (1994) conducted studies on loose pollen grains carrying capacity of insect-visitors of apple bloom and found that the amount of loose pollen on the body varies with the plant species and the varieties on which the insects are working.

Talpur *et al.* (1993) conducted studies on insect pollinators associated with safflower. Results showed that *A. florea* was the most abundant pollinator followed by *Anthophora* spp.

Heard (1994) studied the behaviour and pollinator efficiency of stingless bees (*Trigona carbonaria*) and honeybee (*A. mellifera*) on macadamia flowers. Stingless bees mainly collected pollen and this activity resulted in intimate contact with the stigma. Honeybees mainly collected nectar and came into contact with the stigma less often. Racemes which were enclosed in cages which excluded honeybees but allowed visitation by the smaller stingless bees yielded a nut set equal to that on open pollinated racemes, showing that these bees are efficient pollinators. Honeybees worked more quickly than the stingless bees, visiting more flowers in a given time. Both bee species responded to racemes rich in pollen and nectar by remaining longer at those racemes and visiting more flowers on them.

Ish-Am and Eisikowitch (1998) studied the mobility of honey bees (*A. mellifera* L.) during foraging avocado orchards and found that the average number of bees crossing between adjacent rows in a 10 min. period was linearly correlated to bee density, and the corresponding percentage increased with the increase in wind velocity, and decreased with increasing distance from the pollen source. The pollination of guava (*Psidium guajava* Linn.) was found to be effected by four insects viz. *A. c. indica, A. florea, Melipona fasciata* and *Musca domestica.* The relative abundance, pollen depletion, pollen deposition and time spent at flowers revealed that the honeybees, *A. c. indica* and *A. florea* were the major pollinators of guava. The diurnal activity of pollinators showed a significant negative correlation with humidity. The amount of pollen deposited by the pollinators during the successive visits was found to decrease because of the decreasing stigma receptivity with time. The amount of pollen depleted and deposited was found to be more at 0800 h due to more pollen stickiness and stigma receptivity (Prakash *et al.*,1993).

Further studies on pollination of guava (*P. guajava* Linn.) by honey bees (*A. c. indica* F.) by Jyothi (2004) at East Godavari district of Andhra Pradesh came to a conclusion that fruit set was increased by honey bee pollination.

Haq *et al.* (1978) studied the effect of insect pollinators mostly *A. dorsata* and *A. florea* on fruit bearing in kinnow mandarin (*Citrus reticulata*). Significantly more fruit set and matured on branches accessible to insect pollinators than from where insects were repelled or excluded. Effects on fruit size and the number of seeds were also significant.

Souza and Cauto (2002) studied pollination by insects in sweet orange (*Citrus sinensis* L. Osbeck) cultivars. They found that the uncovered flower buds produced more fruits than the covered ones. The flower buds covered in the morning produced less fruits than the ones covered in the afternoon. It was also observed that fruits derived from covered treatment were smaller and having smaller number of seeds.

Vaissiere *et al.* (1996) determined the pollination effectiveness of honeybees in a kiwifruit (*Actinidia eleticiosa*) orchard and concluded that honeybees are effective pollinators of kiwifruit.

Later Howpage *et al.* (2001) studied influence of honeybee (*A. mellifera*) on kiwifruit quality under Australian conditions and found that there were significantly more small fruit in bee saturated vines than in vines that were supplementary pollinated by honeybees. According to them honeybees were the main contributor to pollination and fruit set, although low numbers of other potential insect pollinators such as ladybird beetles and hoverflies were also observed.

Pomeroy and Fisher (2002) also studied pollination of kiwifruit by bumble bees (*Bombus terrestris*). They also found that fruit weight and seed number in the cages increased with increasing bee density.

The entomophily of the cloudberry (*Rubus chamaemorus* L.) was studied by Pelletier *et al.* (2001). According to them the activity of natural pollinators resulted in good fruit set and seed set. When insects were excluded fruit set dropped significantly showing the importance of mid and large sized insects as pollinators. Natural levels of insect activity were sufficient to ensure complete pollination as supplementary hand-pollination did not significantly increase either fruit set or seed set in plots where pollinators had free access. Nocturnal insects may serve as pollinators although they were less effective than diurnal pollinators.

Chagnon *et al.* (1989) observed the effect of honey bee visits on the pollination rate of strawberries. The cumulative effect of the number and length of visits to these flowers significantly increased the pollination rate.

Further studies on complementary aspects of strawberry pollination by honey and indigenous bees conducted by Chagnon *et al.* (1993) revealed that the honeybee, *A. mellifera* L., was more efficient than indigenous pollinators when the frequency of visits was very low.

Chagnon *et al.* (1991) studied honeybee foraging behaviour and raspberry (*Rubus idaeus* L.) pollination and could find that weight of berries and number of drupelets increased with the number and length of visits.

Antonelli *et al.* (1988) conducted studies on pollinating insects and strawberry yields in the Pacific Northwest and found that "Benton" and "Shuksan" strawberry plants denied insect pollinators during bloom produced significantly fewer berries and berry quality was significantly reduced.

Bagnara and Vincent (1988) studied the role of insect pollination and plant genotype in strawberry fruit set and fertility. Open pollination, compared to absence of insects under cages decreased the percentage of poorly pollinated fruit and increased the number of fruit set, the latter being more pronounced in those cultivars which had a lower fruit set under cages.

Abrol (1989 a) conducted studies on ecology and behaviour of insect pollinators frequenting strawberry blossoms and their impact on yield and fruit quality. The study showed that the percentage of fruit set and well formed fruits were much higher in open pollinated plants as compared to those where pollinating insects were not allowed access. The bees, *Lasioglossum* spp. *A. c. indica* were the most numerous visitors. Flies, *Syrphus* spp., *Musca* spp., mosquitoes and butterflies were poorly represented and frequented at interrupted hours. Bee species differed in their responses to abiotic conditions. The honeybee, *A. c. indica* appears to be the efficient pollinator on the basis of its field behaviour, nectar pollen carrying capacity and ability to pollinate flowers per unit time.

Aras *et al.* (1996) noted the effect of honeybee gradient on the pollination and yield of low bush blue berry. Four parameters were estimated to assess blueberry production: seed set, fruit set, berry weight, and maturation rate. All parameters were significantly and positively correlated with an increase in the density of honeybees.

Dedig and Delaplane (2003) studied honey bee pollination of rabbitey blue berry, *Vaccinium ashei* variety "climax" and found that the pollination was pollinator density dependant. Regression analysis showed that fruit set increased linearly with the rate of legitimate bee visits. Mean weight of berries was unaffected by bee density. Average seeds per berry tended to increasing bee density.

Neira *et al.* (1997) observed the entomofauna associated with flowers of raspberry (*Rubus idaeus* L., cv Meeker). The results show that the presence of pollinating insects was essential for fruit formation and to decrease floral abortion and abnormal fruits.

Jones *et al.* (1976) obtained an abnormally high incidence of honey bee visitation to flowers of Chinese gooseberry (*Actinidia chinensis*) in New Zealand. The weight of fruit formed in the cages was not significantly different from that in the surrounding crop, but caged fruits had fewer seeds.

Kitroo and Abrol (1996) conducted studies on abundance, diversity and importance of native pollinators for fruit production in litchi (*Litchi chinensis* Sonn.), and found that honeybees *Apis dorsata* F., *A. mellifera* L., *A. cerana* F., and *Apis florea* F. were the most important and efficient pollinators. According to them insect pollination was responsible for the increase in fruit production and fruits resulting from open pollination were significantly higher in size and weight.

Klug and Buenemann (1985) studied the efficiency of solitary bees as pollinators of pome fruits. The number of solitary bees was very small in comparison to the number of honeybees. Solitary bees and honeybees responded similarly to weather conditions. Solitary bees visited fewer flowers per minute than honeybees. However, in most cases they touched the stigmas compared to honeybees.

Langridge *et al.* (1977) conducted a study on pollination of dessert peaches by *A. mellifera* and found that in trees to which bees had access there was a 2.9x increase in percentage of flowers that set fruit and a 2.6x increase in weight of fruit harvested as compared with trees from which bees were excluded.

Gupta *et al.* (1990) studied the pattern of nectar secretion in wild cherry, *Prunus puddum* Roxb. and the associated foraging behaviour of *A. c. indica* F. and *A. mellifera* L. According to them honey bees foraged both for nectar and pollen on the flowers. The activity of pollen gatherers peaked during early morning hours (8-9 h.) and that of nectar gatherers at 11 h. *A. mellifera* spent more time per flower than *A. c. indica*, whether foraging for nectar or pollen.

Abrol (1989 b), when studied the insect pollination of cherry (*Prunes avium* L.), it was found that flowers covered with muslin cloth did not set any fruit while those left for open pollination set 38-56% fruits.

Bhattacharya (2004) conducted a study on pollination of *Anacardium occidentale* and found that bees, flies, butterflies, beetles and ants were the visitors of the flowers. Relative abundance of the visitors coincided with nectar availability. Breeding manipulation by bagging experiments indicated that bees were efficient pollinators increasing fruit set, while ants decreased fruit set by damaging the viable pollen.

Walters and Stiles (1996) studied flower patch size on pollinator visitation of *Impatiens capensis* and found that honeybees, bumblebees and halictid bees made up the majority of visitors. Visitation rates per flower increased slightly, but not significantly, in relation to flower patch size (number of open flowers) and floral density.

2.1.2. Seed Crops

Abrol and Kapil (1998) conducted studies on abundance and importance of insect pollinators for oilseed production. According to them honeybees *A. florea* and *A. dorsata* were the most important and efficient pollinators on all the oil seed crops as they visited the flowers in large numbers throughout the day and flowering period. Other bee pollinators were present in fewer numbers and at interrupted hours. Flower visitation rates revealed that *Xylocopa* spp. and the *Nomia* spp. visited the highest number of flowers per minute.

Importance of pollination of sunflowers by insects for the production of large numbers of seeds with high oil content was noted by Bagnoli (1975).

Studies on the abundance and daily visitation patterns of bees on oil seed sunflower, *Helianthus annuus* L. in Southeastern Arkansas showed that peak activity of bees occurred at 0800 h. and 0900 h. with greatly reduced numbers during afternoon hours (Posey *et al*.,1986).

Initiation, cessation and period of foraging activity of honeybees on sunflower were studied by Kumar and Singh (2001). *A. c. indica* started foraging earlier (0930 h.) than the *A. mellifera* (0946 h.) and ceased its activities first i.e. 1537 h. as compared to *A. mellifera,* which continued foraging upto 1609 h. Age of the flower, day hours, and weather factors all influenced the foraging activity of honeybees.

Hoffman and Watkins (2000) studied the foraging activity of honeybees *A. mellifera* and non-*Apis* bees on hybrid sunflowers (*Helianthus annuus*) and its influence on cross-pollination and seed set. They found that the size of the honey bee population was positively correlated to the area of open flowers on sunflower capitula, while the non-Apis population remained relatively constant throughout bloom. The results indicated that a combined honeybee and non -*Apis* bee population might result in better pollination of hybrid sunflowers than either population alone.

According to Raj and Rana (1994*) A. mellifera* L. and *A. c. indica* F. foragers on rapeseed bloom *Brassica campestris* var. *sarson* did not exhibit significant differences in the mean time spent per flower. Also both the species did not show significant differences at 0900 h., 1200 h. and 1500 h. of the day in relation to time spent per flower. However, both the species spent maximum time per flower at 0900 h. than at 1200 h. or 1500 h. Further, there were significant differences in the time spent per flower by pollen gatherers of *A. mellifera* between 0900 h. and 1200 h.

Mohr and Jay (1988) found that pollen was usually collected incidentally while the bees foraged for the nectar on canola (*Brassica campestris* L. and *Brassica napus* L.). But in one experiment they found the honeybees were collecting the pollen actively. The proportion of pollen gatherers of bee species *A. mellifera* L. and *A. c. indica* F. on rapeseed bloom was highest at 0900 h. and lowest at 1500 h. In both the species, highest percentage of nectar gatherers was recorded at 1500 h. and lowest at 0900 h. The nectar pollen gatherers of both the species were at their peak working spree at 1200 h. (Rana *et al.*,1997).

The pollen loads of *A. mellifera* L. and *A. c. indica* F. differed according to the time of the day, and on different days. Both the species showed almost alike pollen constancy to the rapeseed crop. There was a decline of pollen collection in both the species with the advancement of the age of the crop and bees of both the species were found shifting to other sources for pollen collection (Raj *et al*.,1993).

Foraging activity of insect pollinators, viz., *A. c. indica* F., *A. mellifera* L., *A. dorsata* F., *A. florea* F. as also other hymenopteran, lepidopteran and dipteran insects on Indian mustard, *Brassica juncea* L showed that *A. c. indica* bees were the dominant pollinators of mustard followed by *A. dorsata*, *A. mellifera* and *A. florea*. Visits of *A. c. indica* were positively correlated with temperature, while humidity had no significant correlation. *A. florea* had a significant negative correlation with minimum temperature (Chand *et al*.,1994)

Cresswell *et al.* (1995) predicted pollen dispersal by honeybees (*A.mellifera*) and three species of bumble bees (*Bombus lapidarius, B. pascuorum*, *B. terrestris*) foraging on oil seed rape (*Brassica napus* cv Westar). According to them most of the pollen from a source plant is deposited on immediate neighbours, but that long distance pollen dispersal in this system extends over approximately 20-40 intervening plants from the originating plant, depending on the identity of the pollinator.

Conner and Neumeier (1995) studied the effects of black mustard (*Brassica nigra*) population size on the taxonomic composition of pollinators. Larger plant populations were visited by significantly greater numbers of honeybees and significantly fewer small bees than small populations on a per –plant basis.

Kunin (1997) conducted studies on the population size and density effects in pollination of *Brassica kaber*. He found that the number of individuals in a population had no effect on pollinator visitation or subsequent seed set. However, population density had strong effects on both visitation and reproductive success. The position of a plant within a population had an impact on pollinator constancy, but had no effect on visitation rates or reproductive success.

Mishra *et al.* (1988) found that *A. c. indica* F. was the most common pollinating species in *Brassica campestris* L. var. *sarson* and percent pod setting, seeds per pod and proportion of healthy seeds were significantly higher in open pollinated flowers than in net caged and muslin bagged ones.

In experiments on the importance of honey bees for the pollination of spring rape (*Brassica napus*), Svendsen (1990) found that compared to the caged plots, the yield of open plots increased with 9% seeds on average, but yield varied with year and varieties.

According to Adegas and Cauto (1992) the most frequent insect visitors to the rape (*Brassica napus* L. var *oleifera*) were *A. mellifera*, *Trigona spinipes* and *Dialictus* spp. The visits of *A. mellifera* collecting nectar and pollen contributed to pollination and to an increased production of pods per square meter and individual seed weight.

Singh *et al*. (2004) studied the effect of bee pollination on yield attributes and seed yield of Tori (*Brassica campestris* var. *toria*). Among the different insects *A. florea* was the most common followed by A. *mellifera* while the minimum population was of *A. dorsata*. The maximum mean number of insect visitors were observed at 1200 h. while minimum at 0900 h. The highest population of insect visitors were recorded between 1000 h. to 1400 h. The mean number of siliqua /plant, length of one siliqua, number of seeds per siliqua, seed weight and seed yield in g /plot and g /ha were significantly higher in open pollinated (OP) than bee pollinated (BP) and self pollinated (SP). It was lowest in self pollinated flowers.

The impact of bee pollination on seed yield of Mustard seed *Brassica campestris* L. var. *toria* was studied by Singh and Singh (1992). Bee pollinated plants were found to produce 3 times heavier pods, 4 times more seeds per pod, 50 times more seeds per plant, 11 times more pods per plant and 84 times more seed yield per plant than self pollinated plants.

2.1.3. Plantation Crops

Foraging behaviour of *Apis mellifera mellifera* L., and the solitary bee *Amegilla sapiens* Cockerell, in cardamom (*Eletaria cardamomum* L. Maton, Zingiberaceae) indicated that although less abundant than *A. m. mellifera*, *A. sapiens* was far more important as a pollinator than its relatively low numbers would suggest (Stone and Willmer,1989).

Klein *et al.* (2003) conducted studies on bee pollination and fruit set of *Coffea arabica* and *C. canephora* (Rubiaceae) and the results showed that cross pollination by bees cause a significant increase in fruit set of not only the self sterile, but also the self fertile coffee species.

Preliminary studies on insect pollinators of fennel, *Foeniculum vulgare* P. Miller (Jugtani *et.al*,1993) in Sindh, Pakistan showed that *A. florea* was the most abundant species of insect pollinators followed by *Syrphus* spp. and *X. pubescens*.

Herrera (1989) studied the pollinator abundance, morphology and flower visitation rate of *Lavandula latifolia* (Labiatae), an insect pollinated shrub. Pollinators differed broadly in flower visitation rate. Most of this variation was explained by differences in flower handling time (HT). Hymenopterans had intrinsically shorter handling times than Lepidopterans. Within each group, HT decreased exponentially with increasing proboscis length.

A. dorsata, A. cerana, A. andreniformis and *A. florea* were observed foraging for pollen on the nocturnally-dehiscent king palm (*Archontophoenix alexandrea*). The larger *A. dorsata* and *A. cerana* foraged earliest but in low numbers, presumably exploiting the resource at its most productive time. The smaller *A. andreniformis* and *A. florea* followed in large numbers (Oidroyd *et al.*,1992).

Conceicao *et al.* (2004) evaluated the pollen transportation by ants and bees in coconut inflorescence and found that both groups of insects transported a meaningful amount of pollen and the bees were considered totally able to pollinate the plants. The ants carried lower amount of pollen and they contributed only casually to pollination.

Genty *et al.* (1986) studied entomophilous pollination of the oil palm in Tropical America and they came to a conclusion that in certain geographical zones, local insects are sufficient to ensure a reasonable percentage of fruit formation, whereas in other regions it seems necessary to introduce new species.

Studies on insect pollinators of linseed (*Linum usitatissimum* Linn.) and their effect on yield components by Abrol and Kotwal (1996) revealed that honeybees were the most important and efficient pollinators. Insect pollination significantly influenced the quality and quantity of seed production in linseed. Plots isolated from insect visits set low and poor quality seed.

2.1.4. Fodder Crops

Benedek *et al.* (1977) conducted studies on fertilization and seed setting of red clover as affected by the time of insect pollination and found that permanent shortage of bee activity for shorter or longer time during the blooming period causes proportional decrease in the seed yield.

2.1.5. Tuber Crops

Conner and Rush (1996) studied the effects of flower size and number on pollinator visitation to wild radish, *Raphanus raphanistrum* and found strong, consistent evidence that increase in both flower number and size cause increased visitation by syrphid flies. An increased flower size causes a weak increase in small bee visitation but strong relationships between flower number and small bee visitation.

Young and Stanton (1990) observed that there was no significant relationship between corolla size and either pollen removal or estimates of female reproductive success (pollen deposition on stigmas and seed production) in wild radish (*Raphanus sativus*, Brassicaceae).

A. cerana workers foraged on radish plants for 1105 h. each day, from 0640 h. (26 min. after sunrise) to 1830 h. (18 min. after sunset) with peak foraging between 1100 h. and 1400 h. At 0900 h. 1200 h. and 1500 h. respectively workers averaged 4.3, 5.3, and 12.8 per flower, visited 8.0, 9.0, and 5.0 flowers per minute and collected 11, 10, and 7mg. of pollen. Most workers collected either pollen or nectar, but 4-7% collected both nectar and pollen during the same foraging trip. Pod set, number of seeds per pod, seed weight and germination for radish plants caged with an *A. cerana* colony were greater than for open-pollinated plants. Plants with insect visitors excluded had no pod set (Partap and Verma, 1994).

2.1.6. Ornamental Crops

Totland and Mathews (1998) examined the effects of environmental factors on the pollination activity on *Crocus vernus* by *A. mellifera*, and also whether bees discriminate among flowers on the basis of floral display size and colour. Flower density was much more important than temperature, humidity and time of day and season in explaining variation in bee numbers, the total number of flowers visited by individual bees and the total number of visits per flower (visitation rate). Although flower density positively influenced bee abundance and the number of flowers visited by individual bees, they found a negative relationship between flower density and visitation rates, suggesting that the pool of available pollinators was saturated at flower densities below maximum. There was no significant difference between the size or colour of flowers that were visited, approached, or ignored by bees, and duration of visits was not related to floral display size or colour. The data indicate that there is no pollinator mediated selection on floral display, driven by discriminating pollinators.

The honeybees, *A. c. indica* and *A. florea* and the housefly, *Musca domestica* were observed to be the major visitors of chrysanthemum (*Chrysanthemum indicum* Linn.). Relatively the bees (*A. c. indica* and *A. florea*) depleted more amount of pollen. Maximum amount of pollen was depleted at about 1100 h. Among the pollinators of chrysanthemum, the bees and the housefly were observed to spend comparatively lesser time.

The activity of *A. c. indica* and *A. florea* showed significant positive correlation with temperature and negative correlation with humidity on both cloudy and sunny days. The period from 0700 h. - 1300 h. was observed to be effective pollination period (Parthiban *et al.*, 1994).

Olesen and Wamcke (1989 a) studied the temporal changes in pollen flow and neighbourhood structure in a population of *Saxifraga hirculus* L. The visitors did not have a nearest-neighbour foraging pattern. The foraging flights of pollinators become shorter with increasing flower density.

Jennersten *et al.* (1988) studied phenological differences in pollinator visitation, pollen deposition and seed set in the sticky catchfly, *Viscaria vulgaris* (Caryophyllaceae). Seed set per flower decreased over time because of (1) decrease in ovule number (2) decrease in pollen availability due to protandry, and (3) decrease in pollinator visitation and pollen deposition. Pollen deposition on receptive *V. vulgaris* stigmas was highest during the first half of the flowering season, with the pollen to ovule ratio highest after approximately one week of flowering.

Langridge and Goodman (1977) found that mean yields of seed from *Lupinus angustifolius* (Leguminosae) were significantly greater from plots to which bees and larger insects had access than from plots from which these insects were excluded.

Olesen and Wamcke (1989 b) studied flowering and seasonal changes in flower sex ratio and frequency of flower visitors in a population of *Saxifraga hirculus* and found that stigmatic pollen loads and seed set decreased during the course of the season.

Xylobium squalens Lindi. (Orchidaceae), was found to be pollinated by *Trigona postica*. The percentage of seeds with embryo obtained by natural pollination was higher than the percentage obtained through artificial intraspecific and self pollinations (Pintaudi *et al*., 1990).

Carthew (1993) made an assessment of pollinator visitation to

Banksia spinulosa. Examination of pollen tube growth from experimental treatments indicated that pollination success was similar from both nocturnal and diurnal visitors. However, nocturnal visitors were more effective at removing pollen from newly opened flowers.

Guitian *et al.* (1993) studied the pollen transfer and diurnal versus nocturnal pollination in *Lonicera etrusca* and found that fruit set was 3.5 times higher when only diurnal pollination was allowed than when only nocturnal pollination was allowed.

Behaviour of honey bees (*A. dorsata* and *A. cerana*) as pollinators of *Salvia splendens, S. pratensis* and *Althaea rosea* was observed by Viswanathan and Thiagarajan (1994) and their report showed that the ratio between nectar and pollen collectors of the tested species differs at different times of the day. Number of flowers visited by a bee is high in the morning compared to other times. The frequency of visits is also more in the morning.

Ohara and Higashi (1994) studied the effects of inflorescence size on visits from pollinators and seed set of *Corydalis ambigua* (Papaveraceae). According to them plants with larger inflorescences were visited more often than those with fewer flowers. Fecundity also increased with increasing size of inflorescences. Visitation time (duration of foraging) rather than the frequency of visitations (number of visits) was critical for higher fecundity. Seed production was strongly enhanced by a few long visits (of more than 60s.), and seemed to be independent of large numbers of short visits (of less than 60 s.).

Johnson *et al.* (1995) studied the effect of petal size manipulation on pollen removal, seed set, and insect visitor behaviour in *Campanula americana*. The behaviour of two bees (*Bombus, Halictus*) were assessed. Pollen removal rates did not differ significantly. But seed set was significantly positively correlated with petal size. So they concluded that in plants with many ovules, expenditure on attractive structures may affect seed set.

Inoue *et al.* (1995) conducted studies on different responses of pollinating bees to size variation and sexual phases in flowers of *Campanula*. According to them visitation rates of megachilid bees increased with the flower size. Those of halictid bees and bumblebees did not show particular trends. Bumble bees visited almost all of the flowers consistently. Visitation frequencies to male and female phased flowers were significantly different between megachilids and halictids.

Goldblatt *et al.* (1997) conducted studies on the pollination of *Gladiolus brevifolius* (Iridaceae) by bees and bee mimicking flies and found that flowers are pollinated by a combination of long tongued bees in the genera *Amegilla* and *Allodape* and long tongued flies in the genus *Psilodera*.

Levri (1998) studied the effect of timing of pollination on the mating system and fitness of *Kalmia latifolia* (Ericaceae) and found that timing of pollination did not affect abortion of outcrossed seeds, however delay in pollination increased abortion of selfed seeds and this selection was more intense at the end of the season.

Hof and Lange (1998) studied the influence of insect pollination on yield components in *Dimorphotheca pluvialis* and found that in the absence of insects the populations flowered longer and produced fewer seeds with a lower oil content.

Vaughton and Ramsey (1998) observed floral display, pollinator visitation and reproductive success in the dioecious perennial herb *Wurmbea dioica* (Liliaceae) and found that males produced more and larger flowers than did females. Bees and butterflies responded to this dimorphism and visited males more frequently than females, although flies did not differentiate between the sexes. Within sexes, insect pollinators made more visits to and visited more flowers on plants with many flowers. However, visits per flower did not vary with flower number, indicating that visitation was proportional to the number of flowers per plant. When flower number was experimentally held constant, visitation increased with flower size under sunny but not overcast conditions. Flower size but not number affected pollen removal per flower in males and deposition in females. In males pollen removal increased with flower size. In females pollen deposition increased with flower size. Flower size had no effect on seed production per plant and was negatively related to percent seed set. This indicates that larger flower size in females is unlikely to increase fitness. In both sexes gamete production was positively correlated with flower size. In males greater pollen production would increase the advantage of large flowers, but in females more ovules may represent a resource cost.

Aagren (1996) conducted studies on the population size, pollinator limitation , and seed set in the self-incompatible herb *Lythrum salicaria* and found that there was a positive relationship between population size and seed production per flower and between population size and total seed number per plant.

O'Neil (1999) conducted studies on selection on flowering time in *Lythrum salicaria*. There were significant effects of date (linear and quadratic) and number of flowering stems on the number of pollinator visits per patch. Early in the flowering season pollinator visitation was dependent on the density of plants in flower. However, late in the season pollinators stopped visiting the patch for reasons unrelated to flowering plant density.

Rao and Reddi (1994) studied the reproductive ecology of *Cochlospermum religiosum.* Controlled pollinations revealed fruit initiation in both xenogamy and geitonogamy, but only the xenogamous fruit progressed to maturity with viable seed. The carpenter bees, *Xylocopa latipes* and *X. pubescens* were the principal pollinators.

Dibble and Drummond (1997) conducted studies on floral syndrome in *Amelanchier nantucketensis* (Rosaceae). Their findings supported that optimal foraging theory in that bee visits increases with floral density in these *Amelanchier* spp.

Nansen and Korie (2000) found that half hourly honeybee pollen foraging on *Cistus salvifolius* varied significantly within and between days. They suggested that pollen foraging of honeybees (*A. mellifera*) was determined by the pollen availability.

Barthell *et al.* (2001), when examined the role of non native honeybees (*A. mellifera*) as pollinators of the invasive, non native plant species yellow star thistle (*Centaurea solstitialis*), they could find that a significant correlation existed between honeybee visitation levels and the average number of viable seeds per seed head. Selective exclusion of honeybees at flower heads significantly reduced seed set per seed head.

2.1.7. Vegetable Crops

Chang (1990) studied the importance of honeybee on crop pollination and found that vegetables depend on the cross pollination between varieties to produce valuable seeds or fruits. Insufficient pollination results in less yield and low quality of crops.

Tanda (1985) studied floral biology, pollen dispersal, and foraging behaviour of honeybees in okra (*Abelmoschus esculentum*). According to him the most important insect pollinators of okra were the honeybees *A. mellifera* and *A. c. indica.*

Palanichamy *et al.* (1995) studied the insect pollination of the moringa plant, *Moringa concanensis nimmo* Linn. The relative abundance, pollen deposition, and time spend at flowers reveal that the bumble bee, *Bombus* spp., the little bee *A. florea*, and the black ant *Camponotus compressus* were the major pollinators of moringa. The diurnal activity of

Bombus spp. and *A. florea* on sunny days showed negative correlation with temperature and positive correlation with humidity. On cloudy days these two pollinators showed both negative and positive correlation with temperature and humidity. The pollen depletion from anthers of the moringa flowers by *Bombus* spp. and *A. florea* was more at about 1000 h. and less at about 1600 h.

Spira *et al.* (1996) studied the timing and the effectiveness of sequential pollinations in *Hibiscus moscheutos* and arrived at a conclusion that male reproductive success is more likely to be affected by the timing of pollen dispersal and pollen tube competitive ability than by the total amount of pollen that is exported from flowers.

Pollination ecology of *Solanum sysimbrifolium* Lamk. was studied by Babu *et al.* (1987) and found that two species of *Xylocopa* and one species of *Anthophora* are the active pollinators. All the visitors are diurnal and only larger bees are the effective pollinators.

Abrol (1991 b) studied pollination of brinjal flowers (*Solanum melongena* L.) by bumble bees. Results showed that brinjal flowers were attractive to seven species of insects belonging to four families. Abundance of various pollinating insects was in the order: bumblebees, *B. asiaticus* Morawitz, *B. albopleuralis* Friese, *B. simillimus* Smith, carpenter bee *Xylocopa valga* Gerstacker, honeybees, *A. cerana indica* F., *A. mellifera* L., and halictine bee, *Lasioglossum* spp. Bumblebees were efficient pollinators on the basis of their field behaviour, population dynamics, nectar pollen carrying capacity, and rate of flower visitation in a unit time.

Studies on the influence of honey bee visits to tomato flowers in polyethylene greenhouses (Spangler and Moffett, 1977) showed that *A. mellifera* erratically visited tomato (*Lycopersicon esculentum*) flowers growing in double layered polyethylene greenhouses. The percentage of flowers visited was generally low initially, but increased as the plants matured, then decreased as the plants aged. Flowers of Florida tomatoes exposed to visitation produced significantly more tomatoes by weight (22%) than flowers which were protected from visits by cheese cloth bags.

Dogterom *et al*. (1998) observed that *Bombus vosnesenskii* was an effective pollinator of tomatoes in greenhouses. Bumblebee pollinated flowers produced larger fruit than non-bumble bee pollinated flowers.

Higo *et al.* (2004) conducted studies on honey bee distribution and potential for supplementary pollination in commercial tomato green houses during winter. In one green house significantly larger tomatoes were produced with honey bees present compared with bumble bees alone.

Quagliotti and Marletto (1987) conducted research on the pollination of runner bean (*Phaseolus coccineus* L.) for dry grain production and found that seed production in the plants to which bees had no access to be very low.

2.1.7.1. Pollination in Cucurbitaceous Crops

Majority of vegetable crops belongs to the family cucurbitaceae. But only few studies on the pollination of these crops have been carried out.

Grewal and Sidhu (1978) conducted studies on insect pollinators of some Cucurbits in Punjab and recorded that *Apis* spp. constituted 70.7% of the total number of bees collected from *Cucurbita pepo* in 1974 and 77.2% in 1975. Among the solitary bees *Pithitis smaragdula* (10.8%) was more abundant in 1974 and *X. fenestrata* (7.3%) in 1975. On *Cucumis melo, Apis* spp. were present in predominantly large numbers and constituted over 69% of the total bees collected. The second in importance were *Nomioides variegate* (11.6%) in 1974 and *N. minutissima* (8.6%) in 1975. *Momordica charantia* attracted fewer bees than *C. pepo* or *C. melo*. In the collection made from *M. charantia*, halictids constituted over 60% of the population of bees. *Apis* group was represented mainly by *A. florea*, *A. dorsata* being much less numerous on this crop. The megachilid bees visited flowers of these crops only occasionally.

Ordway *et al.* (1987) conducted studies on pollen dispersal in Buffalo gourd, *Cucurbita foetidissima* by bees of the genera *Apis*, *Peponapis* and *Xenoglossa* and found that honeybees (*A. mellifera*) were the primary pollen vectors in one cultivar field, and the squash bees *Xenoglossa angustior*, *Peponapis timberlakei* and *P. pruinosa* were floral visitors in another field.

Fisher and Pomeroy (1989) studied the pollination of greenhouse muskmelons by bumble bees. The bumble bee workers foraged on the melon flowers from dawn until dusk. And they collected only nectar from male and female flowers. Bee visits were essential for fruit development, although the results contradicted the widely reported view that pollination must be accomplished early in the morning.

Njoroge *et al*. (2004) studied the pollination ecology of *Citrullus lanatus*. It was found that this species depends heavily on the honeybee, *A. mellifera* L., as the main pollinator. Other pollen vectors identified include *Xylocopa* bees, halictid bees, hypotrigona bees, flies and beetles. Phenologically, the plant was found to promote male fitness by producing numerous male flowers, which serve as pollinator attracting structures.

The Four groups of flower visitors comprising hawkmoths (*Hippotion celerio, Agrius convolvuli*), moths (*Noctuidae* spp.), skipper butterfly (*Gorgyra johnstoni*) and honeybee (*A. mellifera*) were considered active pollinators of bottlegourd (*Lagenaria siceraria*). Hawkmoths were suspected to be the major pollinators of this plant in the locations surveyed (Morimoto *et al.*, 2004).

Willis and Kevan (1995) studied the foraging dynamics of *Peponapis pruinosa* on Pumpkin (*C. pepo*). They measured the diurnal and seasonal foraging trends for *P. pruinosa*, a solitary, oligolectic, ground nesting bee and important pollinator of cucurbits in the United States and Mexico and compared their findings with those for *P. pruinosa* elsewhere. The females are active on flowers in the mornings from dawn on. The males are active later in the mornings and spend afternoons and nights in closed flowers. The seasonal emergence of the bees closely parallel that of the plants' anthesis. Diurnal activity is related to the availability of pollen resources on the flowers of *C. pepo*. Almost all pollen is removed from the synandria within 2 h of the start of foraging by female bees.

Dag and Eisikowitch (1999) noted that ventilation of greenhouses increases honeybee foraging activity on melon, *C. melo*. Foraging activity in the open green houses was two to five fold greater than that in the closed greenhouses. The higher activity could be explained by higher flower attractivity due to a higher nectar sugar concentration both in hermaphroditic flowers and male flowers. The higher sugar concentration was probably as a result of the relatively lower humidity there. The greater foraging activity also may have been due to lower air temperatures and better accessibility for the bees. It seems that greenhouse ventilation can improve honeybee pollination activity in melon and probably other greenhouse crops as well.

Ambrose *et al.* (1995) carried out an evaluation of selected commercial bee attractants in the pollination of cucumbers (*C. sativus* L.) and watermelons [*C. lanatus* (Thunb.) Matson and Nakai]. It was found that the bee attractants didn't increase the bee activity on the subject crops when compared to an untreated control, thereby the authors emphasized the need for additional colonies of bees for pollination of cucumbers and watermelons rather than investing in commercial honeybee attractants.

Aguilar and Tabla (2000) studied the importance of conserving alternative pollinators: assessing the pollination efficiency of the squash bee, *P. limitaris* in *Cucurbita moschata*. The results showed that *P. limitaris* to be the most efficient pollinator as: (1) both males and females remove and deposit almost four times as much pollen as *A. mellifera* (2) they make significantly more floral visits than *A. mellifera* and (3) their visit frequency shows a strong relationship to *C. moschata* nectar production during anthesis.

Stanghellini *et al.* (2002 a) studied pollen mobilization in selected cucurbitaceous crops and putative effects of pollinator abundance on pollen depletion rates. The results suggest that total pollen production in these crops may not necessarily reflect total pollen availability to floral visitors. Most of the accessible pollen was removed shortly after anthesis, which is when these crops are most receptive to pollination.

Stanghellini *et al.* (2002 b) studied diurnal activity, floral visitation and pollen deposition by honey bees and bumble bees in field grown cucumber (*Cucumis sativus*) and water melon (*C. lanatus*) and found that bumble bees (*Bombus impatiens*) were more effective than honey bees (*A. mellifera*) for all three parameters on both crops.

Cauto and Calmona (1993) conducted studies on entomophilous pollination in Cucumber (*C. sativus* L. var. Aodai Melhorada), with three different treatments: areas netted without honeybees, netted with honeybees, and open pollinated. Plots visited by bee produced more fruits per square meter and heavier and bigger fruits than other plots. It was concluded that *A. mellifera* was the main pollinating agent of *C. sativus.*

Vaissiere and Froissart (1996) studied the pollination of cantaloupes under spun bonded row cover by honeybees in West Africa and found that total yield, fruit size, and seed content in covered plots and control were significantly greater than the open. Covered plants produced more commercial grade fruit than control plants which received 6 insecticide applications.

Cheng (1996) studied the effects of honeybees on pollination and fruit set of cantaloupe and found that the numbers of hermaphrodite and staminate flowers present did not significantly differ between open and net caged plots, but the number of melons per plant in the caged plots was significantly less than that in the open plots.

Stanghellini *et al.* (1997) studied the effects of honeybee (*A. mellifera* L.) and bumblebee (*Bombus impatiens* Cresson) pollination on fruit set and abortion of cucumber (*C. sativus* L.) and watermelon, *C. lanatus* Thunb.). They found that as the number of bee visits to flowers increased, the number of fruits aborted decreased. Abortion rates for bumble bee-visited flowers were consistently less or equal to those for honeybees at equal bee visit numbers for both crops. There was 100 percent abortion for flowers receiving no entomophilous visitation, and significant abortion rates by flowers receiving low bee visit numbers, emphasizing the need for active transfer of pollen in these crops by insect pollinators. They concluded that bumble bees could serve as a back up or alternate pollinator for honeybees for cucumber and watermelon and possibly other vine crops grown in either greenhouse or field environments.

Gingras *et al.* (1999) conducted studies on visits of honeybees and their effects on Cucumber (*C. sativus* L.) yields in the field. The experiment included flowers not visited by bees, flowers freely visited by bees, and flowers with controlled visits by bees. A single visit to a flower was sufficient to induce fruiting. Flowers that had the greatest number of visits and highest cumulative durations of visits also had the greatest cucumber yields. The rate of pollination was correlated with the cumulative duration but not with the total number of bee visits. The maximum cucumber circumference was significantly correlated with the cumulative duration of bee visits. No significant relation was found between cucumber weight and the number of cumulative duration of visits by bees. The presence of honeybees together with the number and cumulative duration of their visits to the flowers are important to pollination and influence both the quality and quantity of cucumber production.

Stanghellini *et al.* (1998) conducted studies on seed production in watermelon, a comparison between two commercially available pollinators. Study showed that bee visitation level had a strong positive influence on seed set. All flowers bagged to prevent insect visitation aborted, demonstrating the need for active pollen transfer between staminate and pistillate watermelon flowers.

CHAPTER 3

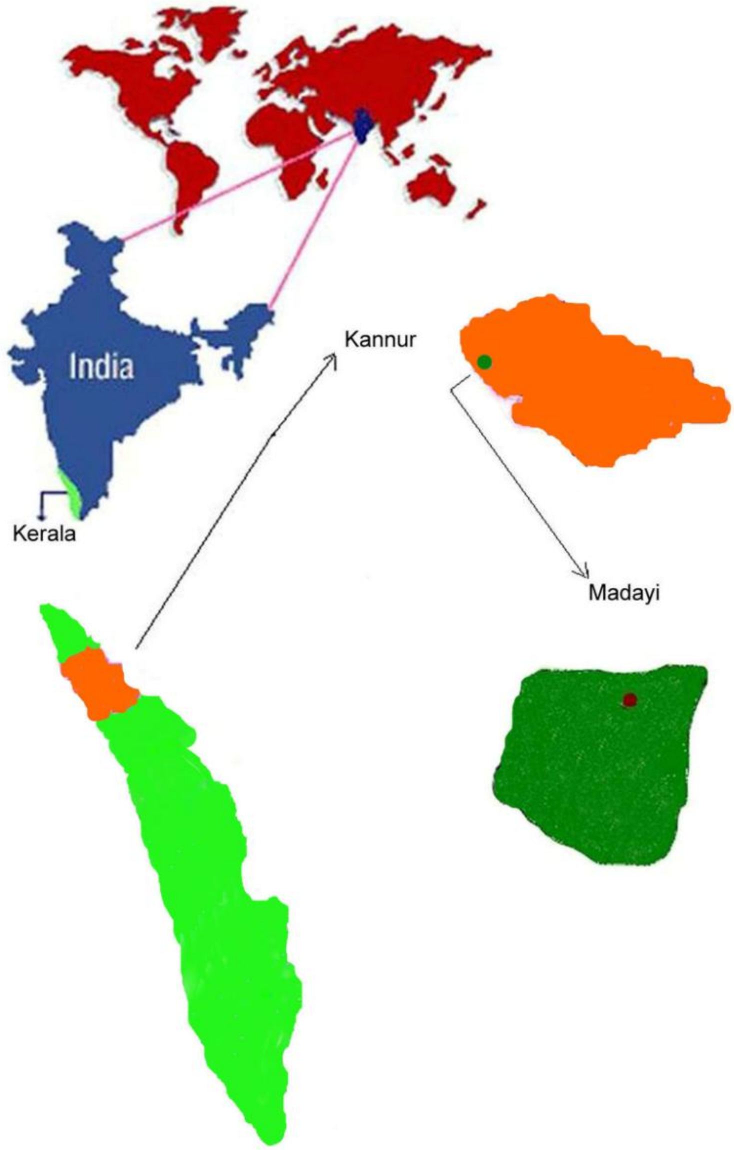
MATERIALS AND METHODS

Insect pollination in the selected cucurbitaceous crops was studied in the field at Madayi which is located between 12º1'N and 75º15'E in Kerala (Plate 1). It is less disturbed habitat and soil type is laterite (Plate 2). Studies were carried out for 4 years (May 2002-October 2005), and done alternatively in 6 natural populations (replicates).

3.1. Crops Selected for the Study

The crops selected are Muskmelon (*Cucumis melo* L.), Cucumber (*Cucumis sativus* L.), Bitter gourd (*Momordica charantia* L.), Ashgourd (*Benincasa hispida* Thunb. and Cogn.) and Pumpkin (*Cucurbita moschata* L.). They are commonly known as vine crops and belong to the family Cucurbitaceae.

Plate 1



Location of the Field

Plate 2

Field at madayi

These species of Cucurbitaceae are similar in habit. They have similar cultivation and nutritional requirements. They are tender crops. These are trailers and have tendrils at the leaf axis. The leaves are alternate, simple, and palmately lobed or palmately compound with three or more leaflets.

The unisexual male and female flowers may be born on the same or different plants. The flowers are generally yellow in colour. The corolla of the flower is often showy, generally lasting a day or less. The female flower contains an ovary that is inferior.

The fruit is a type of berry called pepo, a fruit type in which the ovary wall is fused with the receptacle tissue to form a hard rind. The seeds of some crops have a hardened coat. These plants are mostly entomophilic. So they depend upon the insects to produce fruits and seeds.

3.1.1. Muskmelon [*Cucumis melo* L.]

It is a very popular and a widely cultivated vegetable in India. It is a native of North-West India. The crops seems to have spread to other parts of Asia.

It is a monoecious trailing annual (Plate 3) and its upright stem enables leaves to form a protective arbor like canopy over the flowers and fruit. Flowers are solitary and yellow coloured. Staminate flowers (Plate 3) borne in axillary position with five petals united to slightly beyond the staminal column, then separated and broadly spreading. The staminate flower, supported on a thin stem, consists of a corolla, a single whorl of five stamens, two pairs of which are united with the anthers almost filling the small corolla tube. The pistillate flower (Plate 3) have a broad usually three lobed stigma on a style. The corolla of the flower is on the end of the elongated ovary. Melons develop from the yellow pistillate flower of the leaf and is round to oblong at maturity.

Plate 3


Muskmelon Plant


Muskmelon Male Flower


Muskmelon Female Flower


Cucumber Plant


Cucumber Male Flower


Cucumber Female Flower

3.1.2. Cucumber [*Cucumis sativus* L.]

It is a very popular and widely cultivated vegetable in India. The cucumber is thought to have been domesticated in India. It has been cultivated in Western Asia for 3000 years.

The cucumber is a monoecious subtropical trailing or climbing, annual (Plate 3) with vines covered with stiff bristly hairs. The roughly triangular leaves are supported on petioles or stems which permit the leaves to overshadow the flowers and fruit. The cucumber flowers (Plate 3) are solitary, axillate and the yellow wrinkled petals are quite similar in size and shape. The pistillate flower (Plate 3) is easily recognized by the large ovary at the base of the flower. The ovary is sparsely covered with spiny growths. The pistillate flower has three thick stigma lobes atop and a short broad style. The fruit is pendulous and oblong and has a relatively large stem. When young, its skin has spiny tubercles.

3.1.3. Bittergourd [*Momordica charantia* L.]

This is a minor crop that occurs in the old world tropics. It is considered to be native of India. But it is much esteemed by Malayans and Chinese.

It is a monoecious annual plant (Plate 4) of slender climbing or trailing habit. It is usually grown on a trellis system. Leaves are palmate. The yellow flowers are solitary in the leaf axil. Corolla with five petals. In staminate flowers (Plate 4) the stamens are free, filaments are free, and anthers are united. The pistillate flowers (Plate 4) are slightly smaller. In pistillate flowers, the ovary is inferior with three stigmas. The fruits are long, oblong and oval, narrowed or tapering toward both ends. It is covered with blunt tubercles. They are green when unripe, turning to an orange yellow colour when ripe. The fruits burst upon maturing.

Plate 4

Bittergourd Plant

Bittergourd Male Flower

Bittergourd Female Flower

Ashgourd Plant

Ashgourd Male Flower

Ashgourd Female Flower

3.1.4. Ashgourd [*Benincasa hispida* Thunb. and Cogn.]

It is a native of Japan and Java. It is generally grown throughout India and all other tropical warm countries, such as China, Malaysia, Singapore, Turkey, Iraq for its edible fruits.

It is a long running vine (Plate 4) with brown hairy stem and broad hairy oval leaves. It is monoecious and has solitary yellow flowers. The staminate flowers (Plate 4) have long peduncles, the pistillate ones (Plate 4) are short stalked or almost sessile. The three stigmas lead to many ovules. It produces nearly spherical to oblong long fruit. The unripe fruit is somewhat hairy and is not covered with waxy bloom. The ripe fruit has a whitish waxy surface.

3.1.5. Pumpkin [*Cucurbita moschata* L.]

It is a native of Tropical America and is extensively cultivated in India.

The plant is an annual monoecious vine (Plate 5) having a climbing or trailing habit. The leaves are large and dark green, and are borne on petioles. There are prickly hairs on the stems and leaves. The flowers are solitary and deep orange- yellow coloured. Staminate flowers (Plate 5) at the end of thin stem, and have three anthers producing relatively large pollen grains. Pistillate flowers (Plate 5) are on a short peduncle, the style is thick, and the stigma two lobed. The showy corolla of the pistillate flower is attached to the end of the easily recognized ovary. The ovary is divided into 3-5 carpels.

Plate 5

Pumpkin Plant

Pumpkin Male Flower

Pumpkin Female Flower

3.2. Experimental Design

Insect pollination in the above mentioned crops was studied as per the experimental design by Stanghellini *et al*. (1997), with certain modifications. The study was conducted on a randomized complete block design of cucurbit crops with 6 replicates of 2 beds for each. There were 2 beds /replicate and 12 hills /bed. All crops were grown on raised bed of 2m. wide and 6m. length. The field was directly seeded with 3-5 seeds /hill. Upon emergence (germination) the plants were thinned to one /hill. Spacing between beds was 1.5m. with interplant spacing of 1m. and the inter-replicate spacing of 10m. Each replicate measured 33sq.m.with sequential plantings.

Plant irrigation, fertilization, weeding measures followed were of standard commercial practices of Kerala. The plants were watered once a week until the fruits were 2/3rd their normal size, then it was irrigated at fortnightly intervals.

To quantify floral display, pollinator visitation and its consequences on fruit set observations were made on randomly selected plants. One plant from each bed was selected for observation. To quantify pollinator visitation each staminate and pistillate flower in a plant were observed for five minutes. 12 staminate and 12 pistillate flowers were observed on each day i.e. 4 staminate and 4 pistillate flowers each during each diurnal phase. Observations were carried out in three diurnal phases - initial phase (ip), middle phase (mp) and late phase (lp) according to the longevity of flowers and peak time of pollinator visitation [Muskmelon (ip) 0730 h.-0930 h., (mp) 0930 h.-1130 h., (lp) 1130 h.-1330 h.; Cucumber (ip) 0630 h.-0830 h., (mp) 0830 h.-1030 h., (lp) 1030 h.-1230 h.; Bittergourd (ip) 0600 h.-0800 h., mp: 0800 h.-1000 h., lp: 1000 h.-1200 h.; Ashgourd (ip) 0700 h.-0900 h.; (mp) 0900 h.-1100 h.; (lp) 1100 h.-1300 h.); Pumpkin (ip) 0530 h.-0730 h.; (mp) 0730 h.-0930 h.; (lp) 0930 h.-1130 h.]. Duration of each phase was two hours. They were made for 12 days during initial phase (IP), 18 days during middle phase (MP) and 12 days during late phase (LP) of flowering season. All observations were made on warm sunny days. The data from each diurnal phase and seasonal phase were pooled for analysis.

The following temporal qualitative and quantitative ecological variables were considered for the evaluation of pollination by insects.

I. Phenology

1.Day of first anthesis [♂ flower and ♀ flower].

2.Longevity of flowers [Time of flower opening, Time of flower closing].

3.Number of open flowers / plant /day [♂ flower and ♀ flower].

4.Size /dimension of flower.

II. Entomology

1.Types of pollinators

2.Dynamics of pollinating behaviour.

(a)Visitation frequency of insects on one flower in different seasonal phases [Initial Phase (IP), Middle Phase (MP) and Late Phase (LP) of flowering].

(b)Visitation frequency of insects on one flower in different diurnal phases [initial phase (ip), middle phase (mp) and late phase (lp) of the day].

(c)Number of ♂and ♀ flowers visited by one insect in different seasonal phases [Initial Phase (IP), Middle Phase (MP) and Late Phase (LP) of flowering].

(d)Number of ♂and ♀ flowers visited by one insect in different diurnal phases [initial phase (ip), middle phase (mp) and late phase (lp) of the day].

(e) Diurnal activity (Duration of foraging activity).

(i) Duration of visit of each insect in different seasonal phase [Initial Phase (IP), Middle Phase (MP) and Late Phase (LP) of flowering].

(ii) Duration of visit of each insect in different diurnal phases [initial phase (ip), middle phase (mp) and late phase (lp) of the day].

III. Palynology

1. Quantity of pollen.

(a) Pollen count in different seasonal phases [Initial Phase (IP), Middle Phase (MP) and Late Phase (LP) of flowering].

(b) Pollen count in different diurnal phases [initial phase (ip), middle phase (mp) and late phase (lp) of the day].

(c) Pollen removal in different seasonal phases [Initial Phase (IP), Middle Phase (MP) and Late Phase (LP) of flowering].

(d) Pollen removal in different diurnal phases [initial phase (ip), middle phase (mp) and late phase (lp) of the day].

(e) Pollen deposition on stigma in different seasonal phases [Initial Phase (IP), Middle Phase (MP) and Late Phase (LP) of flowering].

(f) Pollen deposition on stigma in different diurnal phases [initial phase (ip), middle phase (mp) and late phase (lp) of the day].

2. Quality of pollen.

(a) Pollen viability in different seasonal phases [Initial Phase (IP), Middle Phase (MP) and Late Phase (LP) of flowering].

(b) Pollen viability in different diurnal phases [initial phase (ip), middle phase (mp) and late phase (lp) of the day].

IV. Pomology

1. Number of fruits formed in different seasonal phases [Initial Phase (IP), Middle Phase (MP) and Late Phase (LP) of flowering].
2. Number of fruits formed in different diurnal phases [initial phase (ip), middle phase (mp) and late phase (lp) of the day].
3. Nature of fruits formed (malformed, small sized, medium sized, and Optimum sized) in different seasonal phases [Initial Phase (IP), Middle Phase (MP) and Late Phase (LP) of flowering].
4. Nature of fruits formed (malformed, small sized, medium sized, and optimum sized) in different diurnal phases [initial phase (ip), middle phase (mp) and late phase (lp) of the day].
5. Weight of fruits formed in different seasonal phases [Initial Phase (IP), Middle Phase (MP) and Late Phase (LP) of flowering].
6. Weight of fruits formed in different diurnal phases [initial phase (ip), middle phase (mp) and late phase (lp) of the day].
7. Total number of seeds produced in different seasonal phases [Initial Phase (IP), Middle Phase (MP) and Late Phase (LP) of flowering].
8. Total number of seeds produced in different diurnal [initial phase (ip), middle phase (mp) and late phase (lp) of the day].
9. Viability of seeds in different seasonal phases [Initial Phase (IP), Middle Phase (MP) and Late Phase (LP) of flowering].
10. Viability of seeds in different diurnal phases [initial phase (ip), middle phase (mp) and late phase (lp) of the day].

Data regarding the variables as shown above were procured by following apt observation techniques.

Day of first Anthesis

The plants were regularly observed from the day of germination to find out the opening day of first male and female flower.

Longevity of Flowers

In order to find out the opening and closing time of flowers they were observed from early morning to late evening.

Number of Flowers

For each observation period the number of open flowers [♂ and ♀] in each focal plant was recorded. Each flower type was then averaged to derive the mean number of staminate and pistillate flowers produced per plant per day.

Size /Dimension of Flower

Size was measured by measuring the diameter of petals [♂ and ♀]. Measurements were made when the flowers were fully open using digital callipers to 0.01mm accuracy.

Pollen Count

Flowers at the time of anthesis and at the end of each phase of pollination were removed and pollen grains were collected by using a brush. Pollen grains from each sample were washed with water to a petridish for further counting with a counting chamber.

Pollen Removal

To find out the number of pollen grains removed, the staminate flowers were bagged (Plate 6) before anthesis. The bags were fashioned from (closed nylon) pollination cage netting. Aluminium wire was shaped to keep the sides of the bag from contacting the blossom. Selected bags were removed in each phase of pollination to allow restricted insect visits. Flowers from each phase were removed and pollen grains were washed into a petridish with the aid of a brush and further counted by using a counting chamber. Number of pollen grains removed /anther was calculated by substracting the number of pollen grains /dehisced anther from number of pollen grains /undehisced anther.

Stigmatic Pollen Deposition

To find out the number of pollen grains deposited, randomly chosen pistillate flowers were bagged (Plate 6) before anthesis to prevent insect visitation. Selected bags were removed in each phase of pollination to allow restricted insect visits. After insect visitation pollen was removed from stigmas by using warmed fuschin glycerin jelly (gel) mounted on glass microscope slides. Three cubes of gel ($3mm^3$) per slide were used for each treated flower to remove as much pollen as possible. Slides were reheated and a glass coverslip was placed over each cube of gel. Slides were then stored at 4.0ºC for pollen quantification at a later date. Pollen grains were counted using light microscopy. The procedure was repeated in 12 flowers in 3 phases (initial, middle, and late phases) of foraging.

Plate 6

Bagged Flower

Pollen Viability

Viability of pollen grains were tested using Brewbaker and Kwack's culture medium (Brewbaker and Kwack, 1963). Sample of pollen grains were dipped in 30 ml. of the solution and kept it for 2-3 h. in a petridish. Viability was measured based on the number of pollen grains having pollen tube growth.

Identification of Pollinators

During field study, pollinators were caught by sweeping with a long handled insect net and later identified.

Floral Visitation (Dynamics of Pollinating behaviour)

Observations were separated into two hour intervals for each species. On all cultivars, the insects visited per minute in individual flower were quantified over the course of floral anthesis. An insect landing on any part of the flower was counted as a visit. The insect was counted as a pollinator if it went so far into the flower that contact with anthers and pistils was probable. All plot area and foraging insects were chosen randomly for observation.

Numbers of flowers visited were identified by dye transfer. Fluorescent orange dye particles were used to distinguish pollen grains.

Duration of visit (handling time) on each flower was also recorded to provide data on the average time spent on flowers by different insects. For this purpose one species of each type was timed while it visited flowers on plants of each morph.

Insect visitation treatments to test the effect on Fruit setting

Bagging experiment (Plate 6) was done to test the effect of Insect visitation on fruit setting also. Pistillate flowers of each crop were bagged in the early evening before anthesis to control insect visits on the following day. On the day of treatment selected pistillate flowers were unbagged in each phase and insect visits were allowed on each flower. After each flower had received the visits the bags were resealed and tagged with treatment type and date in each phases of pollination. The no visit controls remained bagged for the entire day of anthesis. All bags were removed from the flowers after 1900 h. of the day of treatment after the insect activity in the field ceased.

The sampling period per day was restricted to morning intervals based upon observation on anther dehiscence, stigmatic receptivity and peak foraging activity. Individual plants of the test cultivars were chosen randomly each day for treatment.

Number of Fruits

In all experiments the developing fruits were allowed to mature to a maximum size as seed set was also evaluated as part of a companion study between insect types. All treatment and control flowers that aborted were recorded.

The fruits from different samples were handpicked. The harvested fruits were counted. The number of fruits formed in different controlled pollinated samples were recorded.

Nature of Fruits

Fruits were analysed according to the shape and size variations and sorted them as normal small sized, normal medium sized, normal optimum sized, malformed and aborted. Size was measured by measuring the length

(l) and breadth (b) of fruits. [Muskmelon (lb): small size ≤12 cm. x 6 cm., medium size ≤16 cm. x 8 cm., optimum size ≤20 cm. x 10 cm.; Cucumber (lb): small size ≤15 cm. x 4 cm.; medium size ≤20 cm. x 6 cm.; optimum size ≤25 cm. x 8 cm.; Bittergourd (lb): small size ≤10 cm. x 3 cm., medium size ≤16 cm. x 4 cm., optimum size ≤ 20 cm. x 6 cm.; Ashgourd (lb): small size ≤15 cm. x 12 cm., medium size ≤25 cm. x 20 cm., optimum size ≤30 cm. x 25 cm.; Pumpkin (lb): small size ≤ 20 cm. x 15 cm., medium size ≤30 cm. x 20 cm., optimum size ≤40 cm. x 30 cm.]. Fruits which had normal shape and growth were categorized as normal fruits. And those shapeless and undergrown were included in the category of malformed fruits.

Weight of Fruits

The harvested fruits from the experimental plots were weighed using common balance and weights were recorded.

Number of Seeds

The seed set was determined from sub samples of fruits. The fruits were thawed, cut longitudinally and partially along the convex side. Seeds were manually extracted from the fruits. Along with the developed seeds (ovules) unfertilized ovules were counted.

Viability of seeds

Unfertilized ovules were taken as nonviable seeds. To confirm viability the seeds were soaked in water and kept for 7-16 days to germinate and the number of sprouted and non sprouted seeds were noted.

3.3. Statistical Analysis

Statistica '99 version was used to carry out all statistical analysis.

CHAPTER 4

OBSERVATIONS AND RESULTS

Data on the consequence of insect pollination in five cucurbit crops under study (Muskmelon, Cucumber, Bittergourd, Ashgourd and Pumpkin) showed that the pollinators (Plate 7 and Plate 8) have considerable influence on fruit setting. Variations in behaviour of these pollinators along with different aspects of phenology and palynology resulted in great difference in various aspects of pomology in these crops.

Plate 7

Amegilla parhypate

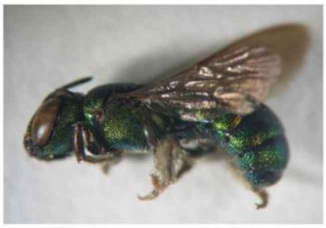
Apis cerana

Apis dorsata

Apis florea

Braunsapis picitarsis

Ceratina heiroglyphica



Ceratina smaragdula

Halictus taprobanae

Plate 8


Halictus timidus


Trigona iridipennis


Xylocopa aestuans


Xylocopa tenuiscapa


Cephonodes picus


Macroglossum troglodytus


Aulacophora foveicollis


Aulacophora lewisii

4.1. Muskmelon

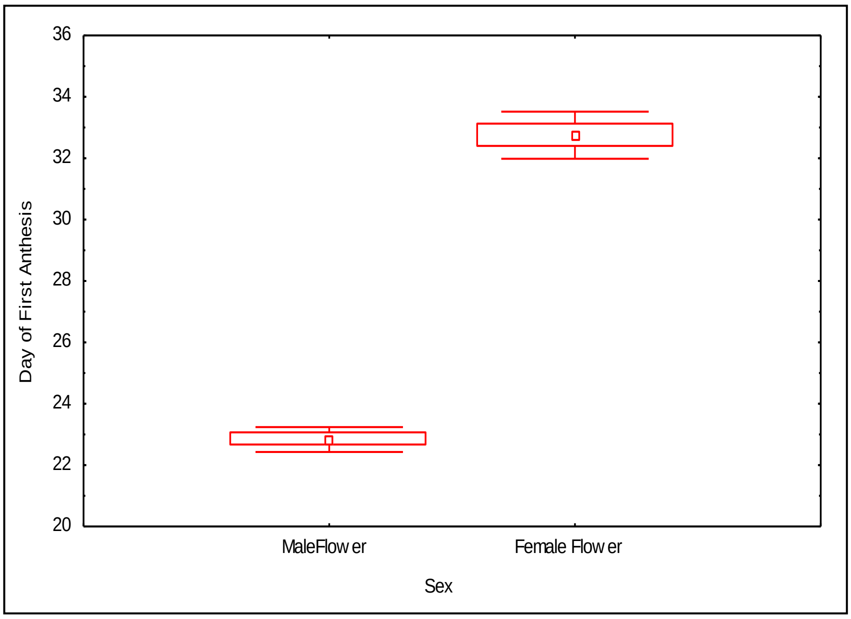
[*Cucumis melo* L.]

4.1.1. Phenology

4.1.1.1. Day of First Anthesis

It was observed that first male (♂) and female (♀) flower opened on 22.83±0.71th and 32.75±1.35th day respectively from the day of germination and they were significantly different (p=0.00) (Figure 1).

Figure.1: Day of first anthesis of male and female flowers after germination



4.1.1.2. Flower Opening Time

Male flower (♂) anthesis commenced between 0645 h. and 0751 h. and female flower (♀) between 0630 h. and 0739 h. Significant difference was found between initiation of opening time of male (♂) and female (♀) flowers (p=0.03). Mean durations taken for full corolla expansion were 1.01±0.01 h. and 1.07±0.01 h. by male (♂) and female (♀) flowers respectively and they were significantly different (p=0.00).

4.1.1.3. Flower Closing Time

Male flower (♂) closing commenced between 1601 h. and 1706 h. and female flower (♀) between 1615 h. and 1722 h. Significant difference was found between initiation of closing time of male (♂) and female (♀) flowers (p=0.00). Mean durations taken for full petal constriction were 2.18±0.09 h. and 2.02±0.00 h. for male (♂) and female (♀) flowers respectively and the difference was significant (p=0.00).

4.1.1.4. Number of Flowers

Mean number of staminate or male (♂) and pistillate or female (♀) flowers produced per plant per day increased from initial phase (IP) of the season (♂=13.93±3.98, ♀=1.43±0.49) to middle phase (MP) of the season (♂=23.58±6.91, ♀=2.27±0.48), where maximum number of flowers were found and then decreased to late phase (LP) (♂=10.38±2.34, ♀=1.21±0.41) of the season where minimum number of flowers were found. Mean number of staminate (♂) and pistillate (♀) flowers within seasonal phases such as IP (p=0.00) (Figure 2); MP (p=0.00) (Figure 3); LP (p=0.00) (Figure 4) and the mean number of flowers produced between seasonal phases were significantly different (p=0.00).

Figure.2: Mean number of male and female flowers produced /plant /day (Initial seasonal phase)

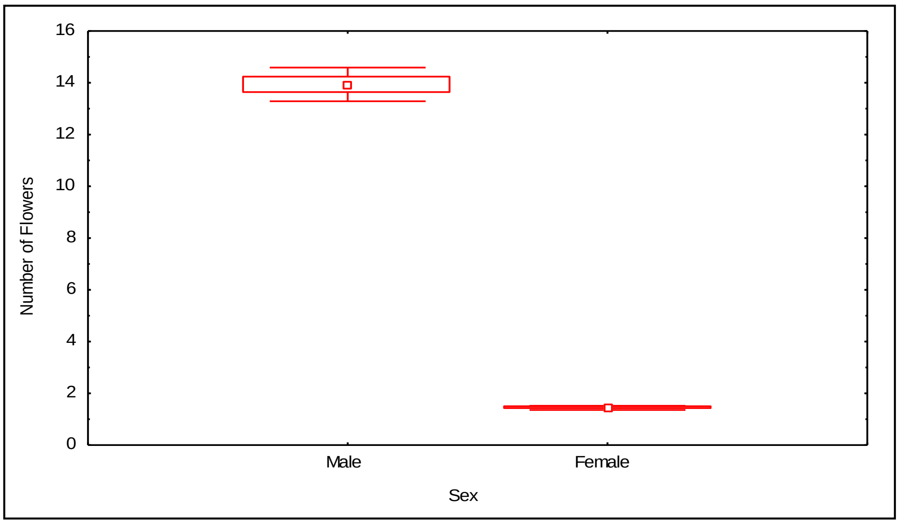


Figure.3: Mean number of male and female flowers produced /plant /day (Middle seasonal phase)

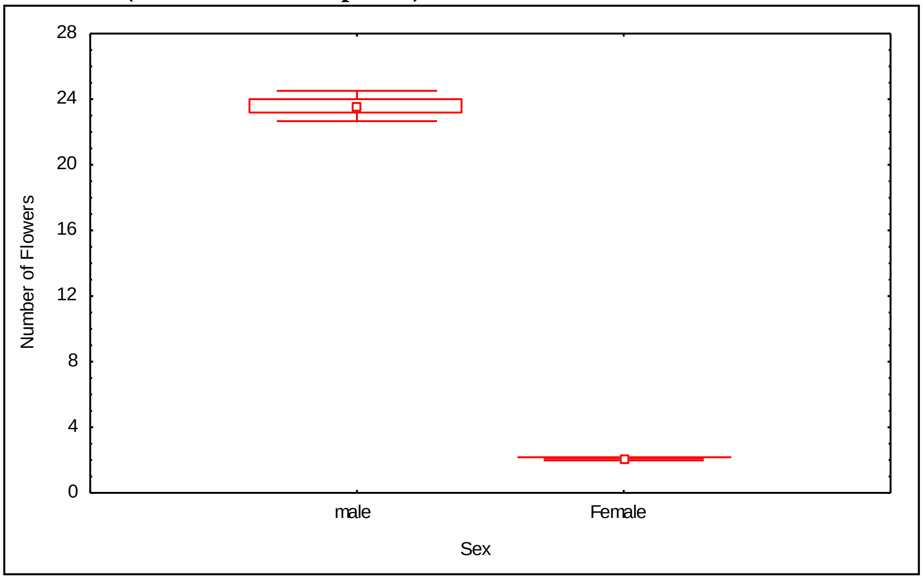
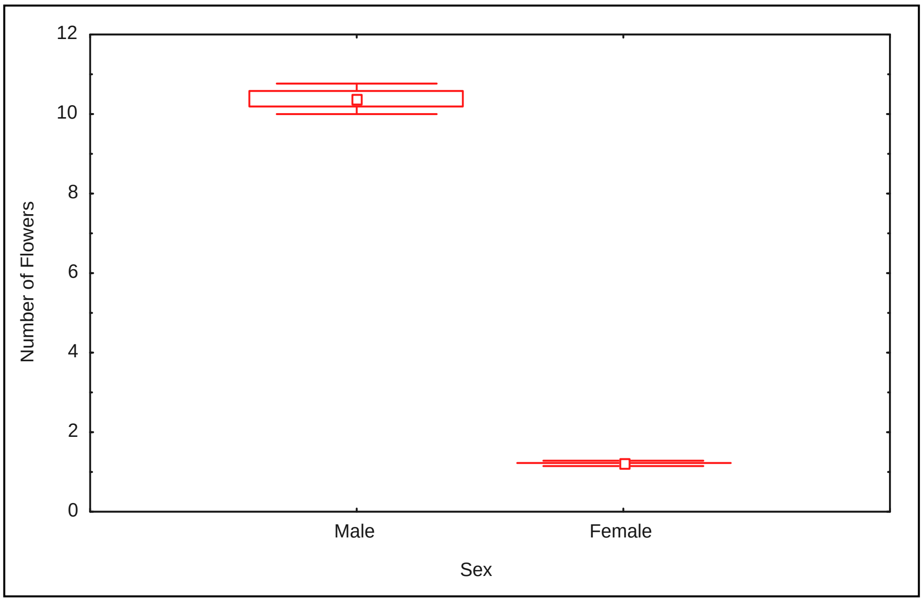


Figure.4: Mean number of male and female flowers produced /plant /day (Late seasonal phase)



4.1.1.5. Size /Dimension of Flower

Mean size of staminate and pistillate flowers produced per plant per day increased from initial phase (IP) of the season (♂=2.47±0.44 cm., ♀=2.97±0.44 cm.) to middle phase (MP) of the season (♂=3.23±0.38 cm.,

♀=3.73±0.38 cm.) where maximum size was observed and then decreased to late phase (LP) (♂=2.17±0.26 cm., ♀=2.66±0.28 cm.) of the season where minimum size was observed. Mean size of staminate and pistillate flowers within seasonal phases such as IP (p=0.00) (Figure 5); MP (p=0.00) (Figure 6); LP (p=0.00) (Figure 7) and between seasonal phases were significantly different (p=0.00).

Figure.5: Mean size of male and female flowers produced (Initial seasonal phase)

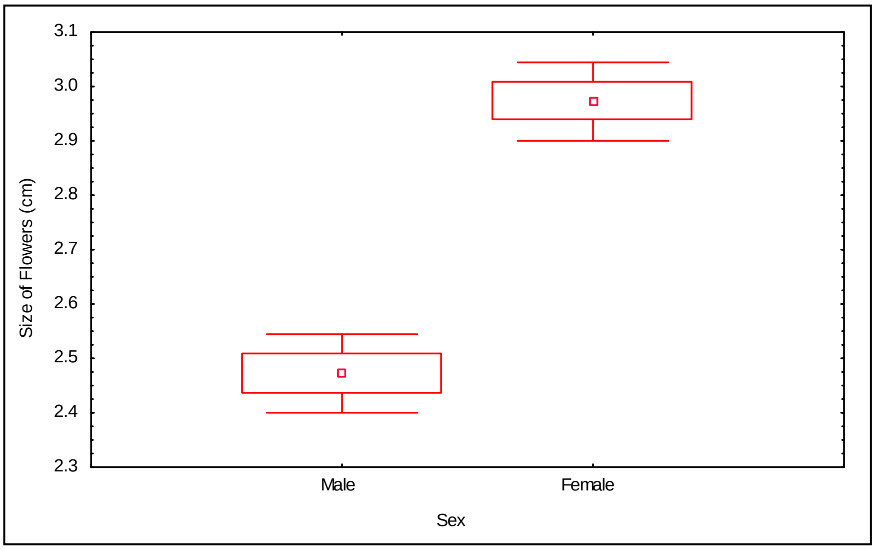


Figure.6: Mean size of male and female flowers produced (Middle seasonal phase)

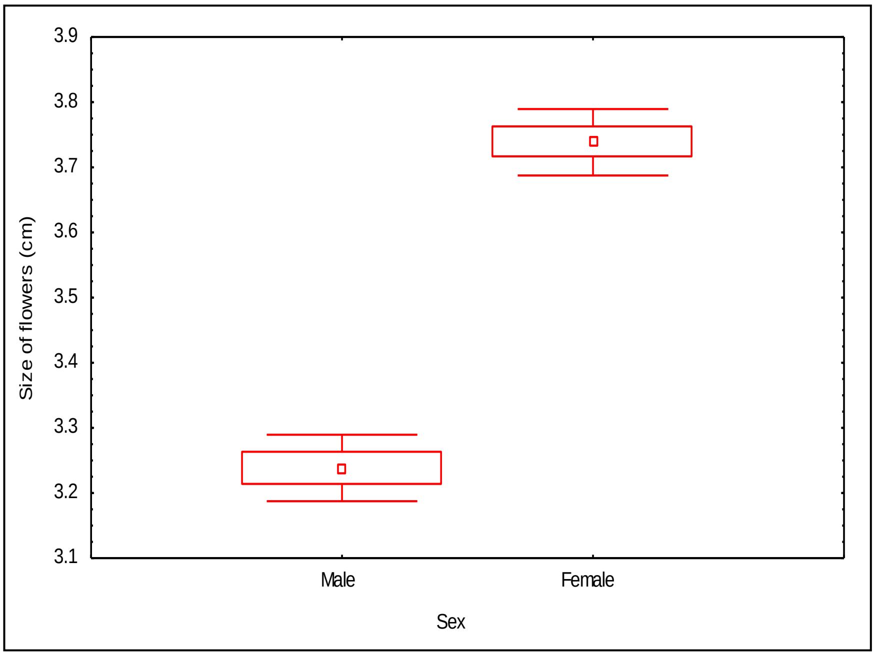
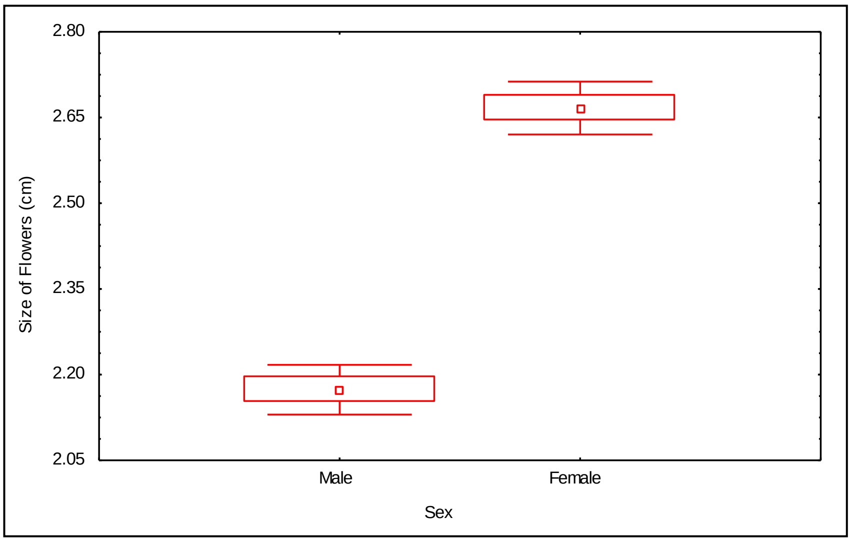


Figure.7: Mean size of male and female flowers produced (Late seasonal phase)



4.1.2. Entomology

4.1.2.1. Identification of Pollinators

A total of 16 species of insect were recorded, from 3 orders, during the study (Plate 7 and Plate 8). The most abundant order was the Hymenoptera including families Apidae, Halictidae, Xylocopidae followed by Coleoptera. Much less abundant was Lepidoptera. The list of pollinators of muskmelon observed during the study is given in Table1.

Table.1: List of pollinators

Order	Family	Species
Hymenoptera	Halictidae	*Halictus timidus* Smith
		Halictus taprobanae Cameron
		Trigona iridipennis Smith
	Apidae	*Ceratina heiroglyphica* Smith
		Apis cerana Fabricius
		Amegilla parhypate Lieftinck
		Apis dorsata Fabricius
		Apis florea Fabricius
		Braunsapis picitarsis Cameron
		Ceratina smaragdula Fabricius
	Xylocopidae	*Xylocopa tenuiscapa* Westwood
		Xylocopa aestuans Linnaeus
Coleoptera	Chrysomelidae	*Aulacophora lewisii* Baly
		Aulacophora foveicollis Lucas
Lepidoptera	Sphingidae	*Cephonodes picus* Cramer
		Macroglossum troglodytus Boisduval

4.1.2.2. Floral visitation (Dynamics of Pollinating behaviour)

4.1.2.2.1. Frequency of Pollinator Visit

The variety of insects encountered and the visits they made were more numerous in the middle phase (MP), than in initial phase (IP) and Late phase (LP). It was observed that a mean of 19 and 15.58 hymenopterans and 2.16 and 1.66 coleopterans visited the male (♂) and female (♀) flowers/day respectively in the initial phase (IP) of the season. In middle phase (MP) a mean of 22.33 and 19.5 hymenopterans, 1.83 and 1.41 coleopterans and 0.41 and 0.41 lepidopterans visited the male (♂) and female (♀) flowers /day respectively. In late phase (LP) of the season a mean of 12.75 and 10.91 hymenopterans and 4.33 and 2.16 coleopterans visited the male (♂) and female (♀) flowers /day respectively. Variation in the case of different diurnal phases in each phase of the season was also observed. Higher frequency of visit was observed in middle diurnal phase of middle phase of season. Lowest frequency of visit was observed in late diurnal phase of late phase of season. The most dominant group was Hymenoptera followed by Coleoptera and Lepidoptera. Significant difference was found in visitation frequency shown by different orders of insects [IP (p=0.00) (Figure 8); MP (p=0.00) (Figure 9); LP (p=0.00) (Figure 10)] (Table 2). Variation in visitation frequency shown by different species of insects belonging to Hymenoptera, Coleoptera and Lepidoptera was also obsereved. *Halictus timidus* was the most frequent pollinator. It was followed by *Ceratina heiroglyphica, Halictus taprobanae, Trigona iridipennis and Apis cerana.* They were regular, consistent and made the higher number of visits compared to other insects, at all sites. The visitation frequency shown by different species of insects varied significantly [IP (p=0.00) (Figure 11); MP (p=0.00) (Figure 12); LP (p=0.00) (Figure 13)] (Table 3). No significant difference in visitation frequency on staminate (♂) and pistillate (♀) flowers [IP (p=0.13); MP (p=0.77); LP (p=0.09)] was found. Frequency of visitation during different diurnal phases varied significantly [IP (p=0.00); MP (p=0.00); LP (p=0.00)]. Different seasonal phases also showed siginificant difference in visitation frequency (p=0.00).

Table.2: Frequency of pollinator (Order) visit /day

Order	Sex of flower	Initial Phase (IP)			Middle Phase (MP)			Late Phase (LP)		
		ip	**mp**	**lp**	**ip**	**mp**	**lp**	**ip**	**mp**	**lp**
Hymenoptera	♂	5.91	10.33	2.75	7.08	12	3.25	4.16	7.66	0.91
	♀	4.83	8.83	1.91	6	10.83	2.66	3.33	7.16	0.41
Coleoptera	♂	0.66	0.41	1.08	0.41	0.33	1.08	1.41	1.33	1.58
	♀	0.5	0.41	0.75	0.41	0.33	0.66	0.75	0.66	0.75
Lepidoptera	♂	0	0	0	0.41	0	0	0	0	0
	♀	0	0	0	0.41	0	0	0	0	0

IP - Initial phase of season
MP -Middle phase of season
LP -Late phase of season

ip - initial phase of day
mp - middle phase of day
lp - late phase of day

♂ -Male flower
♀ -Female flower

Figure.8: Frequency of pollinator (Order) visit /day (Initial seasonal phase)

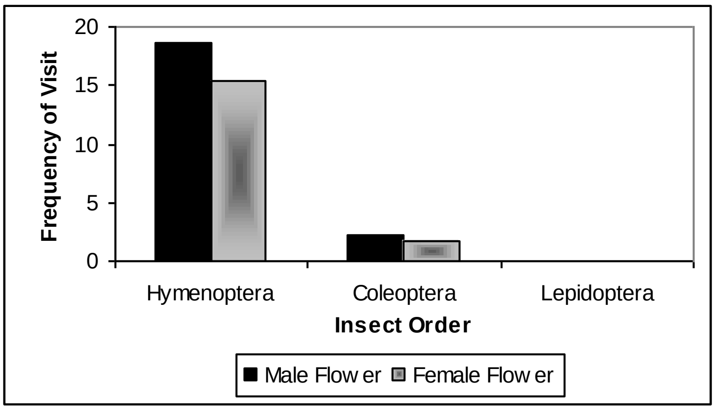


Figure.9: Frequency of pollinator (Order) visit /day (Middle seasonal phase)

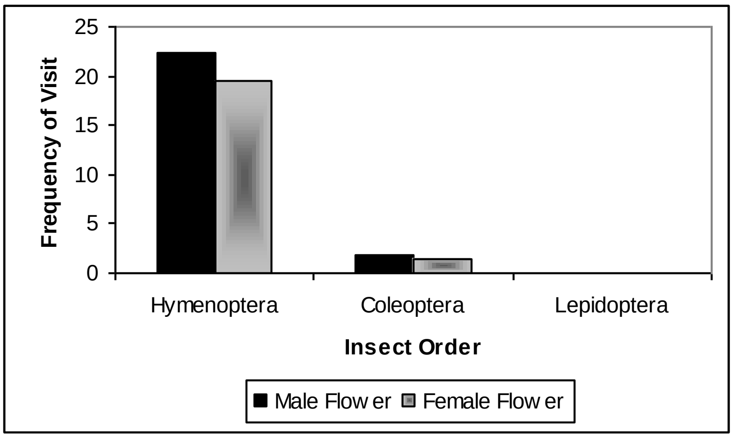


Figure.10: Frequency of pollinator (Order) visit /day (Late seasonal phase)

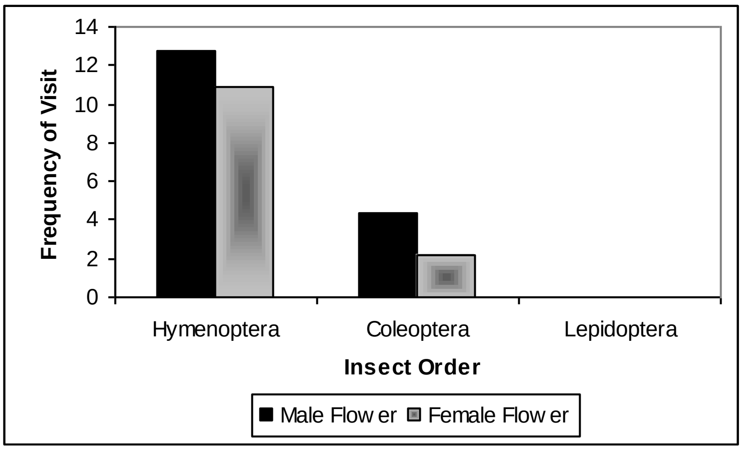


Table.3: Frequency of pollinator (Species) visit /day

Species	Sex of flower	Initial Phase (IP)			Middle Phase (MP)			Late Phase (LP)		
		ip	mp	lp	ip	mp	lp	ip	mp	lp
Halictus timidus	♂	4.41	7.16	1.66	5.25	7.41	1.91	.83	5.91	0.25
	♀	3.66	6.25	1.16	4.41	6.83	1.58	2.41	5.58	0.08
Halictus taprobanae	♂	0.41	0.75	0.25	0.58	0.75	0.33	0.33	0.41	0.25
	♀	0.33	0.5	0.25	0.5	0.58	0.25	0.25	0.41	0.08
Trigona iridipennis	♂	0.25	0.5	0.25	0.33	0.58	0.25	0.25	0.41	0.16
	♀	0.25	0.41	0.08	0.25	0.5	0.25	0.16	0.41	0.08
Ceratina heiroglyphica	♂	0.66	1.58	0.41	0.66	1.75	0.5	0.58	0.66	0.08
	♀	0.5	1.41	0.33	0.58	1.58	0.41	0.41	0.5	0.08
Apis cerana	♂	0.16	0.33	0.16	0.16	0.41	0.25	0.16	0.25	0.16
	♀	0.08	0.25	0.08	0.16	0.33	0.16	0.08	0.25	0.08
Amegilla parhypate	♂	0	0	0	0.08	0	0	0	0	0
	♀	0	0	0	0.08	0	0	0	0	0
Braunsapis picitarsis	♂	0	0	0	0	0.33	0	0	0	0
	♀	0	0	0	0	0.33	0	0	0	0
Apis florea	♂	0	0	0	0	0.16	0	0	0	0
	♀	0	0	0	0	0.08	0	0	0	0
Ceratina smaragdula	♂	0	0	0	0	0.25	0	0	0	0
	♀	0	0	0	0	0.25	0	0	0	0
Apis dorsata	♂	0	0	0	0	0.08	0	0	0	0
	♀	0	0	0	0	0.08	0	0	0	0
Xylocopa aestuans	♂	0	0	0	0	0.16	0	0	0	0
	♀	0	0	0	0	0.16	0	0	0	0
Xylocopa tenuiscapa	♂	0	0	0	0	0.08	0	0	0	0
	♀	0	0	0	0	0.08	0	0	0	0
Aulacophora lewisii	♂	0.41	0.25	0.58	0.25	0.16	0.58	0.83	0.75	1
	♀	0.25	0.25	0.5	0.25	0.16	0.41	0.5	0.41	0.5
Aulacophora foveicollis	♂	0.25	0.16	0.5	0.16	0.16	0.5	0.58	0.58	0.58
	♀	0.25	0.16	0.25	0.16	0.16	0.25	0.25	0.25	0.25
Cephonodes picus	♂	0	0	0	0.25	0	0	0	0	0
	♀	0	0	0	0.25	0	0	0	0	0
Macroglossum troglodytus	♂	0	0	0	0.16	0	0	0	0	0
	♀	0	0	0	0.16	0	0	0	0	0

IP - Initial phase of season   ip - initial phase of day   ♂ -Male flower
MP - Middle phase of season   mp - middle phase of day   ♀ -Female flower
LP - Late phase of season   lp - late phase of day

Figure.11: Frequency of pollinator (Species) visit/day (Initial seasonal phase)

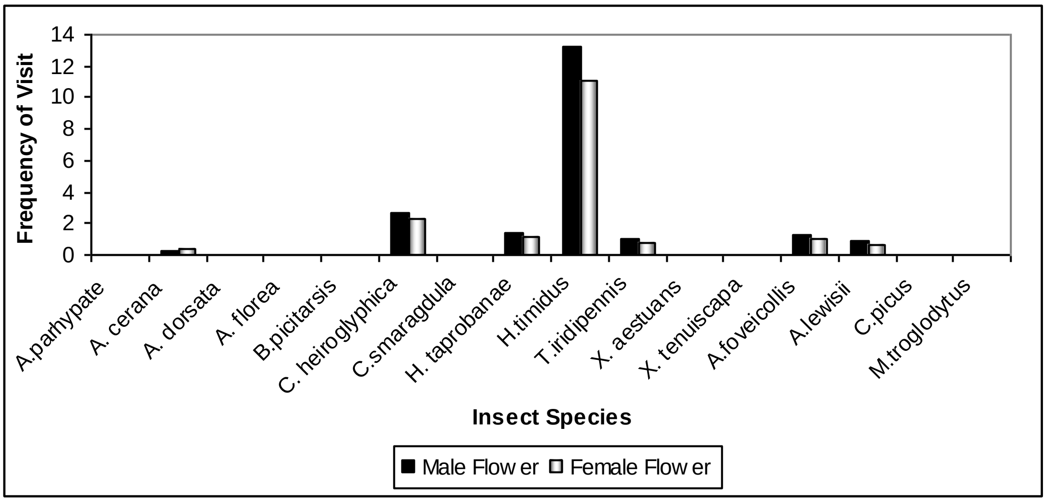


Figure.12: Frequency of pollinator (Species) visit/day (Middle seasonal phase)

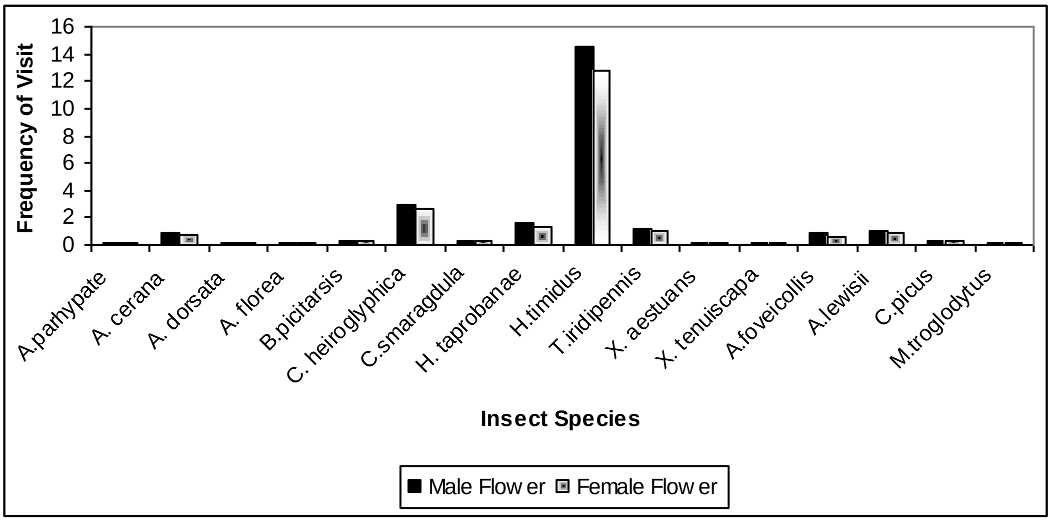
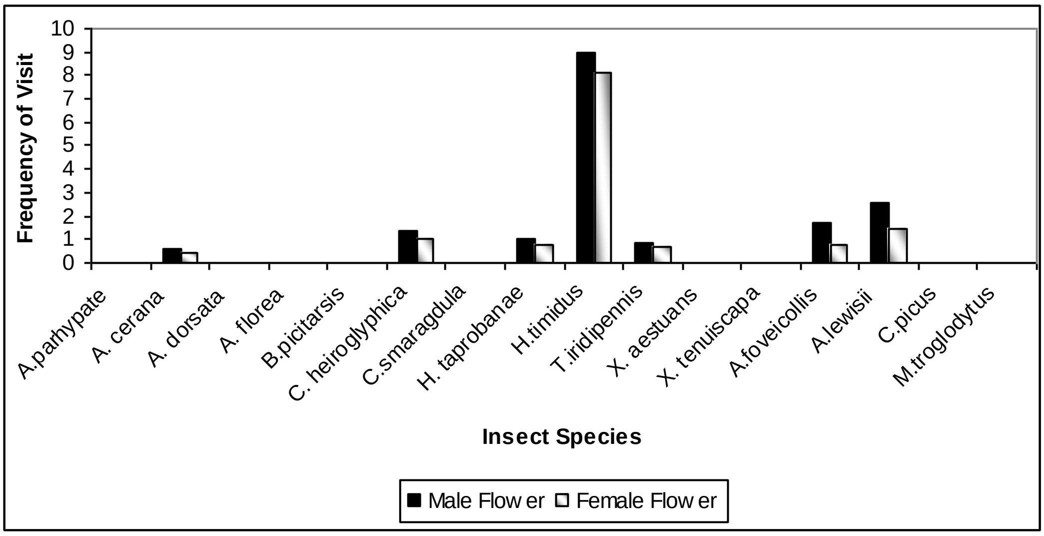


Figure.13: Frequency of pollinator (Species) visit /day (Late seasonal phase)



4.1.2.2.2. Mean Number of Flowers Visited by Pollinators

Mean number of male (♂) and female (♀) flowers visited was recorded during different phases of the day. There was significant difference in the way these components changed in number over the day and season. It increased from initial phase of the season, (IP) to middle phase of the season, (MP) and decreased to late phase of the season, (LP). Hymenopterans visited a mean of 38 male (♂) flowers and 31.33 female (♀) flowers and coleopterans visited a mean of 4.83 male (♂) flowers and 3 female (♀) flower /day in the initial phase (IP) of the season. In middle phase (MP) a mean of 62.25 male (♂) flowers and 49.91 female (♀) flowers were visited by hymenopterans, 3.41 male (♂) flowers and 2.33 (♀) female flowers by coleopterans and 0.5 male (♂) flowers and 0.33 (♀) female flowers by lepidopterans /day. In late phase (LP) of the season it was a mean of 26.5 male (♂) flowers and 19.58 female (♀) flowers by hymenopterans and 4.75 male (♂) flowers and 2.66 female (♀) flowers by coleopterans /day. Variation in number of flowers visited in different diurnal phases in each phase of the season was also observed. More number of flowers were visited in the middle diurnal phase of middle seasonal phase and less number of flowers were visited in the late diurnal phase of late seasonal phase. Hymenopterans visited highest number of flowers. Significant difference was found in number of flowers visited by different orders of insects [IP (p=0.00) (Figure 14); MP (p=0.00) (Figure 15); LP (p=0.00) (Figure 16)] (Table 4). Variation in number of flowers visited by different species of insects belonging to Hymenoptera, Coleoptera and Lepidoptera was also observed [IP (p=0.00) (Figure 17); MP (p=0.00) (Figure 18); LP (p=0.00) (Figure 19)] (Table 5). But there was no significant difference between the numbers of male (♂) and female (♀) flowers visited by foragers [IP (p=0.18); MP (p=0.35); LP (p=0.20). Pollinators visited significantly different number of flowers in different diurnal phases of the season [IP (p=0.00); MP (p=0.00); LP (p=0.00)]. Significant difference was also found between different seasonal phases (p=0.00).

Table.4: Mean number of flowers visited by pollinators (Order) /day

Order	Sex of flower	Initial Phase (IP)			Middle Phase (MP)			Late Phase(LP)		
		ip	mp	lp	ip	mp	lp	ip	mp	lp
Hymenoptera	♂	10.91	19.75	7.33	17.33	32.91	12	10.83	13.58	2.08
	♀	9.16	16.25	5.91	14.83	26.16	8.91	8.25	10.33	1
Coleoptera	♂	1.58	1.83	1.41	1.08	1.33	1	1.58	1.75	1.41
	♀	1	1.16	0.83	0.66	1	0.66	0.91	1.08	0.66
Lepidoptera	♂	0	0	0	0.5	0	0	0	0	0
	♀	0	0	0	0.33	0	0	0	0	0

IP - Initial phase of season
MP - Middle phase of season
LP - Late phase of season
ip - initial phase of day
mp - middle phase of day
lp - late phase of day
♂ -Male flower
♀ -Female flower

Figure.14: Mean number of flowers visited by pollinators (Order) /day (Initial seasonal phase)

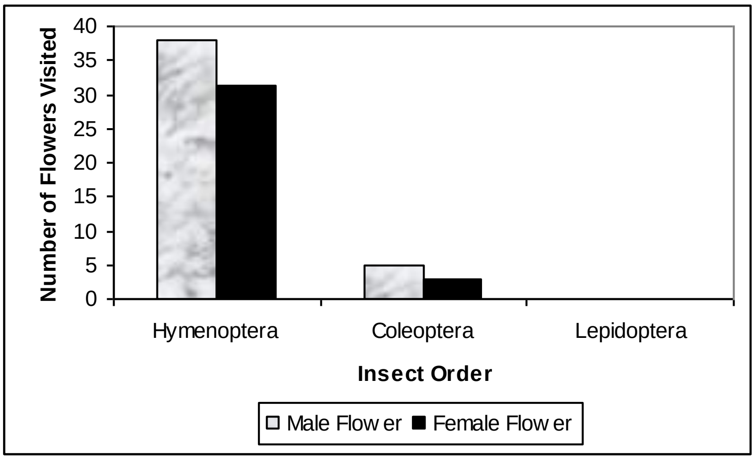


Figure.15: Mean number of flowers visited by pollinators (Order) /day (Middle seasonal phase)

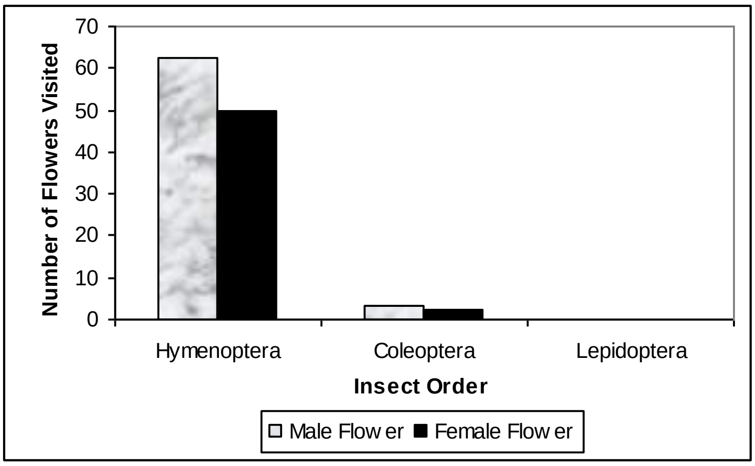


Figure.16: Mean number of flowers visited by pollinators (Order) /day (Late seasonal phase)

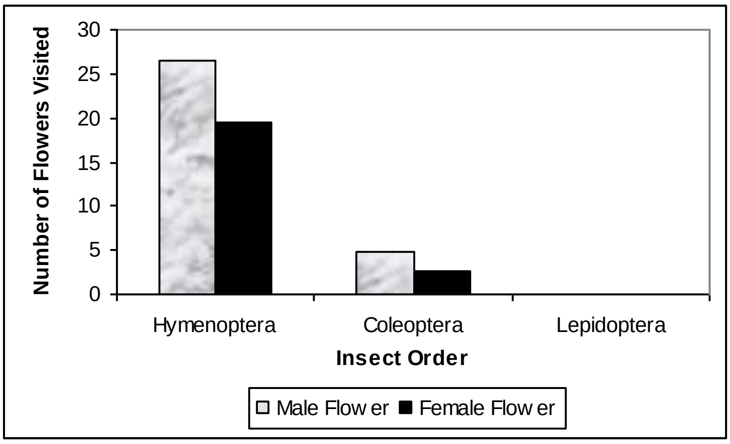


Table.5: Mean number of flowers visited by pollinators (Species) /day

Species	Sex of flower	Initial Phase (IP)			Middle Phase (MP)			Late Phase(LP)		
		ip	mp	lp	ip	mp	lp	ip	mp	lp
Halictus timidus	♂	6.16	9.83	4.33	8.41	11	6.33	5.83	7	0.91
	♀	5.5	9.08	3.75	7.25	10	5	4.75	6.5	0.33
Halictus taprobanae	♂	0.41	0.75	0.25	2.5	5.08	1.75	0.41	0.66	0.25
	♀	0.33	0.5	0.25	2.16	4	1.16	0.33	0.33	0.08
Trigona iridipennis	♂	1.16	2	0.91	2.5	4.25	1.16	1.41	1.5	0.33
	♀	0.75	1.25	0.25	1.66	2.83	0.83	0.75	0.83	0.33
Ceratina heiroglyphica	♂	2.5	5.75	1.58	2.75	8.91	2.16	2.5	3.41	0.33
	♀	2.16	4.83	1.5	2.75	7	1.5	2.08	2.16	0.25
Apis cerana	♂	0.66	1.41	0.25	1.08	2.33	0.58	0.66	1	0.25
	♀	0.41	0.58	0.16	0.91	1.33	0.41	0.33	0.5	0.16
Amegilla parhypate	♂	0	0	0	0.08	0	0	0	0	0
	♀	0	0	0	0.08	0	0	0	0	0
Braunsapis picitarsis	♂	0	0	0	0	0.41	0	0	0	0
	♀	0	0	0	0	0.33	0	0	0	0
Apis florea	♂	0	0	0	0	0.25	0	0	0	0
	♀	0	0	0	0	0.08	0	0	0	0
Ceratina smaragdula	♂	0	0	0	0	0.33	0	0	0	0
	♀	0	0	0	0	0.25	0	0	0	0
Apis dorsata	♂	0	0	0	0	0.08	0	0	0	0
	♀	0	0	0	0	0.08	0	0	0	0
Xylocopa aestuans	♂	0	0	0	0	0.16	0	0	0	0
	♀	0	0	0	0	0.16	0	0	0	0
Xylocopa tenuiscapa	♂	0	0	0	0	0.08	0	0	0	0
	♀	0	0	0	0	0.08	0	0	0	0
Aulacophora lewisii	♂	0.91	1	0.83	0.66	0.66	0.58	0.91	0.91	0.83
	♀	0.5	0.58	0.5	0.41	0.5	0.41	0.5	0.5	0.41
Aulacophora foveicollis	♂	0.66	0.83	0.58	0.41	0.66	0.41	0.66	0.83	0.58
	♀	0.5	0.58	0.33	0.25	0.5	0.25	0.41	0.58	0.25
Cephonodes picus	♂	0	0	0	0.33	0	0	0	0	0
	♀	0	0	0	0.25	0	0	0	0	0
Macroglossum troglodytus	♂	0	0	0	0.16	0	0	0	0	0
	♀	0	0	0	0.08	0	0	0	0	0

IP - Initial phase of season
MP - Middle phase of season
LP - Late phase of season

ip - initial phase of day
mp - middle phase of day
lp - late phase of day

♂ -Male flower
♀ -Female flower

Figure.17: Mean number of flowers visited by pollinators (Species) /day (Initial seasonal Phase)

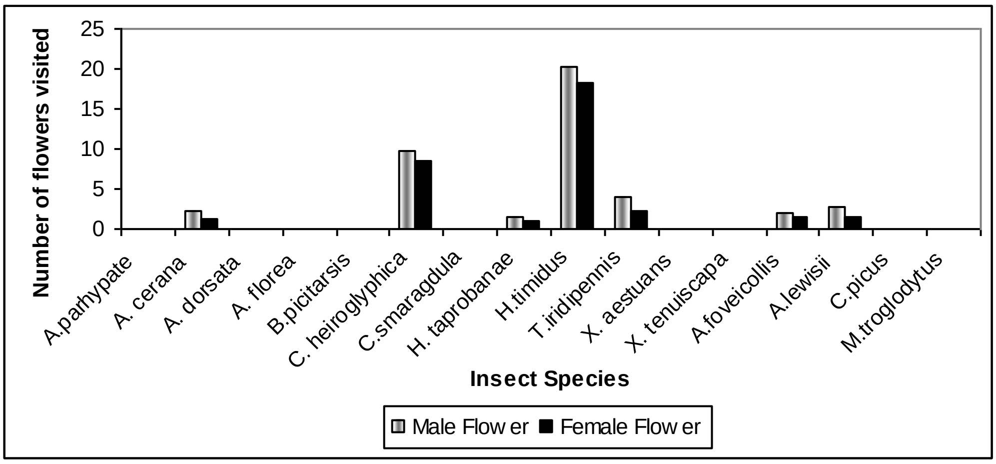


Figure.18: Mean number of flowers visited by pollinators (Species) /day (Middle seasonal phase)

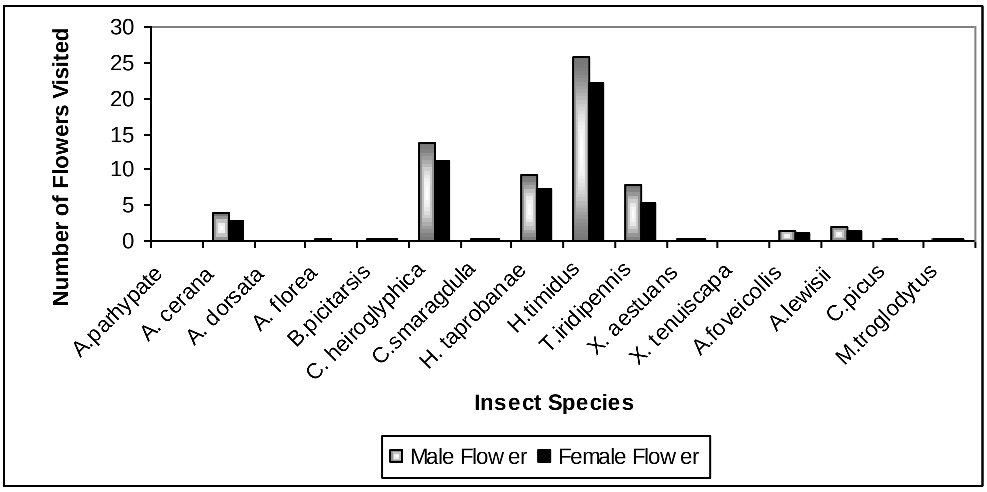
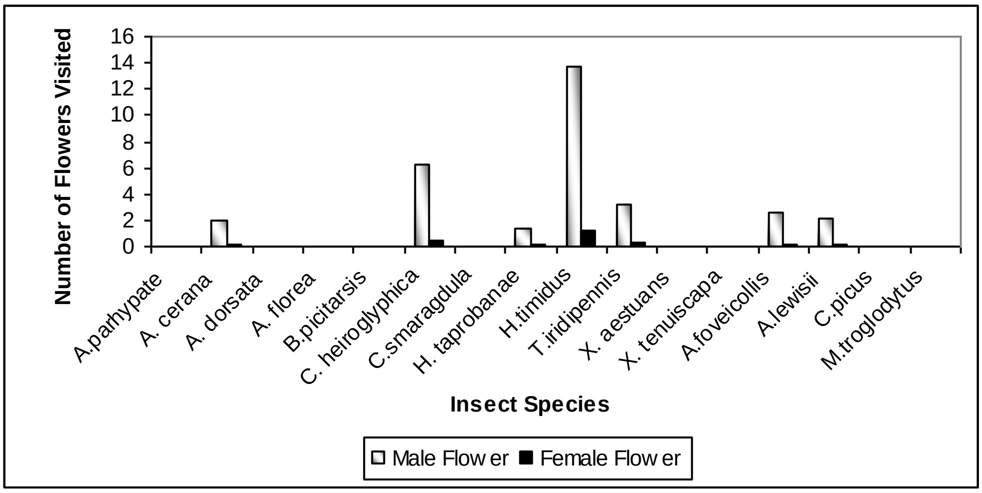


Figure.19: Mean number of flowers visited by pollinators (Species) /day (Late seasonal phase)



4.1.2.2.3. Mean Duration of Pollinator Visit

Duration of visit on each flower was also recorded to provide data on the average time spent on male (♂) and female (♀) flowers by different insects. It was observed that mean duration of pollinator visit increased from initial phase, IP to middle phase MP and decreased to late phase LP of the season. But the mean duration of visit decreased from initial to late in diurnal phases of each seasonal phase. The pollinators took longest duration in initial diurnal phase of middle seasonal phase and shorter duration in late diurnal phase of late seasonal phase. Mean duration of visit taken by hymenopterans was 23.91 sec. on male (♂) flowers and 18.75 sec. on female (♀) flowers and by coleopterans was 5.16 sec. on male (♂) flowers and 3.08 sec. on female (♀) flowers /day in the initial phase (IP) of the season. In middle phase (MP) 34.75 sec. on male (♂) flowers and 26.16 sec. on female (♀) flowers were taken by hymenopterans, 4.5 sec. on male (♂) flowers and 2.5 sec. on female flowers (♀) by coleopterans and 0.66 sec. on male (♂) flowers and 0.5 sec. on female flowers by lepidopterans /day. In late phase (LP) of the season it was 16.16 sec. on male (♂) flowers and 11.25 sec. on female flowers (♀) by hymenopterans and 5.08 sec. on male (♂) flowers and 2.75 sec. on female (♀) flowers by coleopterans /day. Variation in mean duration of visit taken by different orders and different species of insects in different diurnal phases in each phase of the season was also recorded. The duration taken by different orders [IP ($p=0.00$) (Figure 20); MP ($p=0.00$) (Figure 21); LP ($p=0.00$) (Figure 22)] (Table.6) and different species of pollinators varied significantly [IP ($p=0.00$) (Figure 23); MP ($p=0.00$) (Figure 24); LP ($p=0.00$) (Figure 25)] (Table 7). But there was no significant difference between the duration for visiting the male (♂) and female (♀) flowers IP ($p=0.10$); MP ($p=0.13$); LP ($p=0.06$). In diurnal phases of each season durations of pollinator visit were significantly different [IP (p=0.00); MP (p=0.00); LP (p=0.00)]. Significant difference in duration was also found between different seasonal phases (p=0.00).

Table.6: Mean duration of pollinator (Order) visit in seconds

Order	Sex of flower	Initial Phase (IP)			Middle Phase (MP)			Late Phase(LP)		
		ip	**mp**	**lp**	**ip**	**mp**	**lp**	**ip**	**mp**	**lp**
Hymenoptera	♂	9.66	8.58	5.66	13.66	15.58	6.91	8.16	6.5	1.5
	♀	7.91	7	3.83	10.58	11.58	4.83	5.66	4.91	0.66
Coleoptera	♂	2.08	1.58	1.5	1.83	1.41	1.25	2.08	1.58	1.41
	♀	1.16	1	0.91	0.91	0.83	0.75	1.08	0.91	0.75
Lepidoptera	♂	0	0	0	0.66	0	0	0	0	0
	♀	0	0	0	0.5	0	0	0	0	0

IP - Initial phase of season
MP - Middle phase of season
LP - Late phase of season

ip - initial phase of day
mp - middle phase of day
lp - late phase of day

♂ -Male flower
♀ -Female flower

Figure.20: Mean duration of visit on flowers by pollinators (Order) in seconds (Initial seasonal phase)

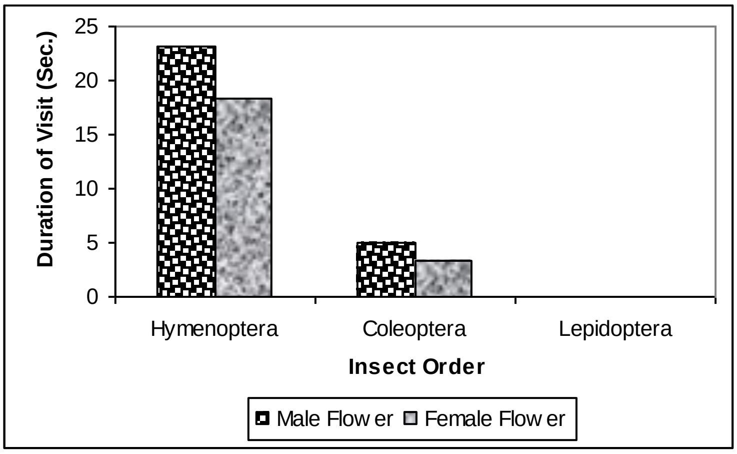


Figure.21: Mean duration of visit on flowers by pollinators (Order) in seconds (Middle seasonal phase)

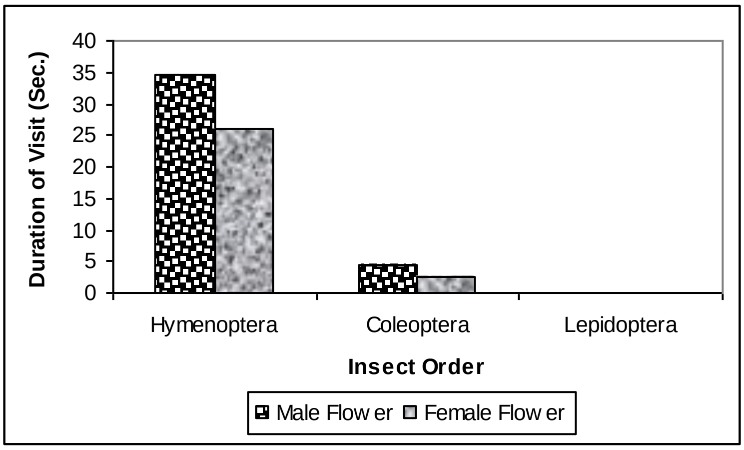


Figure.22: Mean duration of visit on flowers by pollinators (Order) in seconds (Late seasonal phase)

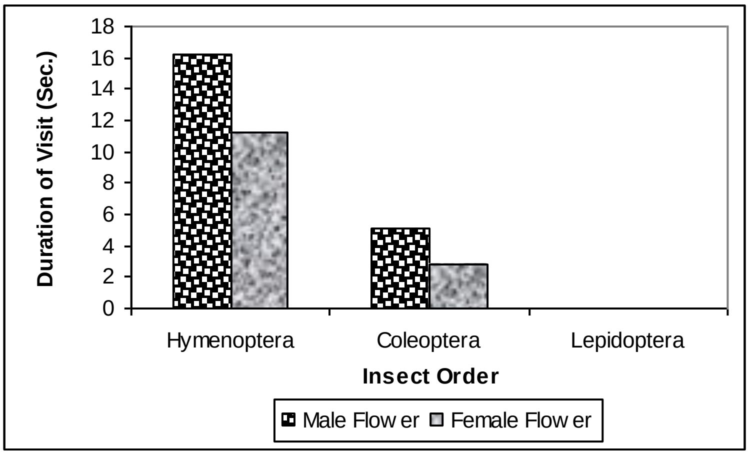


Table.7: Mean duration of pollinator (Species) visit in seconds

Species	Sex of flower	Initial Phase (IP)			Middle Phase (MP)			Late Phase(LP)		
		ip	mp	lp	ip	mp	lp	ip	mp	lp
Halictus	♂	4.25	3.5	2.75	5.83	4.91	3.75	3.41	2.91	0.66
timidus	♀	3.91	3.41	2.25	5	4.16	2.83	2.83	2.58	0.16
Halictus	♂	1.58	1.41	0.75	2.16	2.08	0.83	1.16	0.75	0.33
taprobanae	♀	0.91	0.75	0.5	1.41	1.41	0.5	0.75	0.41	0.16
Trigona	♂	1.08	1	0.58	1.83	1.33	0.58	0.91	0.83	0.16
iridipennis	♀	0.75	0.66	0.16	1.16	0.91	0.41	0.41	0.41	0.08
Ceratina	♂	2.25	2.16	1.16	2.75	2.75	1.25	2.16	1.5	0.16
heiroglyphica	♀	1.91	1.83	0.75	2.16	2	0.83	1.33	1.16	0.16
Apis	♂	0.5	0.5	0.41	0.91	0.91	0.5	0.5	0.5	0.16
cerana	♀	0.41	0.33	0.16	0.75	0.66	0.25	0.33	0.33	0.08
Amegilla	♂	0	0	0	0.16	0	0	0	0	0
parhypate	♀	0	0	0	0.08	0	0	0	0	0
Braunsapis	♂	0	0	0	0	1.16	0	0	0	0
picitarsis	♀	0	0	0	0	0.75	0	0	0	0
Apis	♂	0	0	0	0	0.33	0	0	0	0
florea	♀	0	0	0	0	0.16	0	0	0	0
Ceratina	♂	0	0	0	0	0.25	0	0	0	0
smaragdula	♀	0	0	0	0	0.25	0	0	0	0
Apis	♂	0	0	0	0	0.16	0	0	0	0
dorsata	♀	0	0	0	0	0.16	0	0	0	0
Xylocopa	♂	0	0	0	0	0.16	0	0	0	0
aestuans	♀	0	0	0	0	0.16	0	0	0	0
Xylocopa	♂	0	0	0	0	0.08	0	0	0	0
tenuiscapa	♀	0	0	0	0	0.08	0	0	0	0
Aulacophora	♂	1.08	0.83	0.83	1	0.75	0.66	1.08	0.83	0.83
lewisii	♀	0.58	0.5	0.5	0.58	0.5	0.41	0.58	0.5	0.41
Aulacophora	♂	1	0.75	0.66	0.83	0.66	0.58	1	0.75	0.58
foveicollis	♀	0.58	0.5	0.41	0.33	0.33	0.33	0.5	0.41	0.33
Cephonodes	♂	0	0	0	0.41	0	0	0	0	0
picus	♀	0	0	0	0.33	0	0	0	0	0
Macroglossum	♂	0	0	0	0.25	0	0	0	0	0
troglodytes	♀	0	0	0	0.16	0	0	0	0	0

IP - Initial phase of season
MP - Middle phase of season
LP - Late phase of season

ip - initial phase of day
mp-middle phase of day
lp - late phase of day

♂ - Male flower
♀ - Female flower

Figure.23: Mean duration of visit on flowers by pollinators (Species) in seconds (Initial seasonal phase)

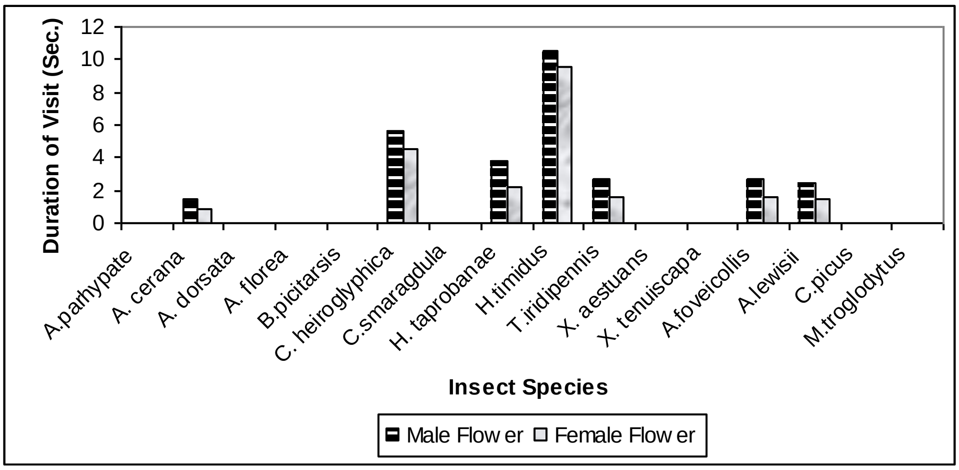


Figure.24: Mean duration of visit on flowers by pollinators (Species) in seconds (Middle seasonal phase)

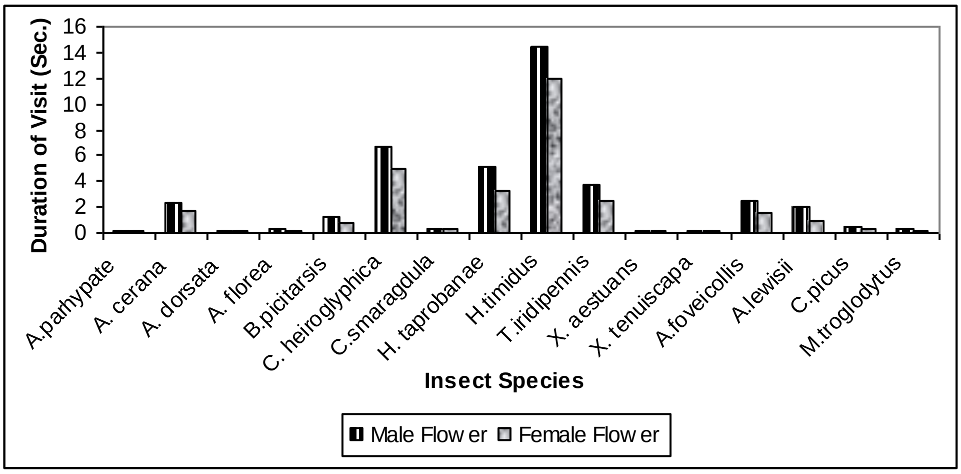
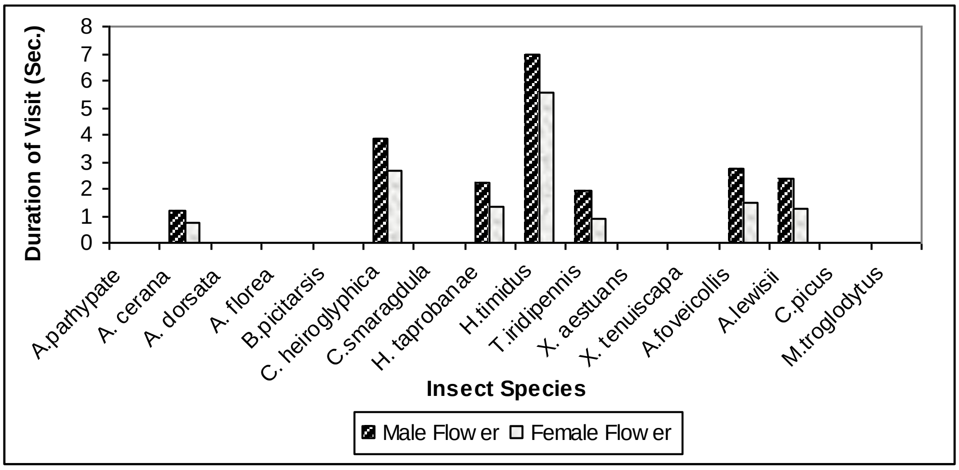


Figure.25: Mean duration of visit on flowers by pollinators (Species) in seconds (Late seasonal phase)



4.1.3. Palynology

4.1.3.1. Pollen Count

The mean number of pollen grains produced by staminate flowers varied by phases of the season. It was highest in MP (11501.33±15.44) than in IP (5784.66±8.95) and LP (4587.75±6.99) of the season. At anthesis staminate flowers contained more pollen grains /flower and the number of pollen grains remaining on anthers decreased over time of day [IP (ip) (5784.66±8.95), (mp) (4761.5±5.71), (lp) (3109.66±15.37); [MP (ip) (11501.33±15.44), (mp) (8765.58±5.45), (lp) (2838.58±26.33); [LP (ip) (4587.75±6.99), (mp) (4005.5±3.60), (lp) (3171±7.21)] and the counts were significantly different in different phases of day such as IP (p=0.00) (Figure 26); MP (p=0.00) (Figure 27); LP (p=0.00) (Figure 28). Significant difference in mean pollen count was also found between seasonal phases (p=0.00) (Figure 29).

Figure.26: Mean pollen counts in diurnal phases (Initial seasonal phase)

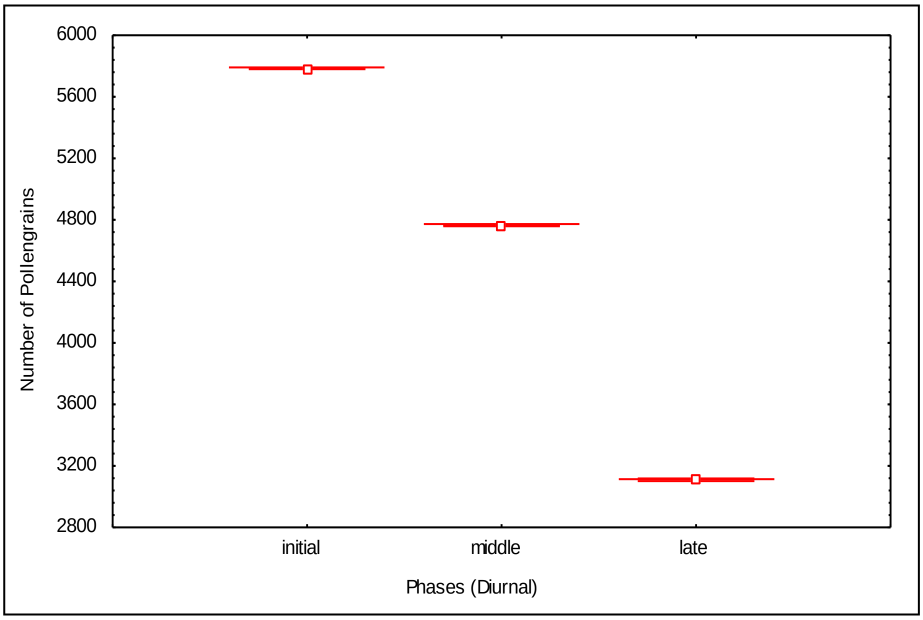


Figure.27: Mean pollen counts in diurnal phases (Middle seasonal phase)

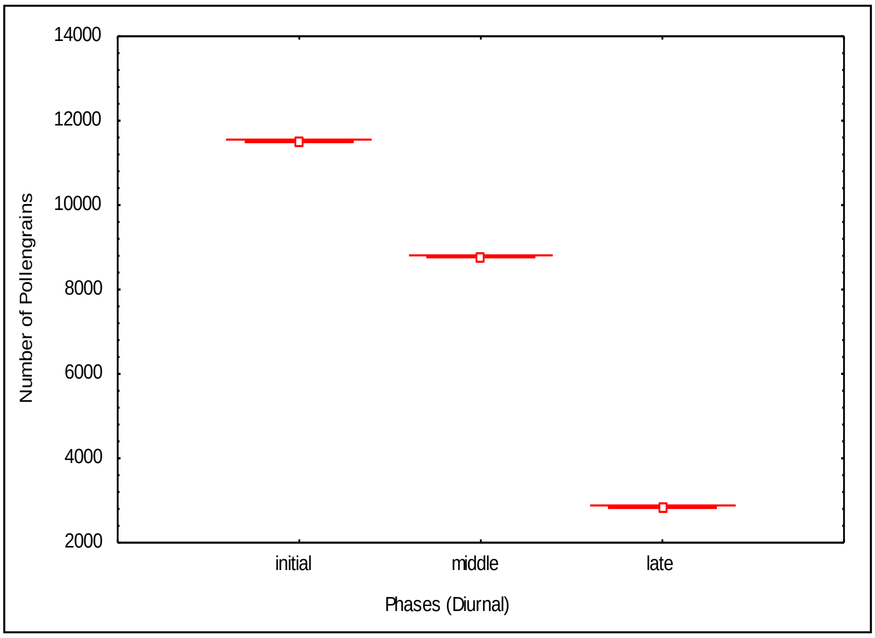


Figure.28: Mean pollen counts in diurnal phases (Late seasonal phase)

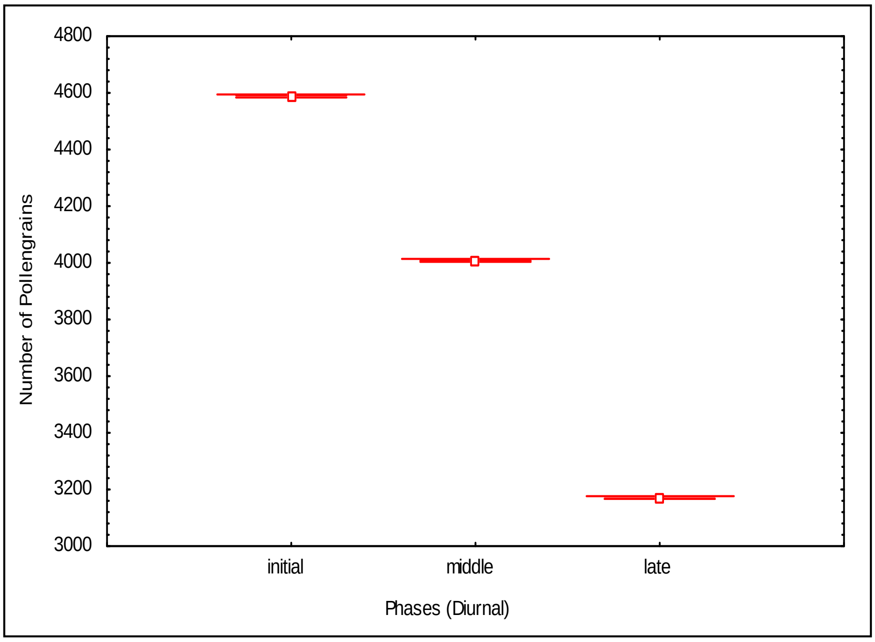
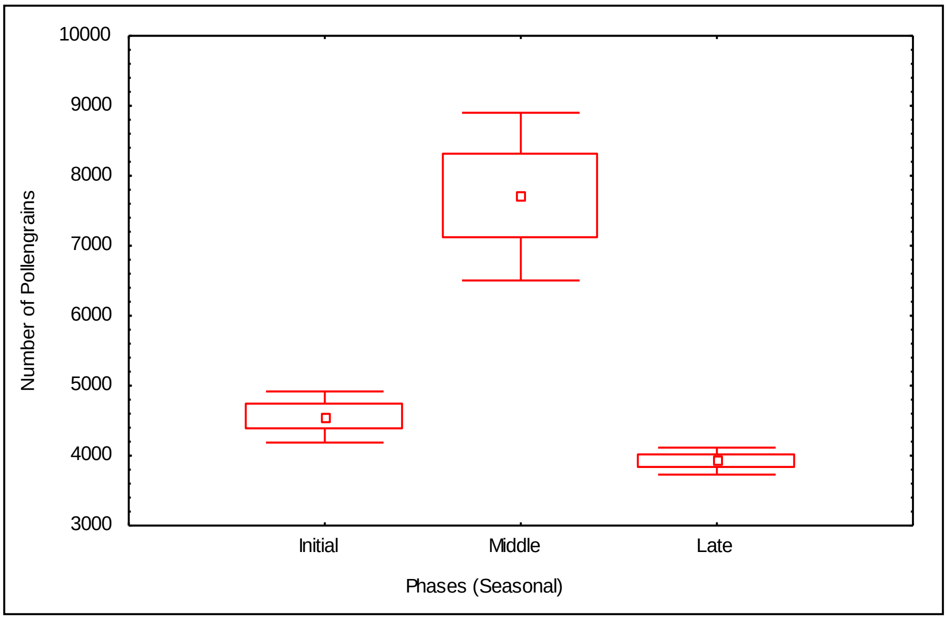


Figure.29: Mean pollen counts in different phases of the season



4.1.3.2. Pollen Removal

The mean number of pollen grains removed from staminate flowers varied by phases of the day and season. Pollen removal increases from IP [ip (1023.16±14.64); mp (1651.83±9.79); lp (364.16±4.01)]; to MP [ip (2735.75±20.83); mp (5927±20.91); lp (830.83±6.79)] and then decreased to LP [ip (582.33±10.46); mp (834.5±3.60); lp (246.91±4.20)] and the counts were significantly different in different diurnal phases of each seasonal phase such as IP (p=0.00) (Figure 30); MP (p=0.00) (Figure 31); LP (p=0.00) (Figure 32). In middle diurnal phase of middle seasonal phase maximum number of pollen grains (5927±20.91) were removed. In late diurnal phase of late seasonal phase minimum number of pollen grains (246.91±4.20) were removed. The counts were significantly different between seasonal phases also (p=0.00) (Figure 33).

Figure.30: Mean pollen removal in diurnal phases (Initial seasonal phase)

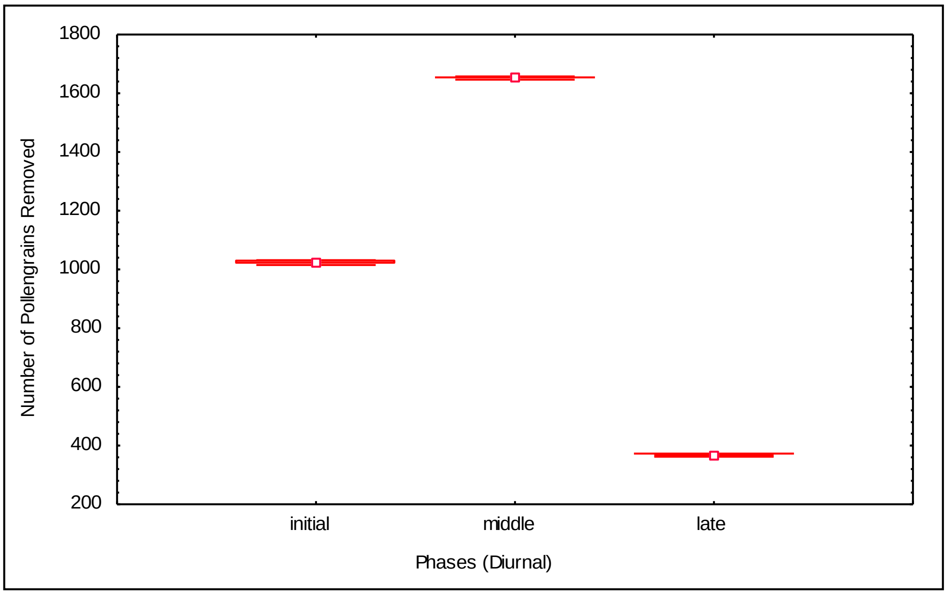


Figure.31: Mean pollen removal in diurnal phases (Middle seasonal phase)

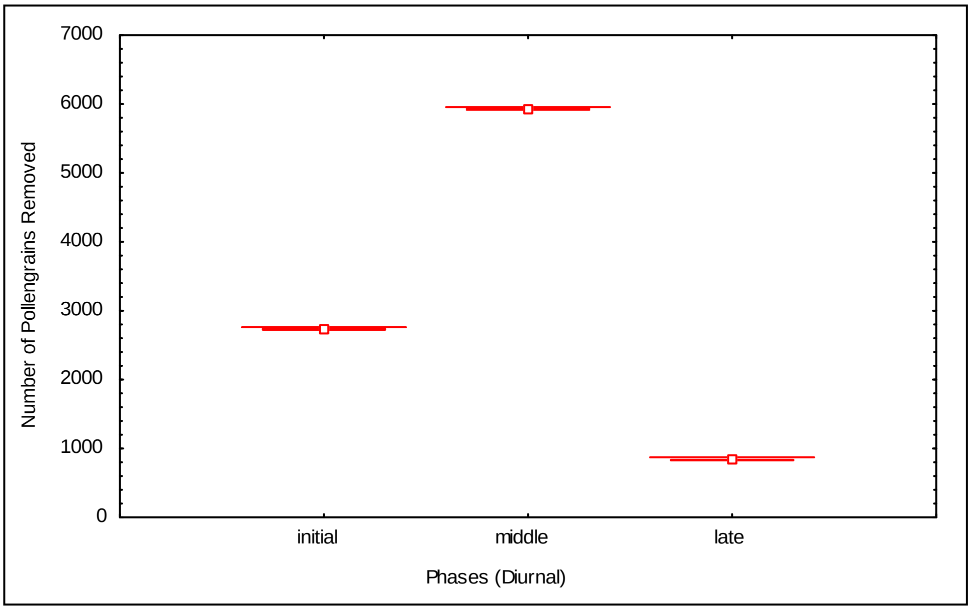


Figure.32: Mean pollen removal in diurnal phases (Late seasonal phase)

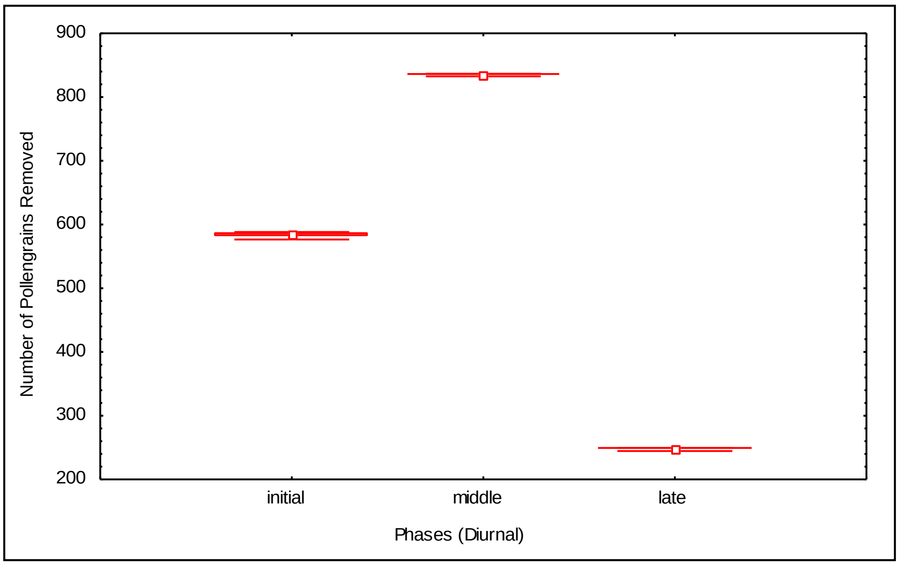
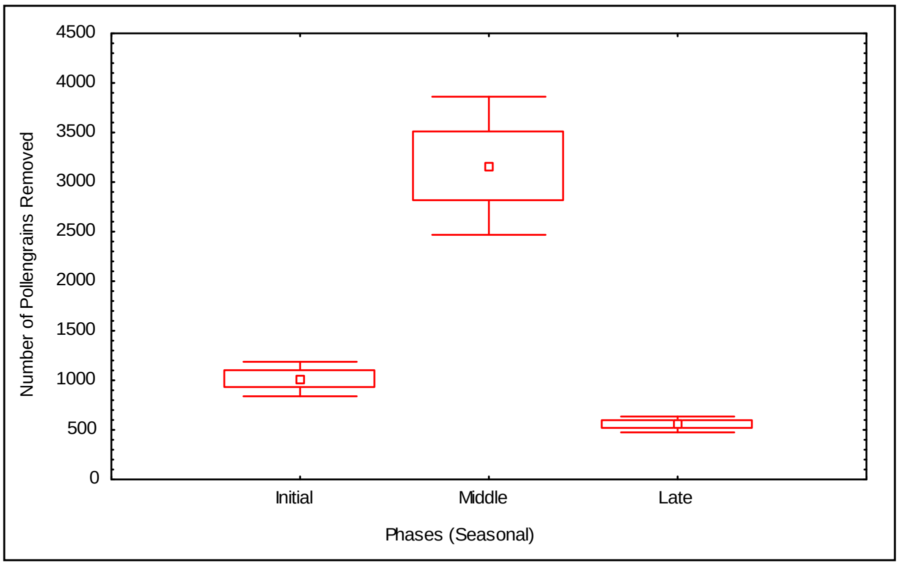


Figure.33: Mean pollen removal in different phases of the season



4.1.3.3. Pollen Deposition

The mean number of pollen grains deposited on stigma of pistllate flowers varied by phases of the day and season. Pollen deposition increased from IP [ip (417.58±8.80); mp (764.91±9.21); lp (108.16±4.19)]; to MP [ip (945±16.21); mp (2798.91±10.47); lp (266.66±9.67)] and then decreased to

LP [ip (193.33±6.71); mp (377.16±6.99); lp (60.5±3.61)]. Pollen deposition was highest in the middle diurnal phase (2798.91±10.47) of middle phase of the season and lowest in the late diurnal phase (60.5±3.61) of late phase of the season. The counts were significantly different in different diurnal phases of each season such as IP (p=0.00) (Figure 34); MP (p=0.00) (Figure 35); LP (p=0.00) (Figure 36) and between seasonal phases (p=0.00) (Figure 37).

Figure.34: Mean pollen deposition in diurnal phases (Initial seasonal phase)

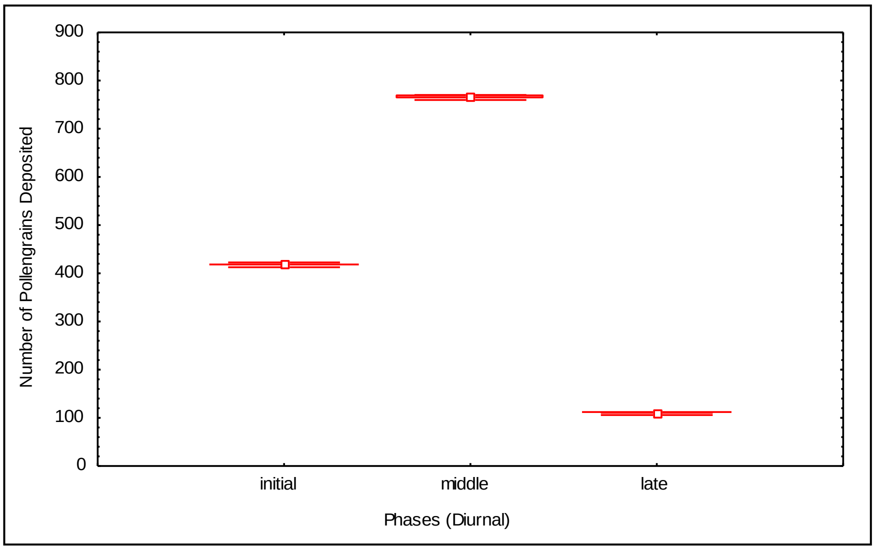


Figure.35: Mean pollen deposition in diurnal phases (Middle seasonal phase)

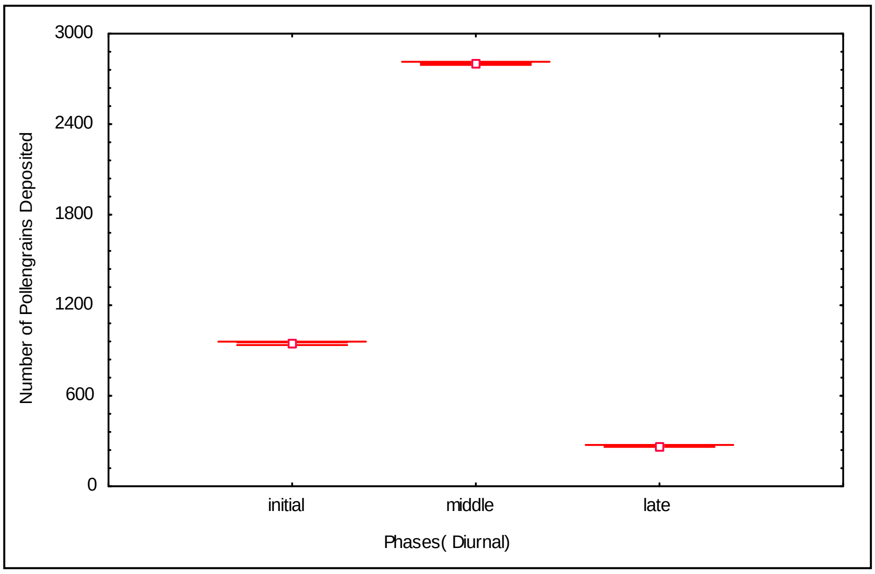


Figure.36: Mean pollen deposition in diurnal phases (Late seasonal phase)

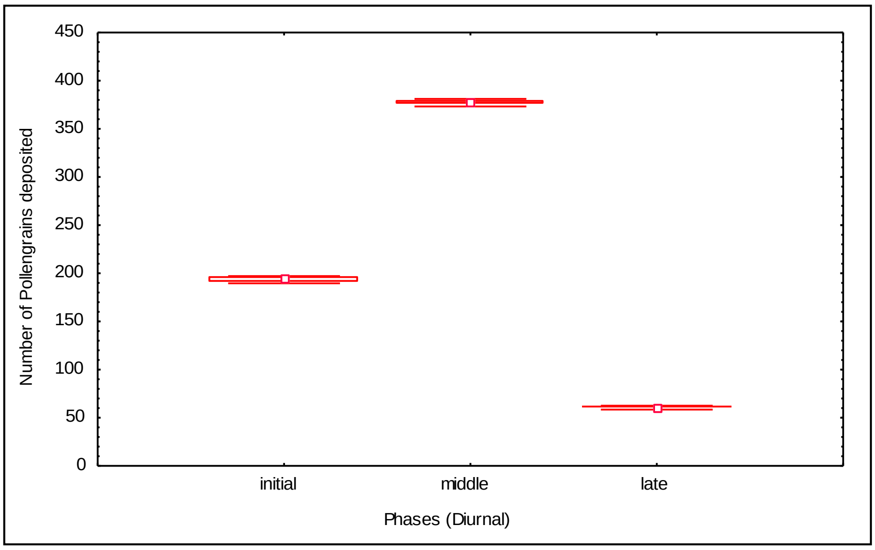
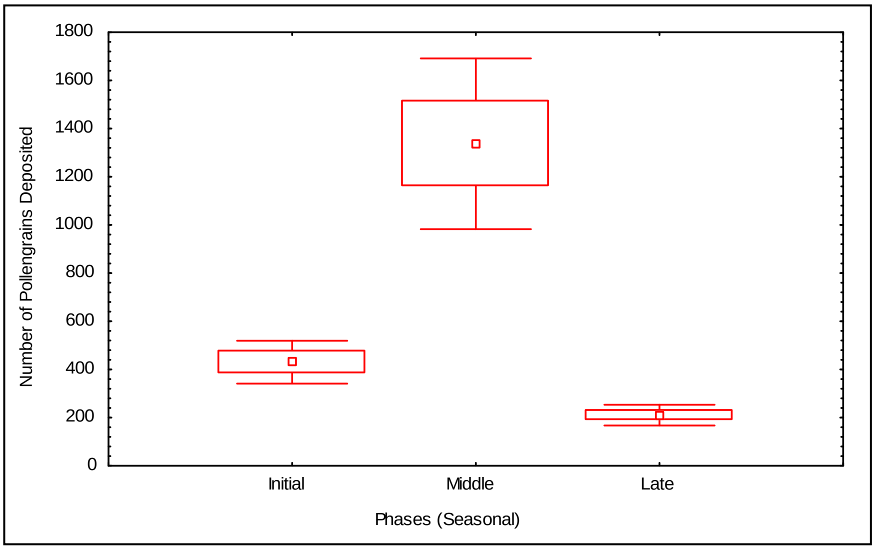


Figure.37: Mean pollen deposition in different phases of the season



4.1.3.4. Pollen Viability

Viability of pollen grains were also found decreasing through diurnal phases of each season IP [ip (589.33±6.61); mp (533.58±9.18); lp (478±9.07)]; MP [ip (2212.75±17.55); mp (1969.08±10.71) lp (1748.83±16.98)]; LP [ip (376.66±7.10); mp (285.66±7.12) lp (239.75±6.39)] and the variations were significantly different [IP (p=0.00) (Figure 38); MP (p=0.00) (Figure 39); LP (p=0.00) (Figure 40)]. But viability increased from initial phase of the season to middle phase. Maximum viable pollen grains were recorded in middle phase of the season. In late phase minimum number of viable pollen grains were recorded. Maximum viable pollen grains were recorded in initial diurnal phase of middle seasonal phase (2212.75±17.55). Minimum number of viable pollen grains were recorded in late diurnal phase (239.75±6.39) of late seasonal phase. Significant difference was also found between seasonal phases (p=0.00) (Figure 41).

Figure.38: Mean pollen viability in diurnal phases (Initial seasonal phase)

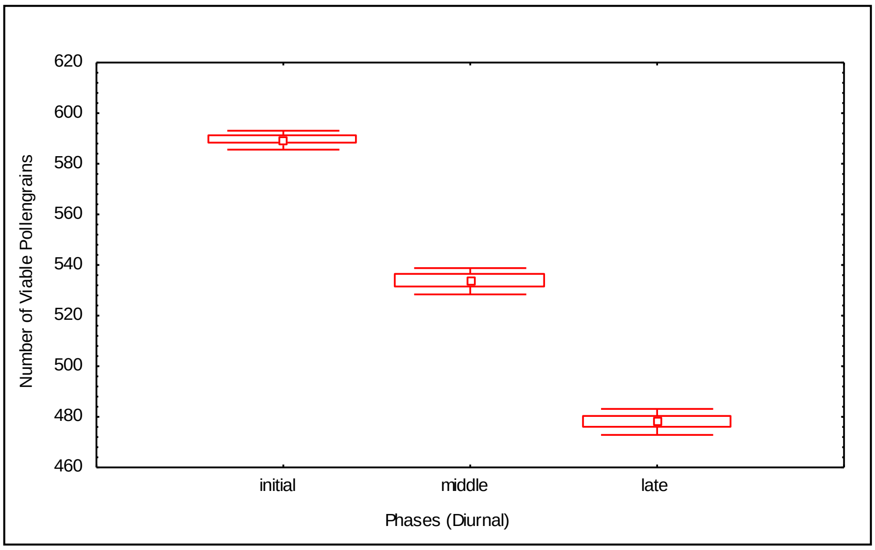


Figure.39: Mean pollen viability in diurnal phases (Middle seasonal phase)

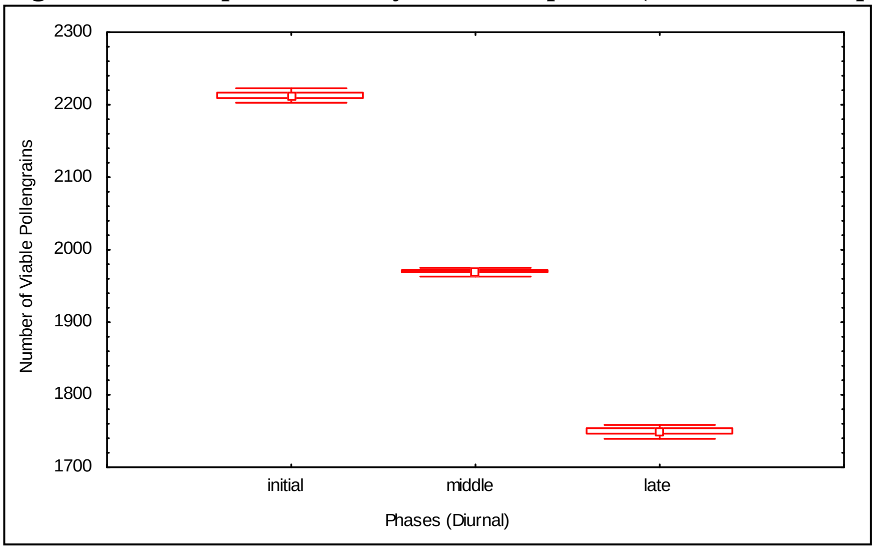


Figure.40: Mean pollen viability in diurnal phases (Late seasonal phase)

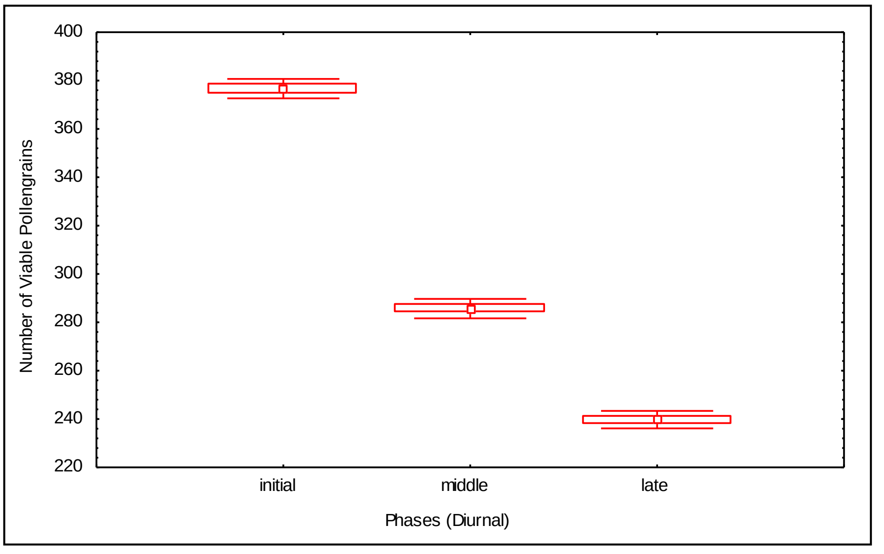
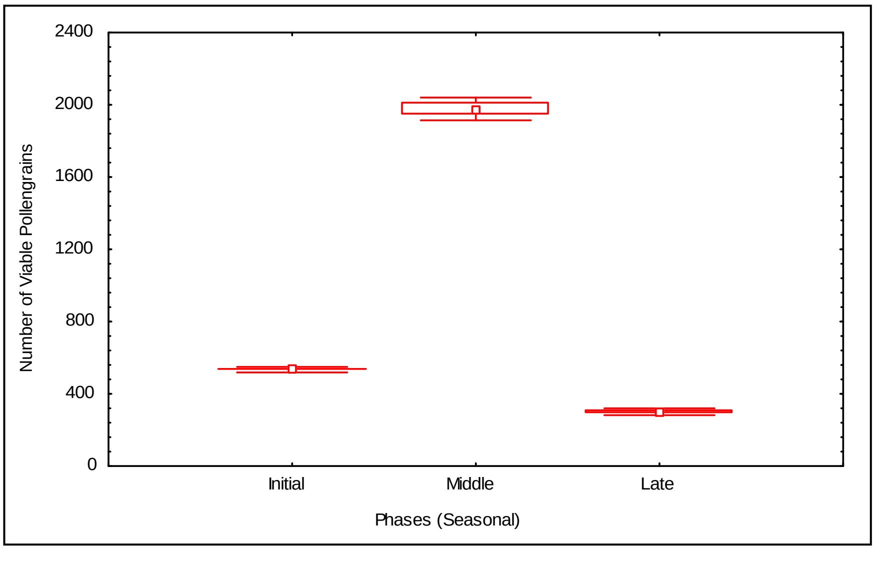


Figure.41: Mean pollen viability in different phases of the season



4.1.4. Pomology

4.1.4.1. Fruit Set

From the bagging experiment it was observed that percentage of fruit set increased from initial phase, [IP (33.84%) : (ip)=10.76%; (mp)=18.46%; (lp)=4.61%] to middle phase [MP (43.07%) : (ip)=13.84%; (mp)=23.07%; (lp)=6.15%]; and then decreased to late phase [LP (23.07%)

: (ip)=7.69%; (mp)=12.31%; (lp)=3.07%] of the day and season. All non pollinated flowers were aborted (np=0). Highest fruit set was recorded in middle diurnal phase of middle seasonal phase (23.07%). Lowest fruit set was recorded in late diurnal phase of late seasonal phase (3.07%). Percentage of fruits within each seasonal phase such as IP (p=0.00) (Figure 42); MP (p=0.00) (Figure 43); LP (p=0.00) (Figure 44) and between the seasonal phases were significantly different (p=0.00) (Figure 45).

Figure.42: Percentage of fruits in diurnal phases (Initial seasonal phase)

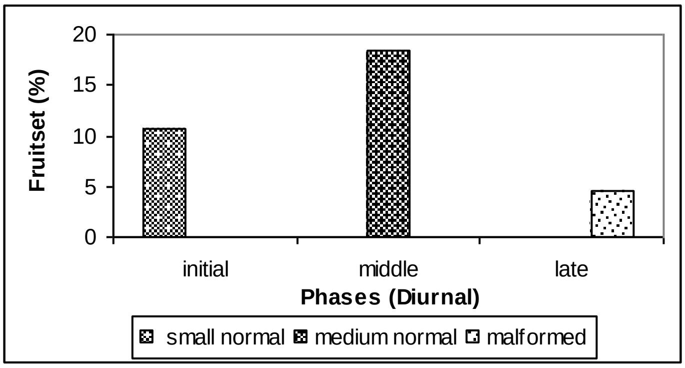


Figure.43: Percentage of fruits in diurnal phases (Middle seasonal phase)

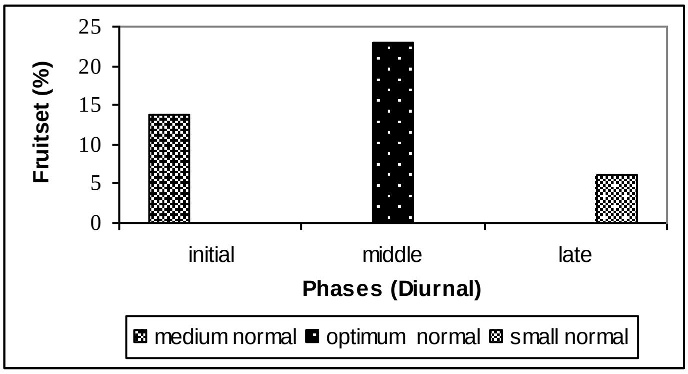


Figure.44: Percentage of fruits in diurnal phases (Late seasonal phase)

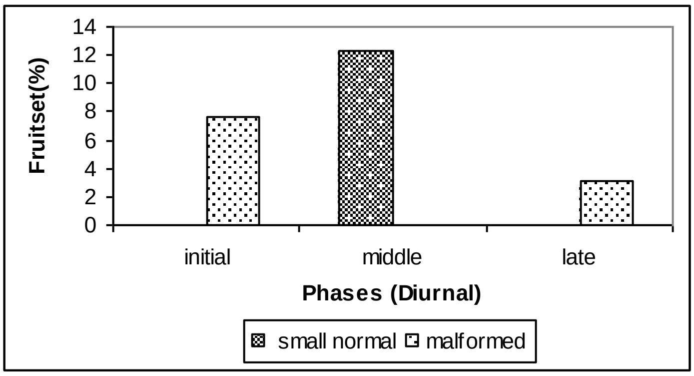
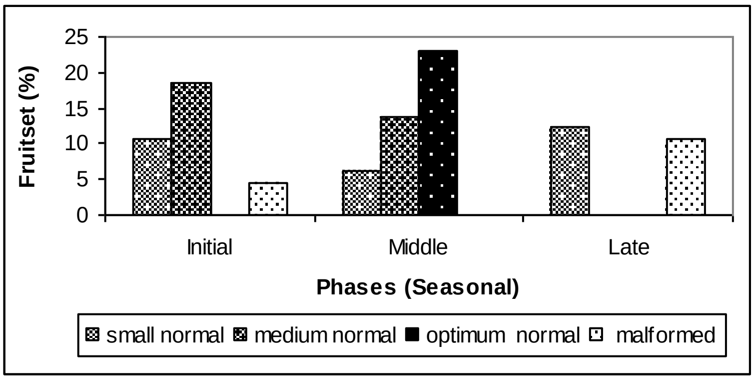


Figure.45: Percentage of fruits in different phases of season



4.1.4.2. Nature of Fruits

Fruits with varied shape and size were produced in the different phases of season. When size was measured in terms of length (l) and breadth (b) it was observed that fruits formed in different diurnal and seasonal phases were differed in the maximum size they attained. By comparing each other fruits with lb ≤12 cm. x 6 cm. were included in small sized ones, ≤16 cm. x 8 cm. and ≤20 cm. x 10 cm. were included in the group of medium and optimum sized ones respectively. Also on the basis of shape the fruits were categorized into normal and malformed ones. So four categories like small normal, medium normal, optimum normal and malformed fruits were recorded when size and shape were considered together for the assessment of nature of fruits [IP (ip)=10.76% small normal; (mp)=18.46% medium normal; (lp)=4.61% malformed; MP (ip)=13.84% medium normal; (mp)=23.07% optimum normal; (lp)=6.15% small normal; LP (ip)=7.69% malformed; (mp)=12.31% small normal; (lp)=3.07% malformed] (Plate 9). All non pollinated flowers were aborted in all phases. Majority of fruits formed in the initial and middle phase were normal shaped and in late phase were malformed. Size and shape of the fruits varied significantly within seasonal phases IP (p=0.00) (Figure 42); MP (p=0.00) (Figure 43); LP (p=0.00) (Figure 44) and between the seasonal phases (p=0.00) (Figure 45).

4.1.4.3. Weight of Fruits

Mean weight of fruits increased from initial phase, IP (ip=94.66±83.63 gm.; mp=297.25±17.4 gm.; lp=11±19.90 gm.) to middle phase, MP (ip=323.75±195.67 gm.; mp=1129.66±52.67 gm.; lp=23.08±34.11 gm.) and then decreased to late phase, LP (ip=41.25±51.00 gm.; mp=91.33±67.66 gm.; lp=3.25±7.59 gm.) of the day and season. Fruits having highest weights were recorded in middle diurnal phase (1129.66±52.67 gm.) of the middle season. In late diurnal phase (3.25±7.59 gm.) of late season least weighed fruits were recorded. As non pollinated flowers were aborted no weights were recorded. Weights of fruits within seasonal phases such as IP (p=0.00) (Figure 46); MP (p=0.00) (Figure 47); LP (p=0.00) (Figure 48) and between the seasonal phases were significantly different **(**p=0.00**)** (Figure 49).

Figure.46: Mean weight of fruits in diurnal phases (Initial seasonal phase)

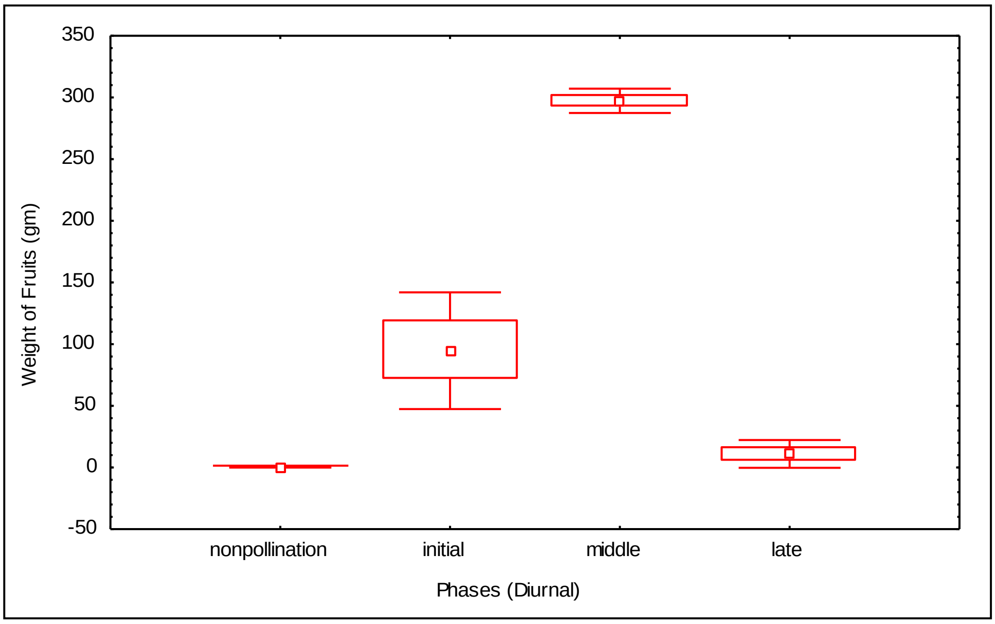


Figure.47: Mean weight of fruits in diurnal phases (Middle seasonal phase)

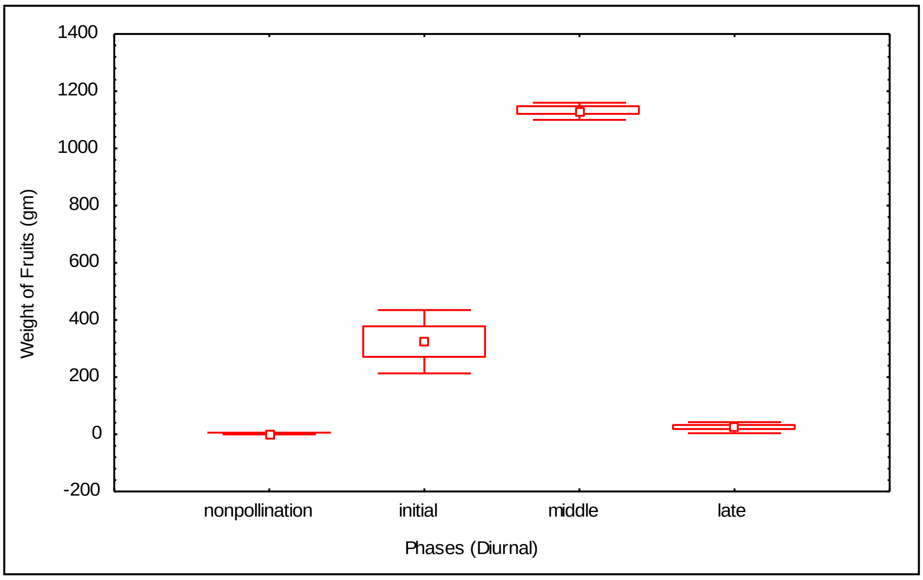


Figure.48: Mean weight of fruits in diurnal phases (Late seasonal phase)

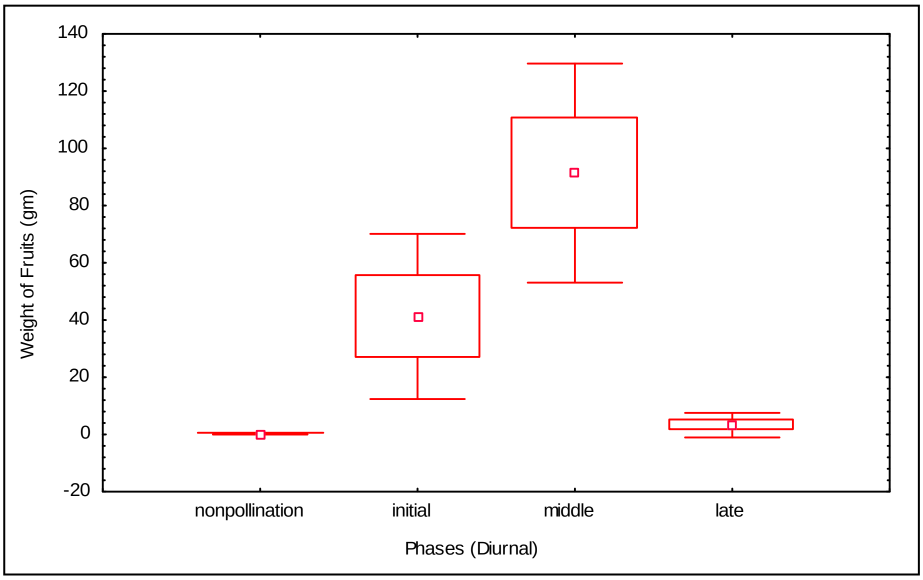
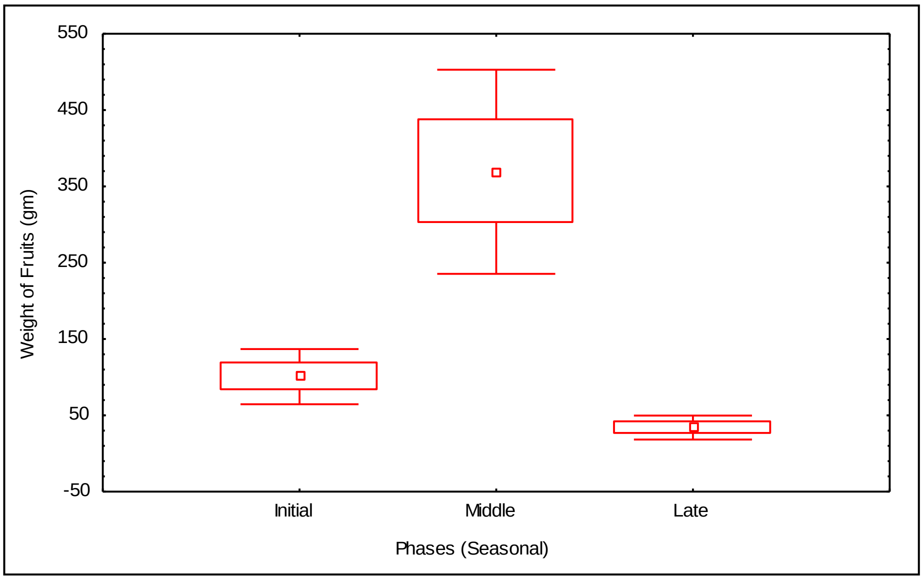


Figure.49: Mean weight of fruits in different phases of season



4.1.4.4. Number of Seeds

Mean number of seeds increased from initial phase of the season IP [ip=9.66±8.58; mp=32±3.81; lp=1±1.8] to middle phase of the season MP [ip=36.75±22.49; mp=130.91±13.31; lp=2.83±4.19] and then decreased to late phase LP [ip=4.75±5.87; mp=10.08±7.56; lp=0.33±0.77] of the season. As non pollinated flowers were aborted no seeds were recorded. Maximum number of seeds were recorded in middle diurnal phase (130.91±13.31) of middle seasonal phase. In late diurnal phase of late seasonal phase minimum number of seeds (0.33±0.77) were recorded. Number of seeds within each seasonal phase such as IP (p=0.00) (Figure.50); MP (p=0.00) (Figure 51); LP (p=0.00) (Figure 52) and between the seasonal phases were significantly different (p=0.00) (Figure 53).

Figure.50: Mean number of seeds in diurnal phases (Initial seasonal phase)

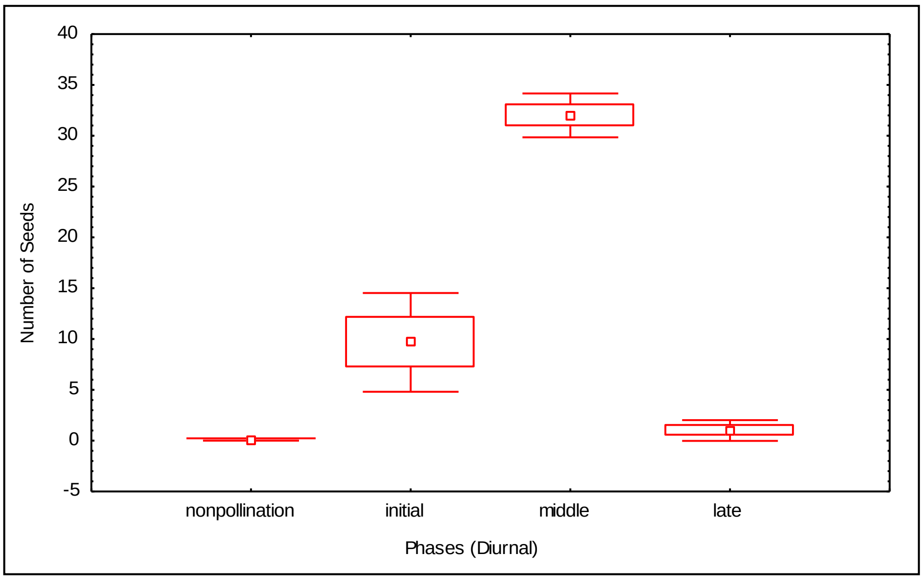


Figure.51: Mean number of seeds in diurnal phases (Middle seasonal phase)

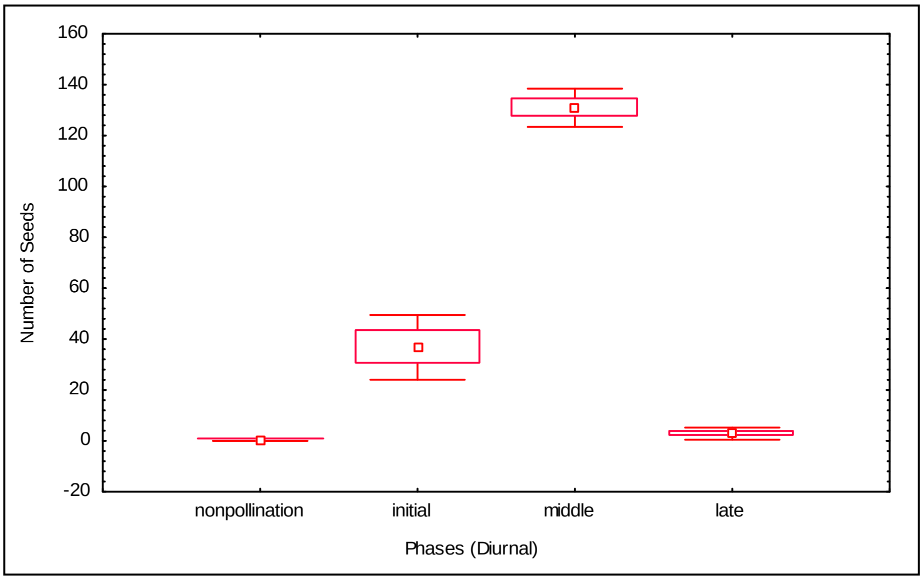


Figure.52: Mean number of seeds in diurnal phases (Late seasonal phase)

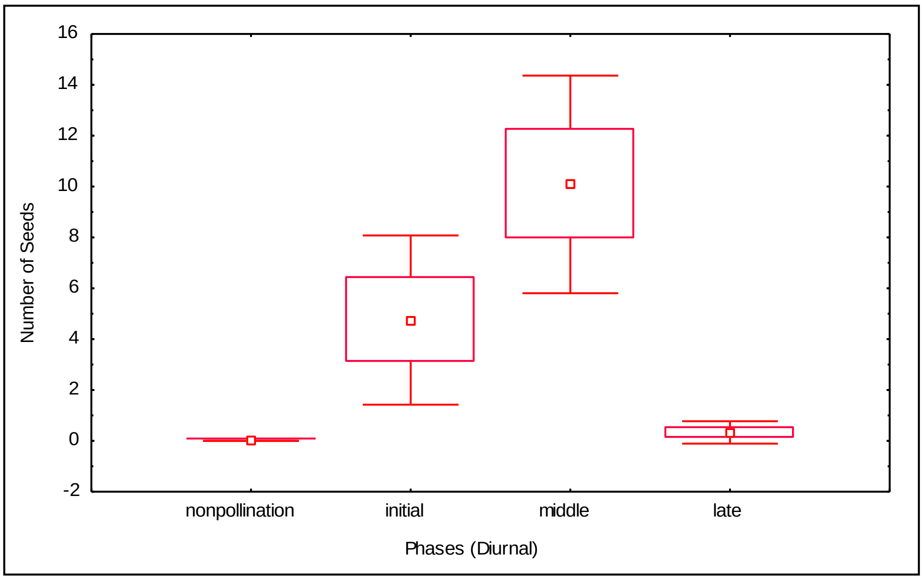
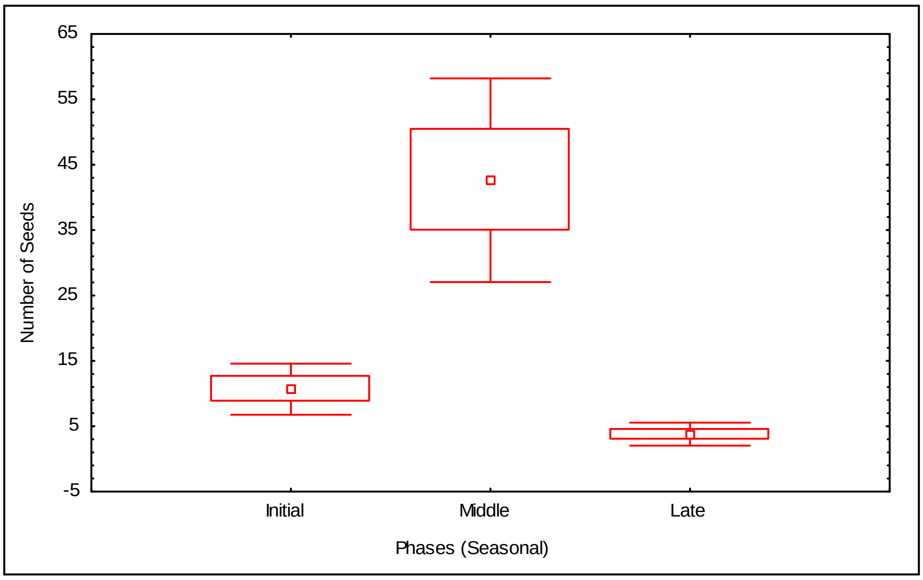


Figure.53: Mean number of seeds in different phases of season



4.1.4.5. Viability of Seeds

Mean number of viable seeds increased from initial phase of the season IP [ip=7.08±6.28; mp=24.66±3.05; lp=0.66±1.23] to middle phase of the season MP [ip=30.58±18.72; mp=116.75±12.06; lp=1.91±2.84] and then decreased to late phase LP [ip=2.33±2.90; mp=5.08±3.84; lp=0.16±0.38] of the season. Maximum viable seeds were recorded in middle diurnal phase (116.75±12.06) of middle seasonal phase. In late diurnal phase of late seasonal phase minimum number of viable seeds (0.16±0.38) were recorded. As non pollinated flowers were aborted no viable seeds were recorded. Number of viable seeds within each seasonal phase such as IP (p=0.00) (Figure 54); MP (p=0.00) (Figure 55); LP (p=0.00) (Figure 56) and between the seasonal phases were significantly different (p=0.00) (Figure 57).

Figure.54: Mean number of viable seeds in diurnal phases (Initial seasonal phase)

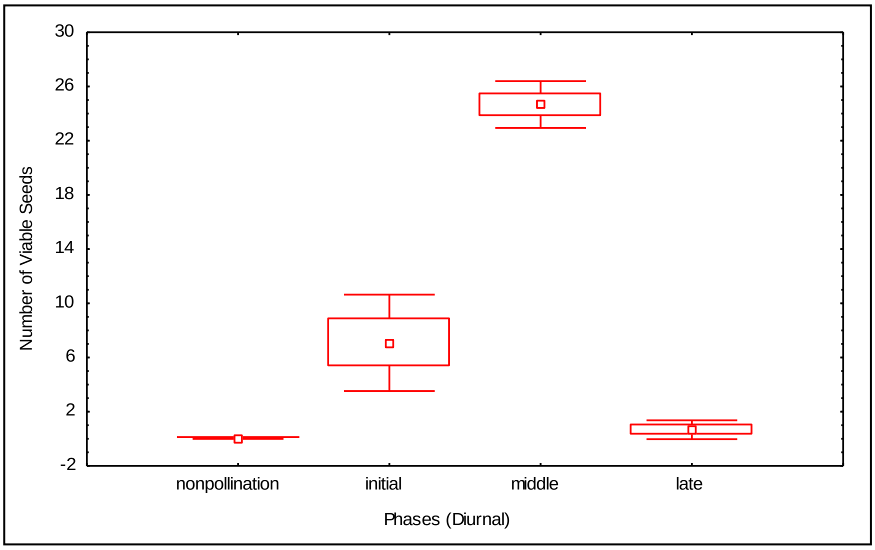


Figure.55: Mean number of viable seeds in diurnal phases (Middle seasonal phase)

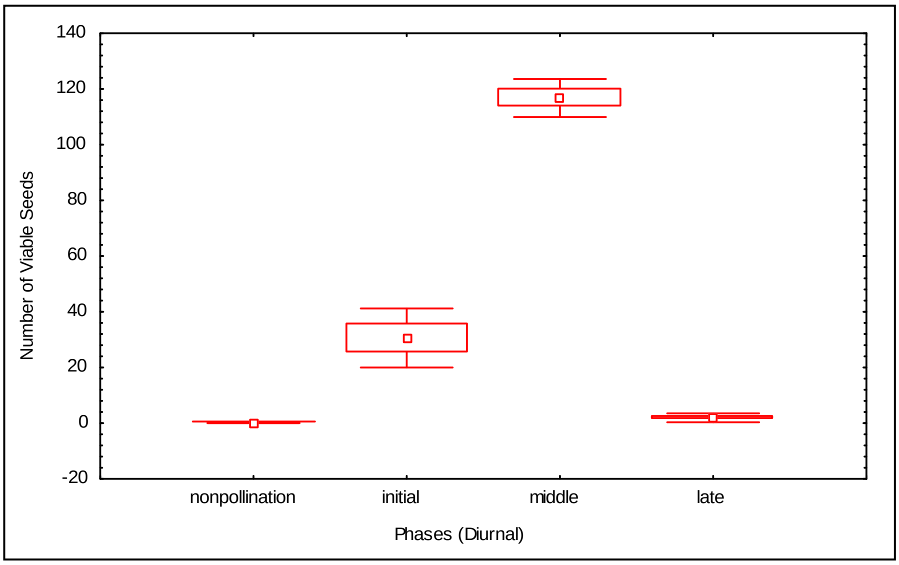


Figure.56: Mean number of viable seeds in diurnal phases (Late seasonal phase)

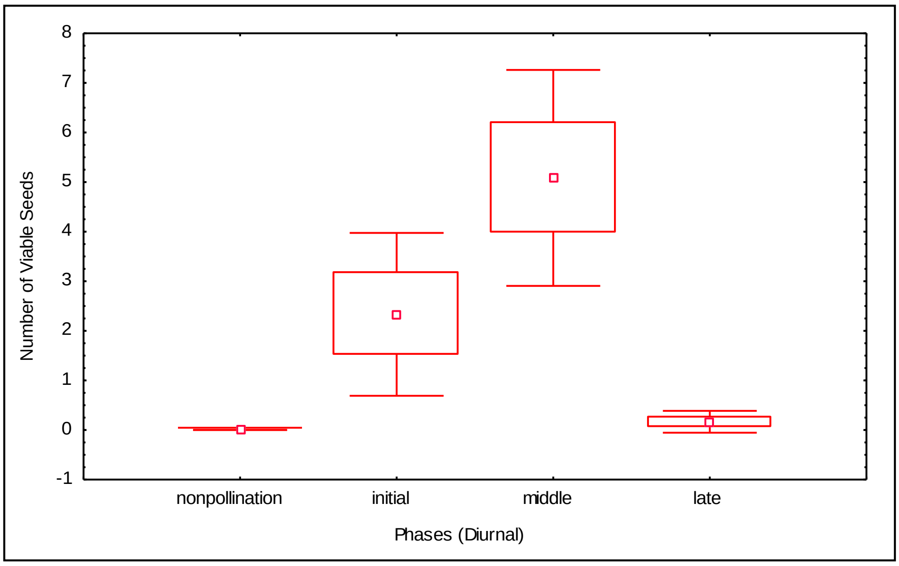
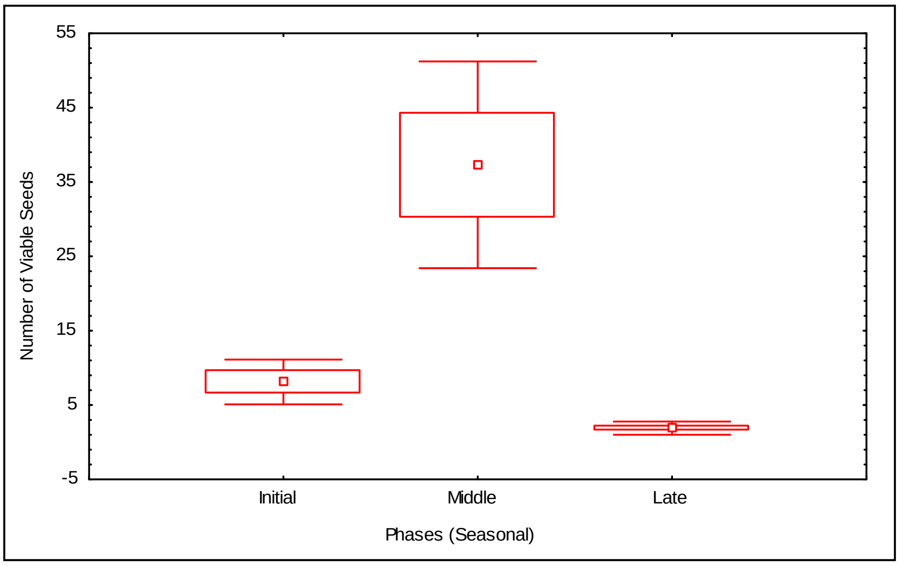


Figure.57: Mean number of viable seeds in different phases of season



4.1.5. Correlation

Positive correlation was observed between number of flowers and number of insects visited (r=0.98) (Figure 58), size of flowers and number of insects visited (r=0.99) (Figure 59), number of insects visited and number of pollen grains deposited (r=0.79) (Figure 60), duration of insect visit and number of pollen grains deposited (r=0.91) (Figure 61), number of pollen grains deposited and percentage of fruit set (r=0.85) (Figure 62), number of pollen grains deposited and weight of fruit (r=0.85) (Figure 63), number of pollen grains deposited and number of seeds (r=0.86) (Figure 64) and number of pollen grains deposited and number of viable seeds (r=0.89) (Figure 65).

Figure.58: Correlation between number of flowers /plant and number of insects visited

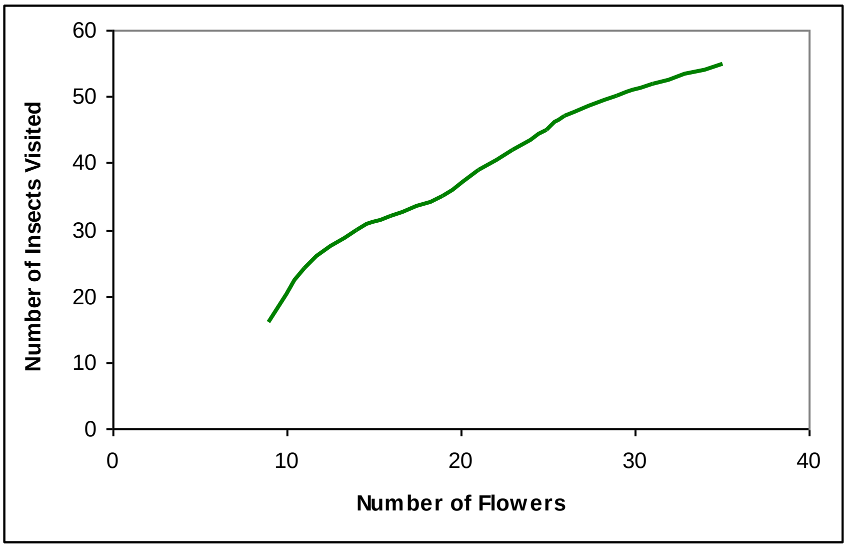


Figure.59: Correlation between size of flowers and number of insects visited

Figure.60: Correlation between number of insects visited and number of pollen grains deposited

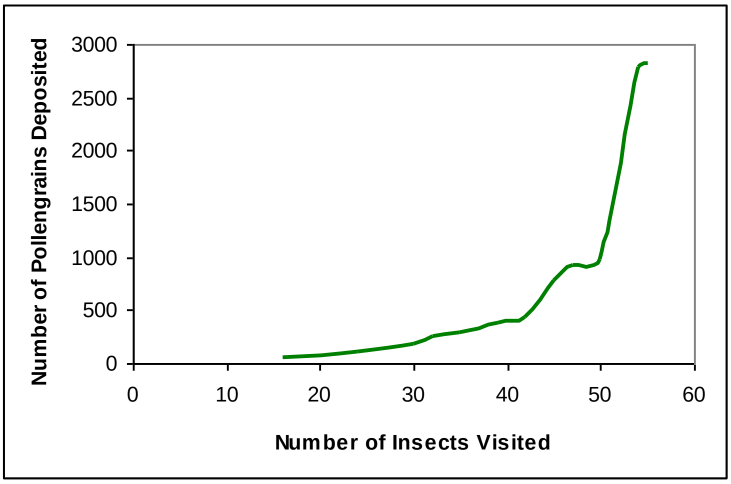


Figure.61: Correlation between duration of visit and number of pollen grains deposited

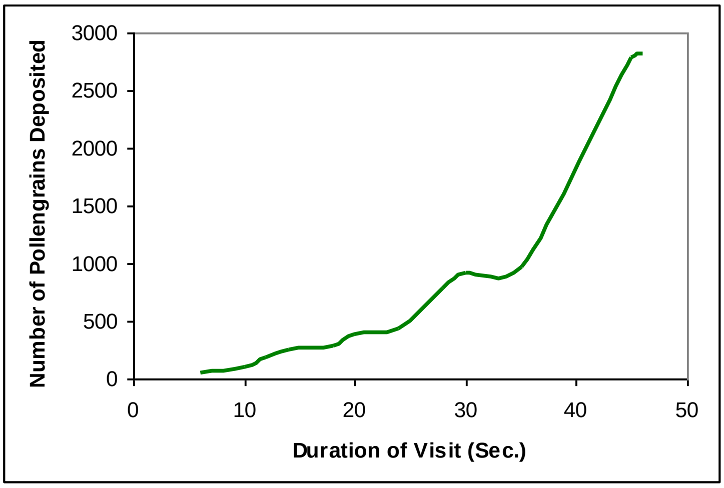


Figure.62: Correlation between number of pollen grains deposited and percentage of fruit set.

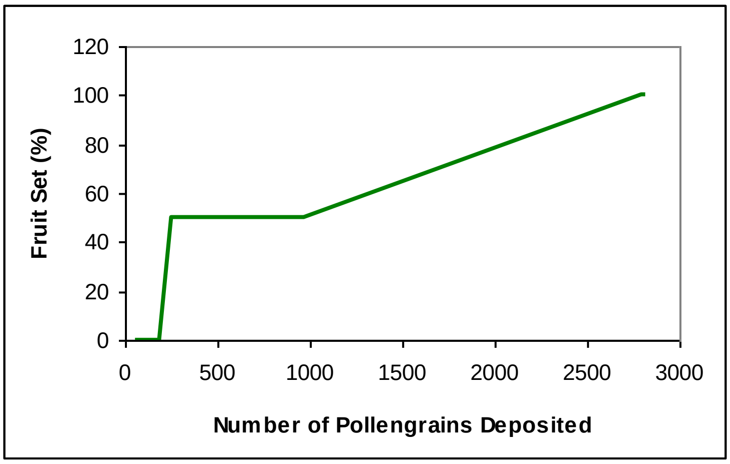


Figure.63: Correlation between number of pollen grains deposited and weight of fruit.

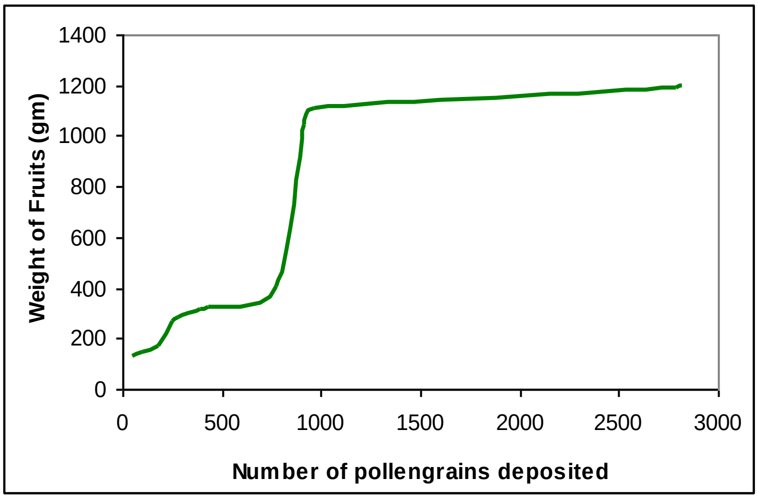


Figure.64: Correlation between number of pollen grains deposited and number of seeds.

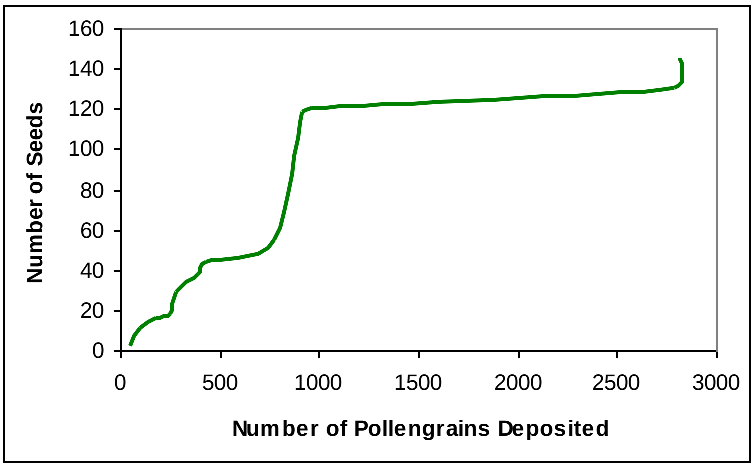


Figure.65: Correlation between number of pollen grains deposited and number of viable seeds.

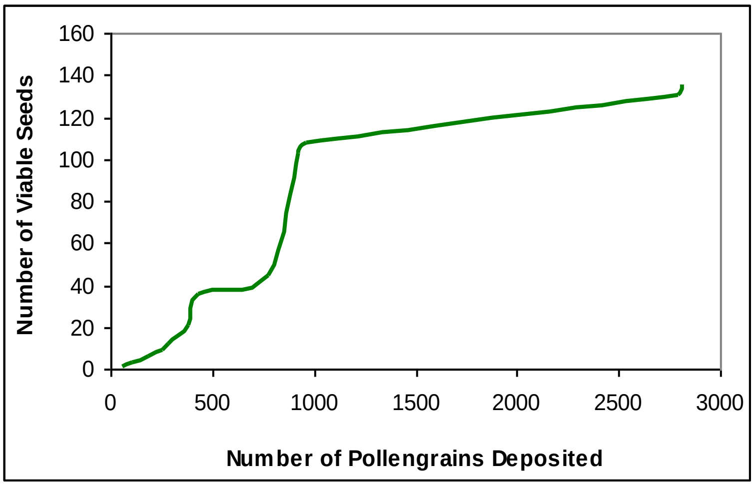


Plate 9

Muskmelon Fruit

Muskmelon Nonpollinated Ovary

Muskmelon Malformed Fruit

Cucumber Fruit

Cucumber Nonpollinated Ovary

Cucumber Malformed Fruit

4.2. Cucumber

[*Cucumis sativus* L.]

4.2.1. Phenology

4.2.1.1. Day of First Anthesis

It was observed that first male (♂) and female (♀) flower opened on 28.41±1.88th and 40.66±2.38th day respectively from the day of germination. Both male and female anthesis were significantly different (p=0.00) (Figure 66).

Figure.66: Day of first anthesis of male and female flowers after germination

4.2.1.2. Flower Opening Time

Male flower (♂) anthesis commenced between 0502 h. and 0607 h. and female flower (♀) between 0445 h. and 0553 h. The times at which male (♂) and female (♀) flowers opened were significantly different (p=0.00). Mean durations taken for full corolla expansion were 1.01±0.11 h. and 1.08±0.10 h. by male (♂) and female (♀) flowers respectively and they varied significantly (p=0.03).

4.2.1.3. Flower Closing Time

Male flower (♂) closing commenced between 1531 h. and 1635 h. and female flower (♀) between 1547 h. and 1651 h. Significant difference was found between initiation of closing time of male (♂) and female (♀) flowers. (p=0.03). Mean durations taken for full petal constriction were 2.03±0.11 h. and 2.16±0.11 h. by male (♂) and female (♀) flowers respectively and they showed significant difference (p=0.02).

4.2.1.4. Number of Flowers

Mean number of staminate or male (♂) and pistillate or female (♀) flowers produced per plant per day increased from initial phase (IP) of the season (♂=12.77±3.14, ♀=1.38±0.48) to middle phase (MP) of the season (♂=21.09±4.19, ♀=2.07±0.51), where maximum number of flowers were recorded and then decreased to late phase (LP) (♂=9.27±1.98, ♀=1.18±0.38), where minimum number of flowers were recorded. Number of staminate (♂) and pistillate (♀) flowers within seasonal phases such as IP (p=0.00) (Figure 67); MP (p=0.00) (Figure 68); LP (p=0.00) (Figure 69) and number of flowers produced between seasonal phases were significantly different (p=0.00).

Figure.67: Mean number of male and female flowers produced /plant /day (Initial seasonal phase)

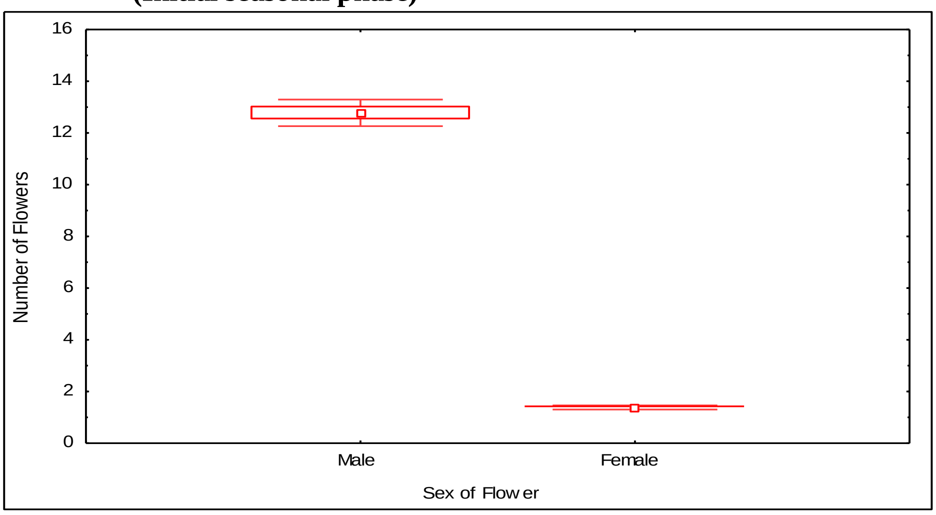


Figure.68: Mean number of male and female flowers produced /plant /day (Middle seasonal phase)

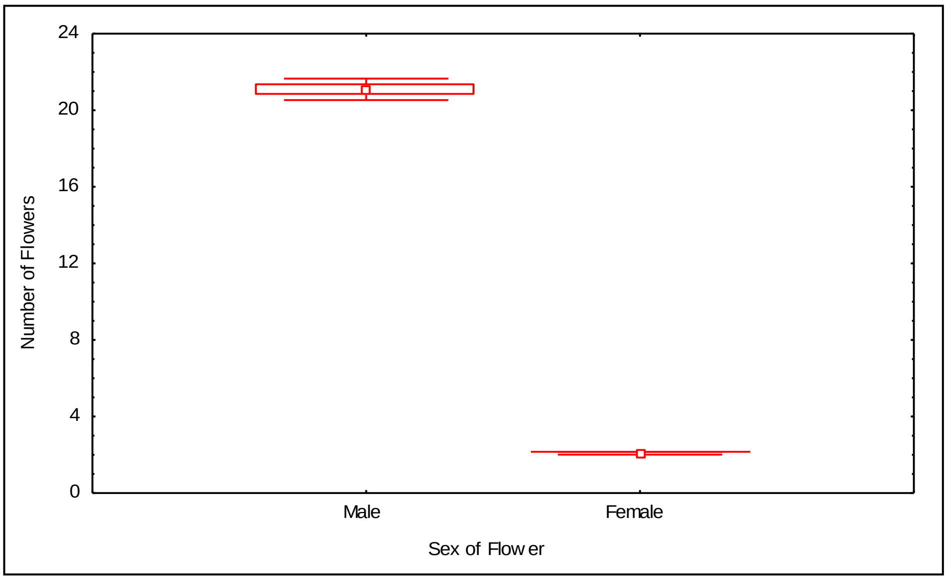
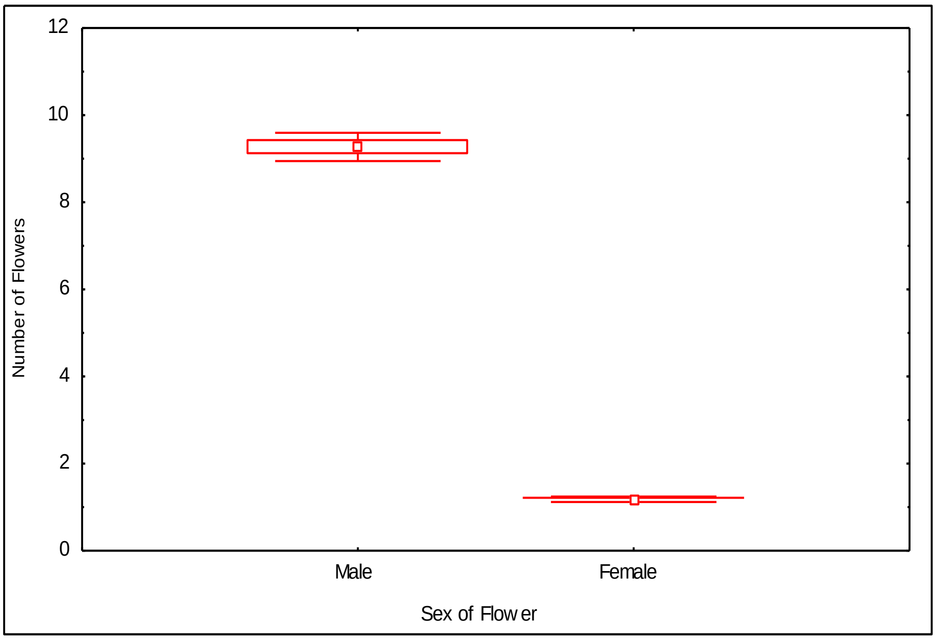


Figure.69: Mean number of male and female flowers produced /plant /day (Late seasonal phase)



4.2.1.5. Size /Dimension of Flower

Mean size of staminate or male (♂) and pistillate or female (♀) flowers produced per plant per day increased from initial phase (IP) of the season (♂=2.77±0.38 cm., ♀=3.28±0.39 cm.) to middle phase (MP) of the season (♂=3.73±0.39 cm., ♀=4.23±0.39 cm.), where maximum size was observed and then decreased to late phase (LP) (♂=2.64±0.33 cm., ♀=3.13±0.33 cm.), where minimum size was observed. Size of staminate and pistillate flowers within seasonal phases such as IP (p=0.00) (Figure 70); MP (p=0.00) (Figure 71.); LP (p=0.00) (Figure 72) and between the seasonal phases were significantly different (p=0.00).

Figure.70:Mean size of male and female flowers produced (Initial seasonal phase)

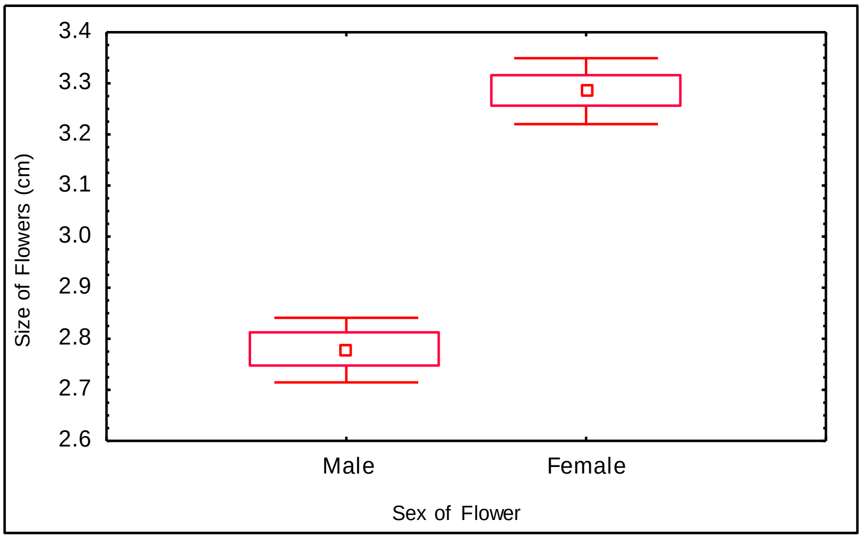


Figure.71: Mean size of male and female flowers produced (Middle seasonal phase)

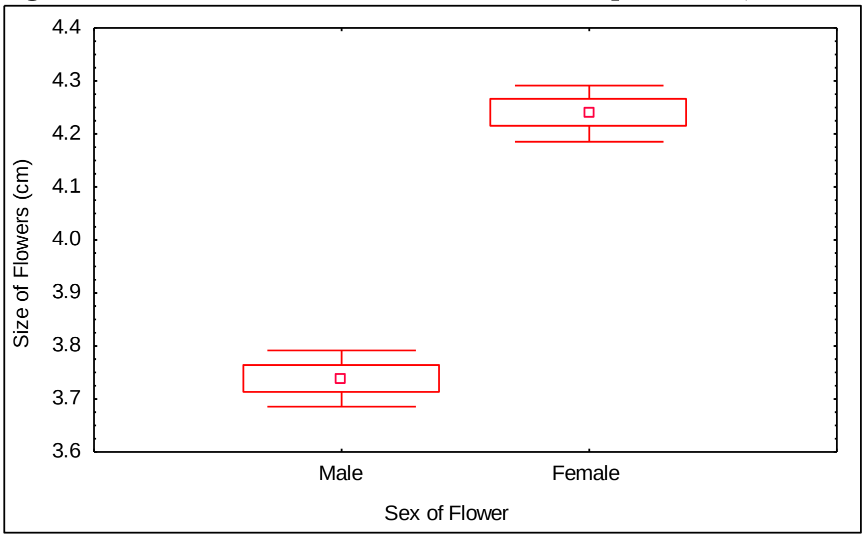


Figure.72: Mean size of male and female flowers produced (Late seasonal phase)

4.2.2. Entomology

4.2.2.1. Identification of Pollinators

A total of 16 species of insect were recorded from 3 orders during the study (Plate 7 and Plate 8). The most abundant order was the Hymenoptera, including families Apidae, Halictidae, Xylocopidae followed by Coleoptera. Much less abundant was Lepidoptera. The list of pollinators of cucumber observed during the study is given in Table 8.

Table.8: List of pollinators

Order	**Family**	**Species**
Hymenoptera	Halictidae	*Halictus taprobanae* Cameron
		Halictus timidus Smith
		Trigona iridipennis Smith
	Apidae	*Ceratina heiroglyphica* Smith
		Apis cerana Fabricius
		Amegilla parhypate Lieftinck
		Apis dorsata Fabricius
		Apis florea Fabricius
		Braunsapis picitarsis Cameron
		Ceratina smaragdula Fabricius
	Xylocopidae	*Xylocopa aestuans* Linnaeus
		Xylocopa tenuiscapa Westwood
Coleoptera	Chrysomelidae	*Aulacophora lewisii* Baly
		Aulacophora foveicollis Lucas
Lepidoptera	Sphingidae	*Cephonodes picus* Cramer
		Macroglossum troglodytus Boisduval

4.2.2.2.Floral visitation (Dynamics of Pollinating behaviour)

4.2.2.2.1. Frequency of Pollinator Visit

The number of insects visited the flowers increased from initial phase to middle phase of the day and season. Thereafter a continuous decline in pollinator number was observed. It was observed that a mean of 17.83 and 15.25 hymenopterans and 3.66 and 2.33 coleopterans visited the male (♂) and female (♀) flowers /day respectively in the initial phase (IP) of the season. In middle phase (MP) a mean of 22.08 and 19.25 hymenopterans, 2.25 and 1.75 coleopterans and 0.58 and 0.58 lepidopterans visited the male (♂) and female (♀) flowers /day respectively. In late phase (LP) of the season a mean of 13.33 and 11.66 hymenopterans and 4.41 and 2.41 coleopterans visited the male (♂) and female (♀) flowers /day respectively. Variation in the case of different diurnal phases in each phase of the season was also observed. Highest frequency of visit was observed in middle diurnal phase of middle phase of season. Lowest frequency of visit was observed in late diurnal phase of late phase of season. Hymenopterans were the most frequent visitors. Significant difference was found in visitation frequency shown by different orders of insects [IP (p=0.00) (Figure 73); MP (p=0.00) (Figure 74); LP (p=0.00) (Figure 75)] (Table 9). Variation in visitation frequency shown by different species of insects belonging to Hymenoptera, Coleoptera and Lepidoptera was also obsereved. *Halictus taprobanae* was the most frequent pollinator. It was followed by *Ceratina heiroglyphica, Halictus timidus, Trigona iridipennis and Apis cerana.* They were regular, consistent and made the higher number of visits compared to other insects, at all sites. The visitation frequency shown by different species of insects varied significantly [IP (p=0.00) (Figure 76); MP (p=0.00) (Figure 77); LP (p=0.00) (Figure 78)] (Table 10). No significant difference in visitation frequency on staminate (♂) and pistillate (♀) flowers [IP (p=0.92); MP (p=0.32); LP (p=0.35)] was observed. Frequency of visitation during different diurnal phases varied significantly [IP (p=0.00); MP (p=0.00); LP (p=0.01)]. Different seasonal phases also showed significant differences in visitation frequency (p=0.00).

Table.9: Frequency of pollinator (Order) visit /day

Order	Sex of flower	Initial Phase (IP)			Middle Phase (MP)			Late Phase (LP)		
		ip	mp	lp	ip	mp	lp	ip	mp	lp
Hymenoptera	♂	5.58	9.75	2.5	6.41	12.33	3.33	4.41	7.75	1.16
	♀	4.75	8.58	1.91	5.5	11.08	2.66	3.66	7.5	0.5
Coleoptera	♂	1.16	1.08	1.41	0.91	0.16	1.16	1.41	1.41	1.58
	♀	0.83	0.66	0.83	0.83	0.16	0.75	0.83	0.75	0.83
Lepidoptera	♂	0	0	0	0.58	0	0	0	0	0
	♀	0	0	0	0.58	0	0	0	0	0

IP - Initial phase of season
MP - Middle phase of season
LP - Late phase of season

ip - initial phase of day
mp - middle phase of day
lp - late phase of day

♂ -Male flower
♀ -Female flower

Figure.73: Frequency of pollinator (Order) visit /day (Initial seasonal phase)

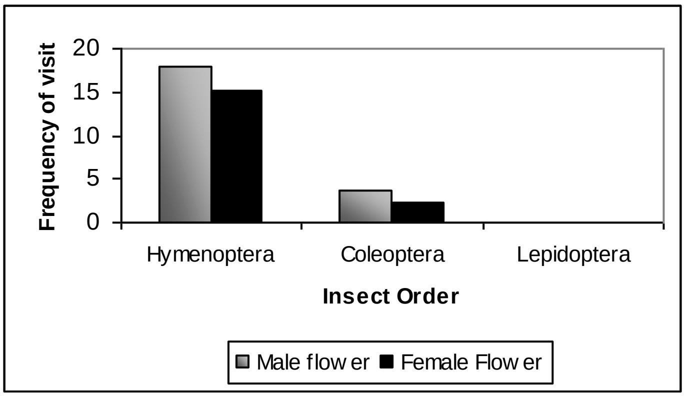


Figure.74: Frequency of pollinator (Order) visit /day (Middle seasonal phase)

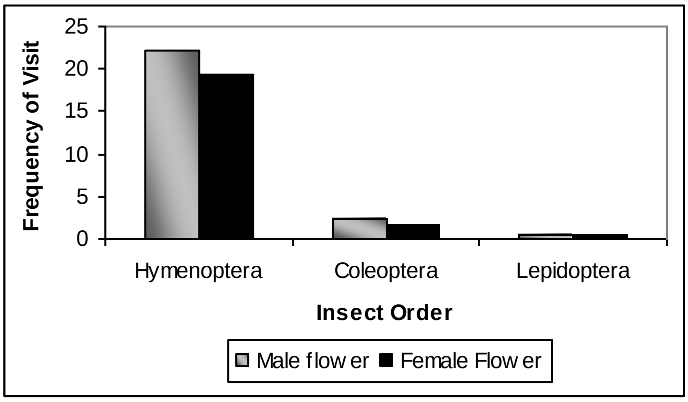


Figure.75: Frequency of pollinator (Order) visit /day (Late seasonal phase)

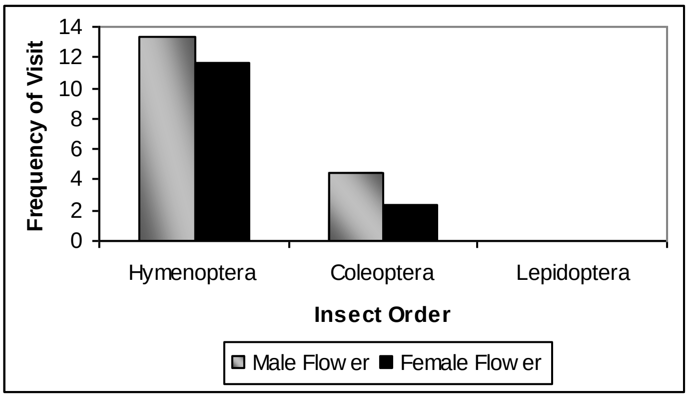


Table.10: Frequency of pollinator (Species) visit /day

Species	Sex of flower	Initial Phase (IP)			Middle Phase (MP)			Late Phase (LP)		
		ip	mp	lp	ip	mp	lp	ip	mp	lp
Halictus	♂	3.66	7.5	1.5	4	8.33	2	2.83	5.83	0.33
taprobanae	♀	3.25	6.5	1.08	3.58	7.91	1.66	2.66	5.75	0.16
Halictus	♂	0.5	0.66	0.33	0.66	0.75	0.41	0.41	0.5	0.16
timidus	♀	0.33	0.66	0.16	0.58	0.66	0.25	0.33	0.5	0.08
Trigona	♂	0.41	0.41	0.16	0.41	0.5	0.25	0.33	0.41	0.16
iridipennis	♀	0.33	0.41	0.16	0.33	0.5	0.16	0.16	0.33	0.08
Ceratina	♂	0.66	0.75	0.33	0.75	0.91	0.5	0.5	0.66	0.33
heiroglyphica	♀	0.58	0.66	0.33	0.66	0.75	0.41	0.33	0.58	0.08
Apis	♂	0.33	0.41	0.16	0.41	0.5	0.16	0.33	0.33	0.16
cerana	♀	0.25	0.33	0.16	0.25	0.41	0.16	0.16	0.33	0.08
Amegilla	♂	0	0	0	0.16	0	0	0	0	0
parhypate	♀	0	0	0	0.08	0	0	0	0	0
Braunsapis	♂	0	0	0	0	0.33	0	0	0	0
picitarsis	♀	0	0	0	0	0.25	0	0	0	0
Apis	♂	0	0	0	0	0.25	0	0	0	0
florea	♀	0	0	0	0	0.16	0	0	0	0
Ceratina	♂	0	0	0	0	0.25	0	0	0	0
smaragdula	♀	0	0	0	0	0.16	0	0	0	0
Apis	♂	0	0	0	0	0.16	0	0	0	0
dorsata	♀	0	0	0	0	0.08	0	0	0	0
Xylocopa	♂	0	0	0	0	0.25	0	0	0	0
aestuans	♀	0	0	0	0	0.08	0	0	0	0
Xylocopa	♂	0	0	0	0	0.08	0	0	0	0
tenuiscapa	♀	0	0	0	0	0.08	0	0	0	0
Aulacophora	♂	0.66	0.58	0.75	0.58	0.08	0.66	0.75	0.75	0.83
lewisii	♀	0.5	0.41	0.5	0.5	0.08	0.41	0.5	0.41	0.5
Aulacophora	♂	0.5	0.5	0.66	0.33	0.08	0.5	0.66	0.66	0.75
foveicollis	♀	0.33	0.25	0.33	0.33	0.08	0.33	0.33	0.33	0.33
Cephonodes	♂	0	0	0	0.33	0	0	0	0	0
picus	♀	0	0	0	0.33	0	0	0	0	0
Macroglossum	♂	0	0	0	0.25	0	0	0	0	0
troglodytus	♀	0	0	0	0.25	0	0	0	0	0

IP - Initial phase of season
MP - Middle phase of season
LP - Late phase of season

ip - initial phase of day
mp - middle phase of day
lp - late phase of day

♂ -Male flower
♀ -Female flower

Figure.76: Frequency of pollinator (Species) visit /day (Initial seasonal phase)

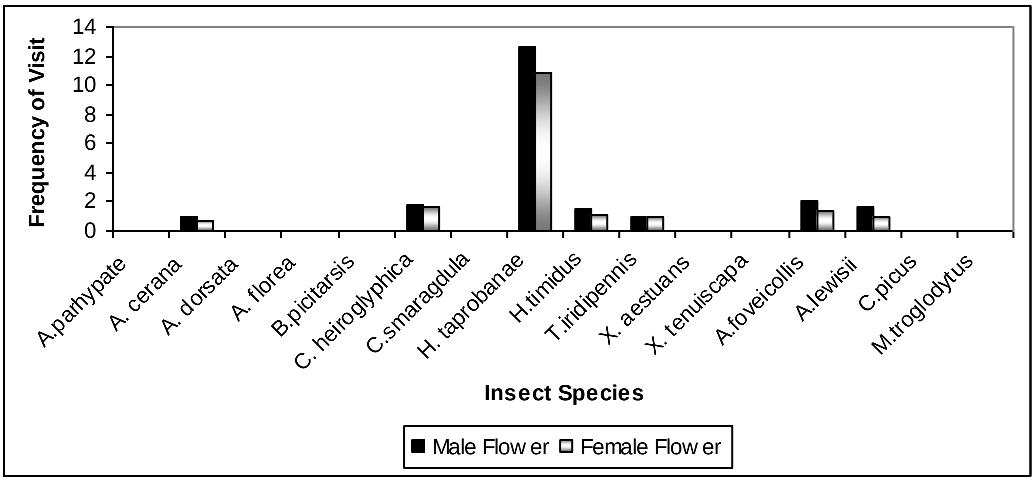


Figure.77: Frequency of pollinator (Species) visit /day (Middle seasonal phase)

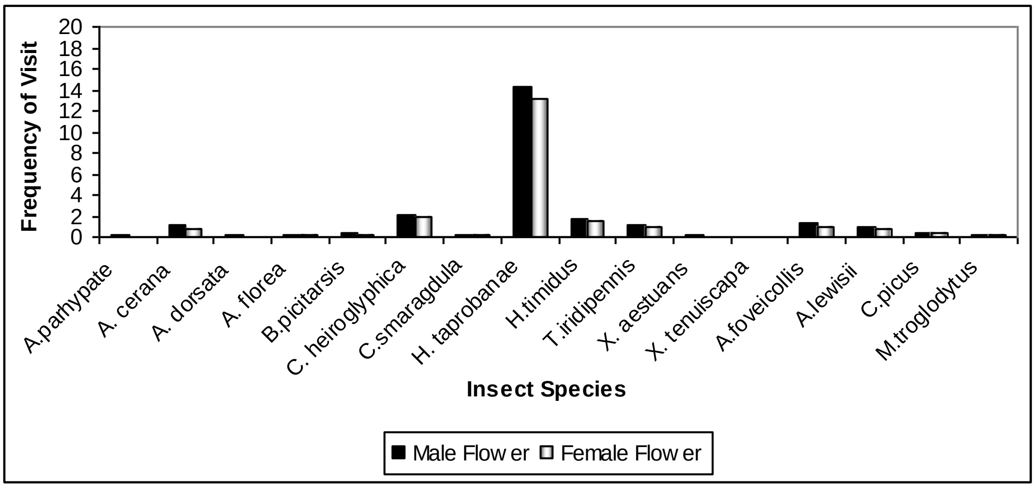
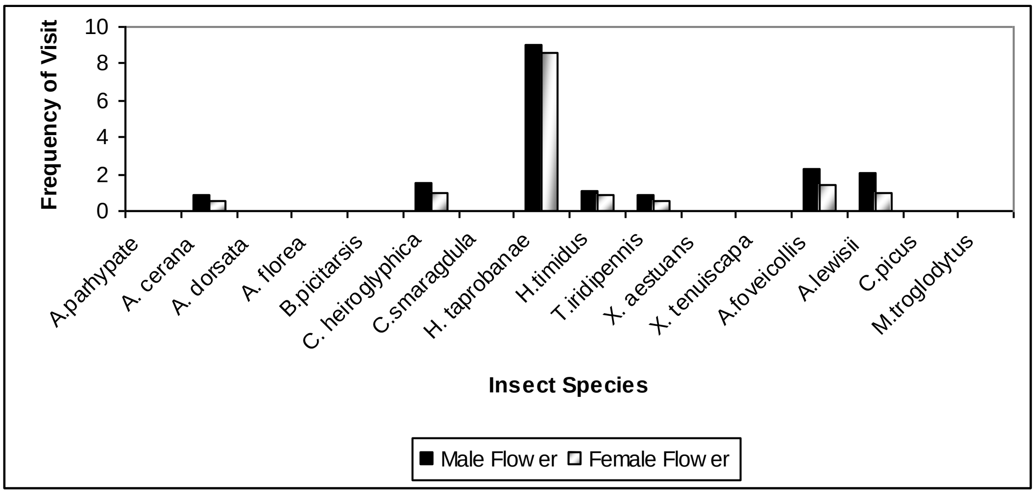


Figure.78: Frequency of pollinator (Species) visit / day (Late seasonal phase)



4.2.2.2.2. Mean Number of Flowers Visited by Pollinators

Mean number of male (♂) and female (♀) flowers visited was recorded during different phases of the day. It increased from initial phase of the season (IP) to middle phase of the season, (MP) and decreased to late of the season (LP). There was significant difference in the way these components changed in number over the day and season. Hymenopterans visited a mean of 32.91 male (♂) flowers and 26.41 female (♀) flowers and coleopterans visited a mean of 7.66 male (♂) flowers and 4.33 female (♀) flowers /day in the initial phase (IP) of the season. In middle phase (MP) a mean of 41.66 male (♂) flowers and 29.91 female (♀) flowers were visited by hymenopterans, 3.16 male (♂) flowers and 2.75 female (♀) flowers by coleopterans and 0.75 male (♂) flowers and 0.58 female (♀) flowers by lepidopterans /day. In late phase (LP) of the season it was a mean of 24.25 male (♂) flowers and 16.58 female (♀) flowers by hymenopterans and 6.83 male (♂) flowers and 3.75 female (♀) flowers by coleopterans /day. Variation in number of flowers visited in different diurnal phases in each phase of the season was also observed. Maximum number of flowers were visited in the middle diurnal phase of middle seasonal phase and minimum number of flowers were visited in the late diurnal phase of late seasonal phase. Hymenopterans visited highest number of flowers. Significant difference was found in number of flowers visited by different orders of insects [IP (p=0.00) (Figure 79); MP (p=0.00) (Figure 80) and LP (p=0.00) (Figure 81) (Table 11)]. Variation in number of flowers visited by different species of insects belonging to Hymenoptera, Coleoptera and Lepidoptera was also observed. Number of flowers visited by different species of pollinators varied significantly [IP (p=0.00) (Figure 82); MP (p=0.00) (Figure 83); LP (p=0.00) (Figure 84)] (Table 12). And there was also significant difference in the mean number of flowers visited by pollinators in different diurnal phases in each seasonal phase [IP (p=0.00); MP (p=0.00); LP (p=0.00)]. In the mean number of male (♂) and female (♀) flowers visited by different foragers no significant difference was found [IP (p=0.69); MP (p=0.15); LP (p=0.13). Significant difference in the mean number of flowers visited by pollinators was also found between different phases of the season (p=0.00).

Table.11: Mean number of flowers visited by pollinators (Order) /day

Order	Sex of flower	Initial Phase (IP)			Middle Phase (MP)			Late Phase (LP)		
		ip	mp	lp	ip	mp	lp	ip	mp	lp
Hymenoptera	♂	11	16.17	5.75	13.75	19.5	8.41	9	12.16	4.41
	♀	8.75	13.58	4.08	9.58	14.83	5.5	5.75	9.41	2.16
Coleoptera	♂	2.41	3.33	1.91	1	1.33	0.83	2.33	2.58	1.91
	♀	1.41	1.75	1.16	0.83	1.166	0.75	1.25	1.41	1.08
Lepidoptera	♂	0	0	0	0.75	0	0	0	0	0
	♀	0	0	0	0.58	0	0	0	0	0

IP - Initial phase of season   ip - initial phase of day   ♂ -Male flower
MP - Middle phase of season   mp - middle phase of day   ♀ -Female flower
LP - Late phase of season   lp - late phase of day

Figure.79: Mean number of flowers visited by pollinators (Order) /day (Initial seasonal phase)

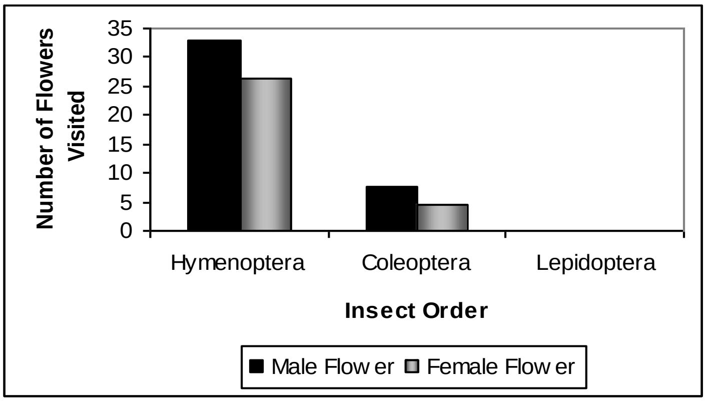


Figure.80: Mean number of flowers visited by pollinators (Order) /day (Middle seasonal phase)

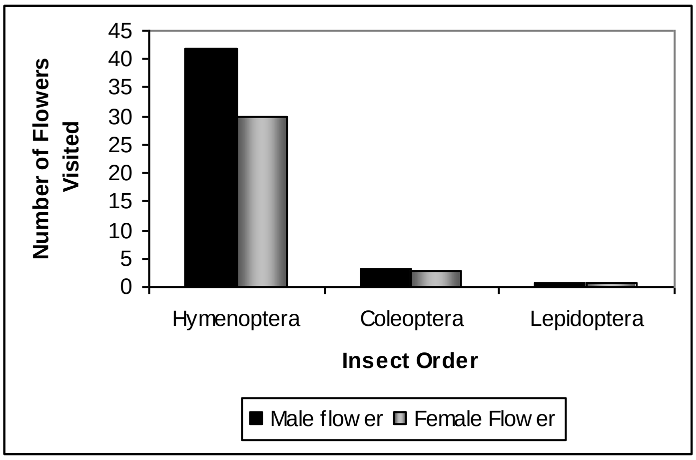


Figure.81: Mean number of flowers visited by pollinators (Order) /day (Late seasonal phase)

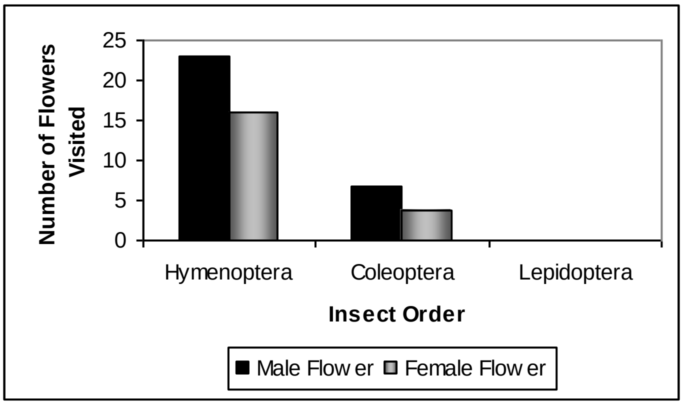


Table.12: Mean number of flowers visited by pollinators (Species) /day

Species	Sex of flower	Initial Phase (IP)			Middle Phase (MP)			Late Phase (LP)		
		ip	mp	lp	ip	mp	lp	ip	mp	Lp
Halictus taprobanae	♂	6	8.16	3	7.33	9.41	5.41	4.58	6.33	1.16
	♀	5.41	7.66	2.33	6	8.41	3.58	4.16	5.83	0.58
Halictus timidus	♂	1.41	2.5	1.58	2	2.58	0.75	1.33	1.75	0.41
	♀	1	0.66	0.25	1.08	1.66	0.41	0.41	1	0.25
Trigona iridipennis	♂	0.83	1.5	0.58	1	1.75	0.66	0.83	1.16	0.41
	♀	0.58	1.41	0.41	0.58	0.75	0.25	0.41	0.83	0.16
Ceratina heiroglyphica	♂	2.08	2.91	1.16	2.5	3	1.25	1.58	2.08	0.75
	♀	1.25	2.08	0.83	1.33	2.08	1	0.41	1	0.25
Apis cerana	♂	0.66	1.08	0.33	0.75	1.16	0.33	0.66	0.83	0.33
	♀	0.5	0.83	0.25	0.5	0.83	0.25	0.33	0.75	0.16
Amegilla parhypate	♂	0	0	0	0.16	0	0	0	0	0
	♀	0	0	0	0.08	0	0	0	0	0
Braunsapis picitarsis	♂	0	0	0	0	0.41	0	0	0	0
	♀	0	0	0	0	0.25	0	0	0	0
Apis florea	♂	0	0	0	0	0.33	0	0	0	0
	♀	0	0	0	0	0.25	0	0	0	0
Ceratina smaragdula	♂	0	0	0	0	0.25	0	0	0	0
	♀	0	0	0	0	0.16	0	0	0	0
Apis dorsata	♂	0	0	0	0	0.25	0	0	0	0
	♀	0	0	0	0	0.16	0	0	0	0
Xylocopa aestuans	♂	0	0	0	0	0.16	0	0	0	0
	♀	0	0	0	0	0.16	0	0	0	0
Xylocopa tenuiscapa	♂	0	0	0	0	0.16	0	0	0	0
	♀	0	0	0	0	0.08	0	0	0	0
Aulacophora lewisii	♂	1.33	2	1	0.58	0.75	0.41	1.25	1.33	1
	♀	0.83	1.16	0.75	0.5	0.66	0.41	0.8	0.91	0.66
Aulacophora foveicollis	♂	1.08	1.33	0.91	0.41	0.58	0.41	1.08	1.25	0.91
	♀	0.58	0.58	0.41	0.33	0.5	0.33	0.41	0.5	0.41
Cephonodes picus	♂	0	0	0	0.33	0	0	0	0	0
	♀	0	0	0	0.25	0	0	0	0	0
Macroglossum troglodytus	♂	0	0	0	0.41	0	0	0	0	0
	♀	0	0	0	0.33	0	0	0	0	0

IP - Initial phase of season
MP - Middle phase of season
LP - Late phase of season

ip - initial phase of day
mp - middle phase of day
lp - late phase of day

♂ -Male flower
♀ -Female flower

Figure.82: Mean number of flowers visited by pollinators (Species) /day (Initial seasonal phase)

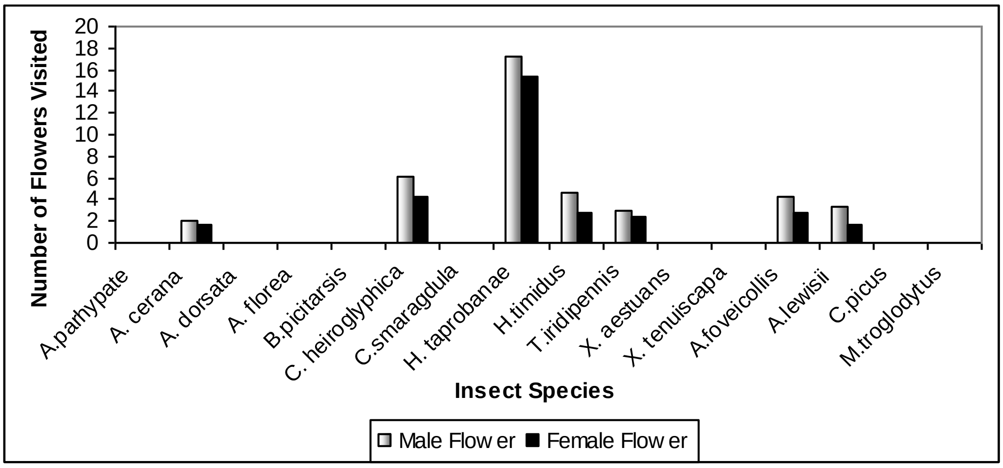


Figure.83: Mean number of flowers visited by pollinators (Species) /day (Middle seasonal phase)

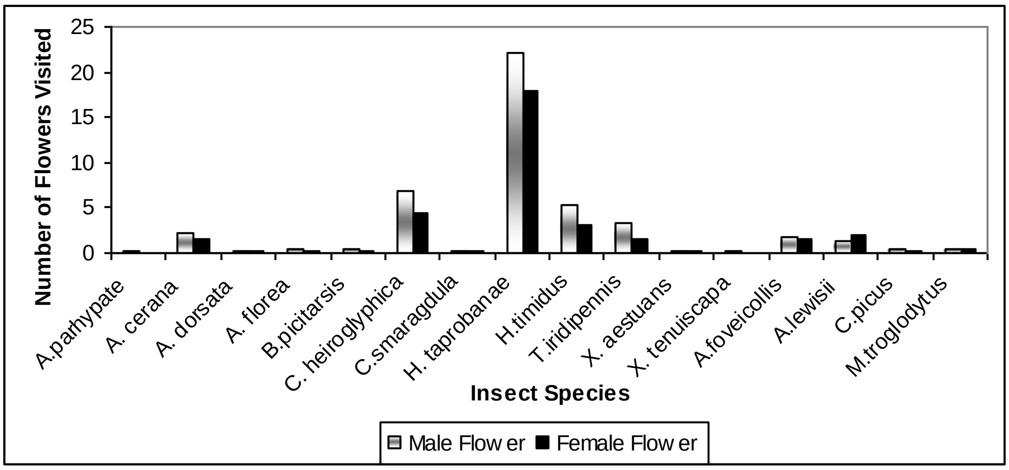
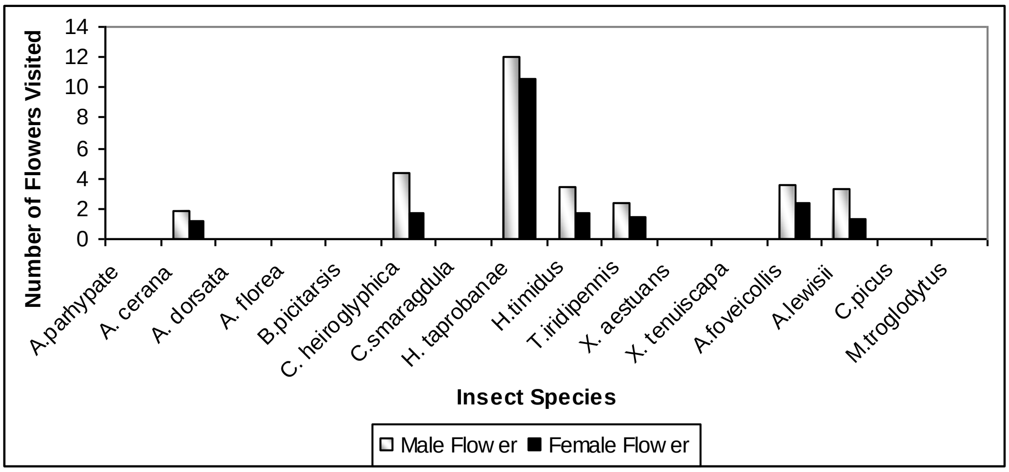


Figure.84: Mean number of flowers visited by pollinators (Species)/day (Late seasonal phase)



4.2.2.2.3. Mean Duration of Pollinator Visit

Duration of insect visit on each flower was also recorded in seconds (sec.) to provide data on the average time spent on male (♂) and female (♀) flowers by different insects. It was observed that mean duration of pollinator visit increased from initial phase (IP) to middle phase (MP) and decreased to late phase (LP) of the season. But the mean duration of visit decreased from initial to late in diurnal phases of each seasonal phase. The pollinators took longest duration in initial diurnal phase of middle seasonal phase and shortest duration in late diurnal phase of late seasonal phase. Mean duration of visit taken by hymenopterans was 25 sec. on male (♂) flowers and 18.83 sec. on female (♀) flowers and by coleopterans was 9 sec. on male (♂) flowers and 5.33 sec. on female (♀) flowers /day in the initial phase (IP) of the season. In middle phase (MP) 33.75 sec. on male (♂) flowers and 23.5 sec. on female (♀) flowers were taken by hymenopterans, 4.75 sec. on male (♂) flowers and 3.41 sec. on female (♀) flowers by coleopterans and 1.083 sec. on male (♂) flowers and 0.75 sec. on female (♀) flowers by lepidopterans /day. In late phase (LP) of the season it was 20.83 sec. on male (♂) flowers and 14.5 sec. on female flowers (♀) by hymenopterans and 8.91 sec. on male (♂) flowers and 4.66 sec. on female (♀) flowers by coleopterans /day. Variation in mean duration of visit taken by different orders in different diurnal phases in each phase of the season was also observed. The duration taken by different orders [IP (p=0.00) (Figure 85); MP (p=0.00) (Figure 86) and LP (p=0.00) (Figure 87)] (Table 13) of pollinators in all phases of season varied significantly. Variation in duration taken by different species of insects belonging to Hymenoptera, Coleoptera and Lepidoptera was observed. The duration taken by different species of pollinators in all phases of season also varied significantly [IP (p=0.00) (Figure 88); MP (p=0.00) (Figure 89); LP (p=0.00) (Figure 90)] (Table 14). There was no significant difference in mean duration of visit to male (♂) and female (♀) flowers [IP (p=0.07); MP (p=0.08); LP (p=0.06)]. But the duration of visit during diurnal phases of each season [IP (p=0.00); MP (p=0.00); LP (p=0.00)] varied significantly. Seasonal phases also showed significant difference in mean duration of visit (p=0.00).

Table.13: Mean duration of pollinator (Order) visit in seconds

Order	Sex of flower	Initial Phase (IP)			Middle Phase (MP)			Late Phase (LP)		
		ip	mp	lp	ip	mp	lp	ip	mp	lp
Hymenoptera	♂	11.5	8.58	4.91	15	12	6.75	10	7.25	3.58
	♀	8.66	6.58	3.58	10.33	8.41	4.75	7	5.33	2.16
Coleoptera	♂	3.83	3	2.16	2.91	0.91	0.91	3.83	2.91	2.16
	♀	2.33	1.58	1.41	1.91	0.75	0.75	2	1.41	1.25
Lepidoptera	♂	0	0	0	1.08	0	0	0	0	0
	♀	0	0	0	0.75	0	0	0	0	0

IP - Initial phase of season ip - initial phase of day ♂ -Male flower
MP - Middle phase of season mp - middle phase of day ♀ -Female flower
LP - Late phase of season lp - late phase of day

Figure.85: Mean duration of visit on flowers by pollinators (Order) in seconds (Initial seasonal phase)

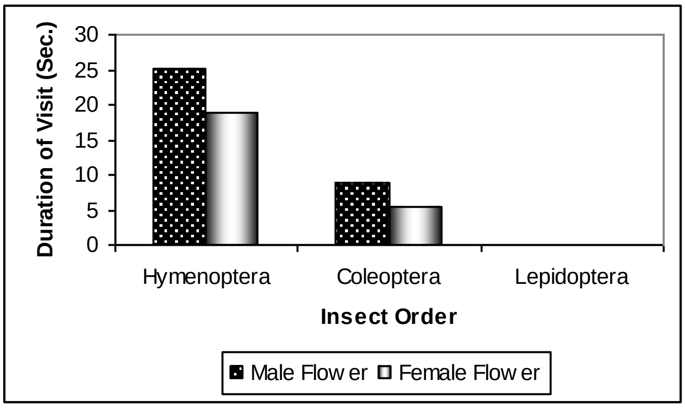


Figure.86: Mean duration of visit on flowers by pollinators (Order) in seconds (Middle seasonal phase)

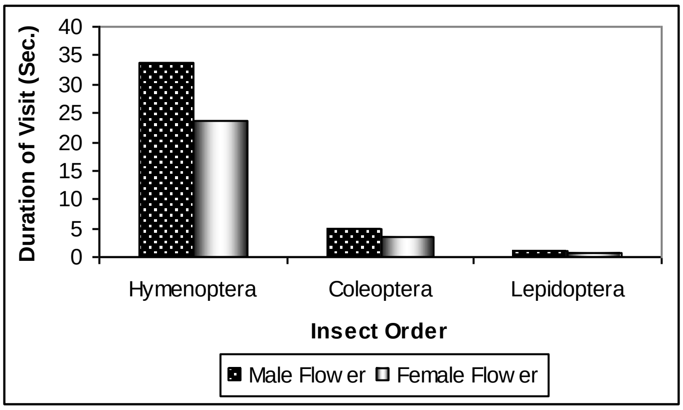


Figure.87: Mean duration of visit on flowers by pollinators (Order) in seconds (Late seasonal phase)

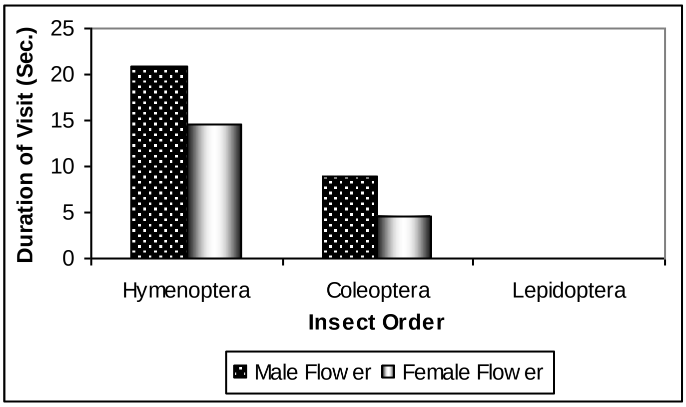


Table.14: Mean duration of pollinator (Species) visit in seconds

Species	Sex of flower	Initial Phase (IP)			Middle Phase (MP)			Late Phase (LP)		
		Ip	mp	Lp	ip	mp	lp	ip	mp	lp
Halictus taprobanae	♂	5.91	3.83	2.66	6.41	4.16	3.58	4.58	2.91	1.83
	♀	4.66	3.16	2.25	4.91	3.25	2.75	4.25	2.66	1.58
Halictus timidus	♂	1.33	1.33	0.66	2.75	1.75	0.91	1.33	1.25	0.41
	♀	0.91	0.91	0.25	1.83	1.25	0.58	0.75	0.75	0.16
Trigona iridipennis	♂	1.25	0.75	0.41	1.33	1.25	0.58	1.25	0.75	0.33
	♀	0.83	0.66	0.25	0.91	0.66	0.25	0.66	0.66	0.16
Ceratina heiroglyphica	♂	2	1.91	0.75	3.16	2	1.16	1.91	1.66	0.75
	♀	1.66	1.25	0.58	1.66	1.25	0.91	0.83	0.83	0.16
Apis cerana	♂	1	0.75	0.41	1.16	0.83	0.5	0.91	0.66	0.25
	♀	0.58	0.58	0.25	0.83	0.83	0.25	0.5	0.41	0.08
Amegilla parhypate	♂	0	0	0	0.17	0	0	0	0	0
	♀	0	0	0	0.17	0	0	0	0	0
Braunsapis picitarsis	♂	0	0	0	0	0.91	0	0	0	0
	♀	0	0	0	0	0.33	0	0	0	0
Apis florea	♂	0	0	0	0	0.33	0	0	0	0
	♀	0	0	0	0	0.33	0	0	0	0
Ceratina smaragdula	♂	0	0	0	0	0.25	0	0	0	0
	♀	0	0	0	0	0.25	0	0	0	0
Apis dorsata	♂	0	0	0	0	0.25	0	0	0	0
	♀	0	0	0	0	0.08	0	0	0	0
Xylocopa aestuans	♂	0	0	0	0	0.16	0	0	0	0
	♀	0	0	0	0	0.08	0	0	0	0
Xylocopa tenuiscapa	♂	0	0	0	0	0.08	0	0	0	0
	♀	0	0	0	0	0.08	0	0	0	0
Aulacophora lewisii	♂	2.08	1.66	1.25	1.83	0.5	0.5	2.08	1.66	1.25
	♀	1.41	1.16	1	1.33	0.41	0.41	1.41	1	0.83
Aulacophora foveicollis	♂	1.75	1.33	0.91	1.08	0.41	0.41	1.75	1.25	0.91
	♀	0.91	0.41	0.41	0.58	0.33	0.33	0.58	0.41	0.41
Cephonodes picus	♂	0	0	0	0.5	0	0	0	0	0
	♀	0	0	0	0.33	0	0	0	0	0
Macroglossum troglodytus	♂	0	0	0	0.58	0	0	0	0	0
	♀	0	0	0	0.41	0	0	0	0	0

IP - Initial phase of season
MP - Middle phase of season
LP - Late phase of season

ip - initial phase of day
mp - middle phase of day
lp - late phase of day

♂ -Male flower
♀ -Female flower

Figure.88: Mean duration of visit on flowers by pollinators (Species) in seconds (Initial seasonal phase)

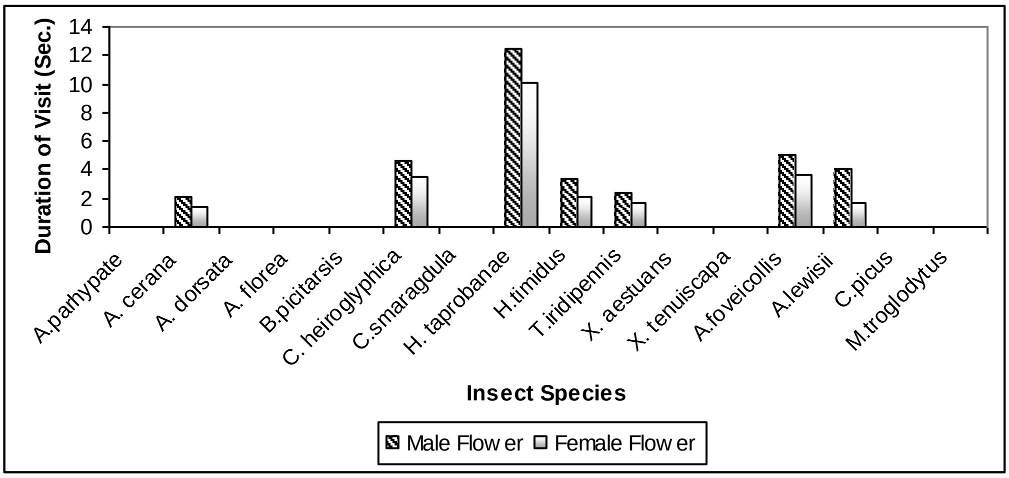


Figure.89: Mean duration of visit on flowers by pollinators (Species) in seconds (Middle seasonal phase)

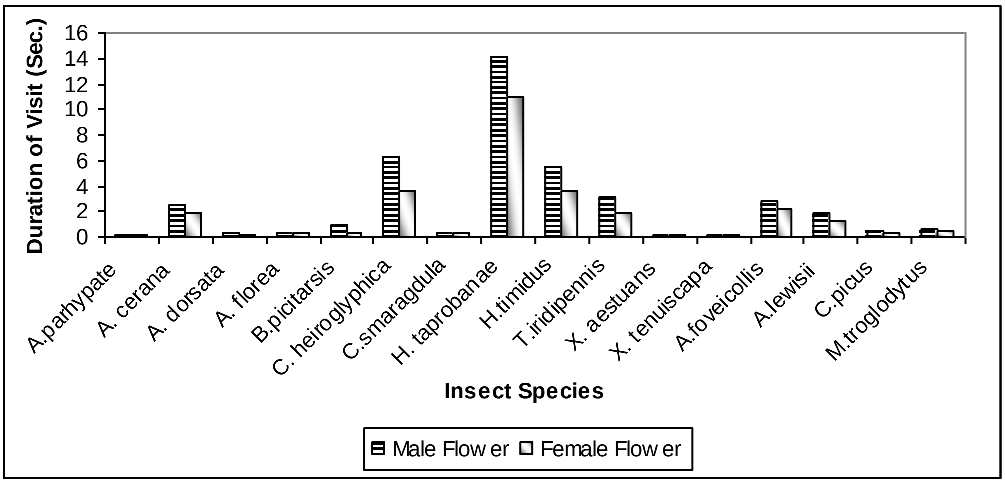
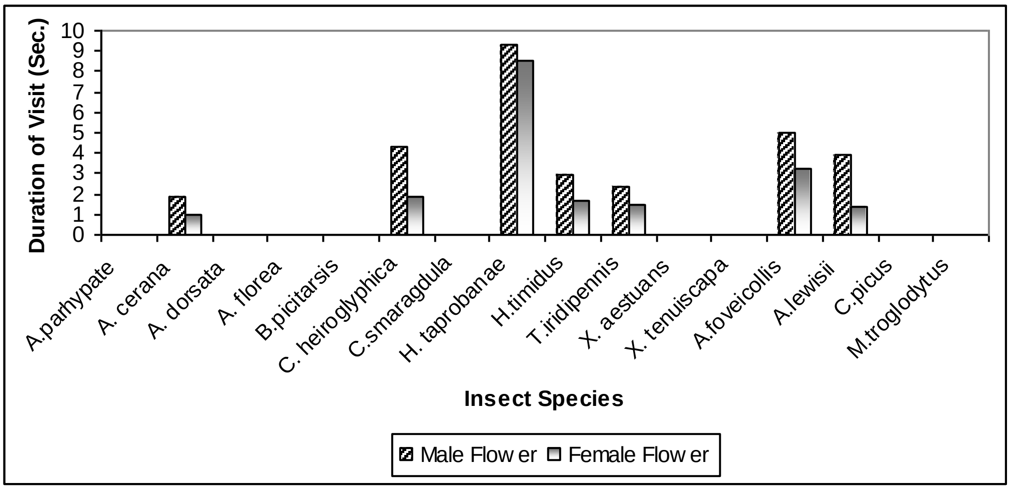


Figure.90: Mean duration of visit on flowers by pollinators (Species) in seconds (Late seasonal phase)



4.2.3. Palynology

4.2. 3.1. Pollen Count

The mean number of pollen grains produced by staminate flowers varied by phases of the season. It was highest in MP (10313.58±4.21) than in IP (5512.33±4.61) and LP (4756.41±3.75) of the season. At anthesis staminate cucumber flowers contained more pollen grains /flower and the number of pollen grains remaining on anthers decreased over time of day [IP : (ip) (6779.33±11.47), (mp) (5512.33±4.62), (lp) (3431.58±13.71); MP : (ip) (13708±26.01), (mp) (10313.58±4.20), (lp) (3130.91±26.61); LP : (ip) (5575.58±8.73), (mp) (4756.41±3.75), (lp) (3674.66±12.48)]. The mean number of pollen grains produced was highest in the initial diurnal phase (13708±26.01) of middle seasonal phase and lowest in the late diurnal phase (3674.66±12.48) of late seasonal phase. The counts were significantly different in diurnal phases of each seasonal phase [IP (p=0.00) (Figure 91); MP (p=0.00) (Figure 92); LP (p=0.00) (Figure 93)]. Mean pollen counts between the seasonal phases were also significantly different (p=0.00) (Figure 94).

Figure.91: Mean pollen counts in diurnal phases (Initial seasonal phase)

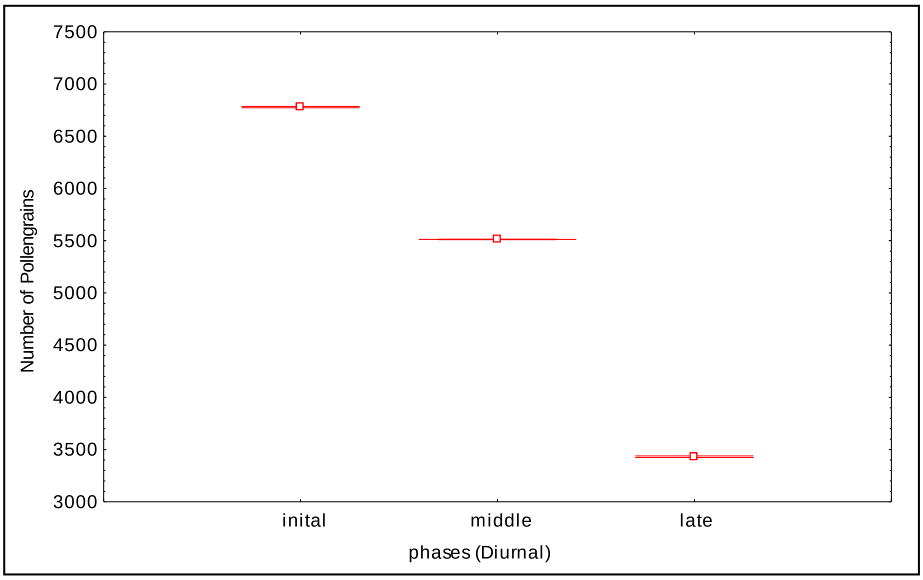


Figure.92: Mean pollen counts in diurnal phases (Middle seasonal phase)

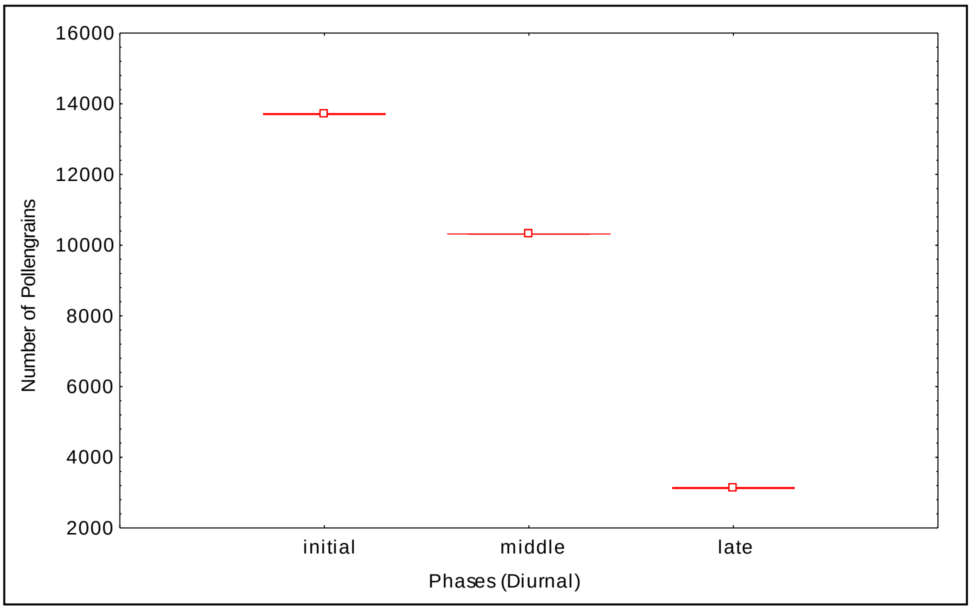


Figure.93: Mean pollen counts in diurnal phases (Late seasonal phase)

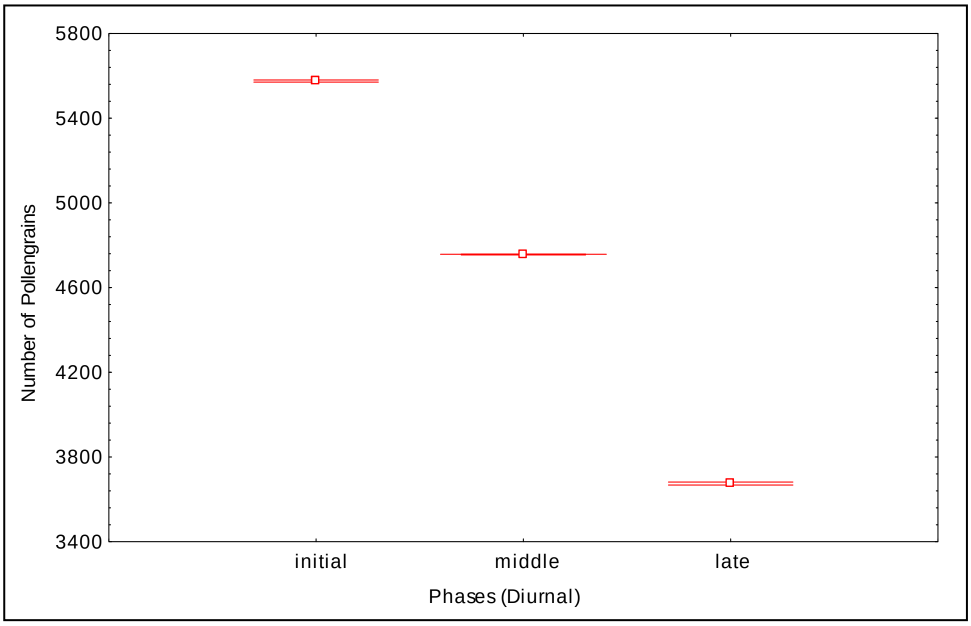
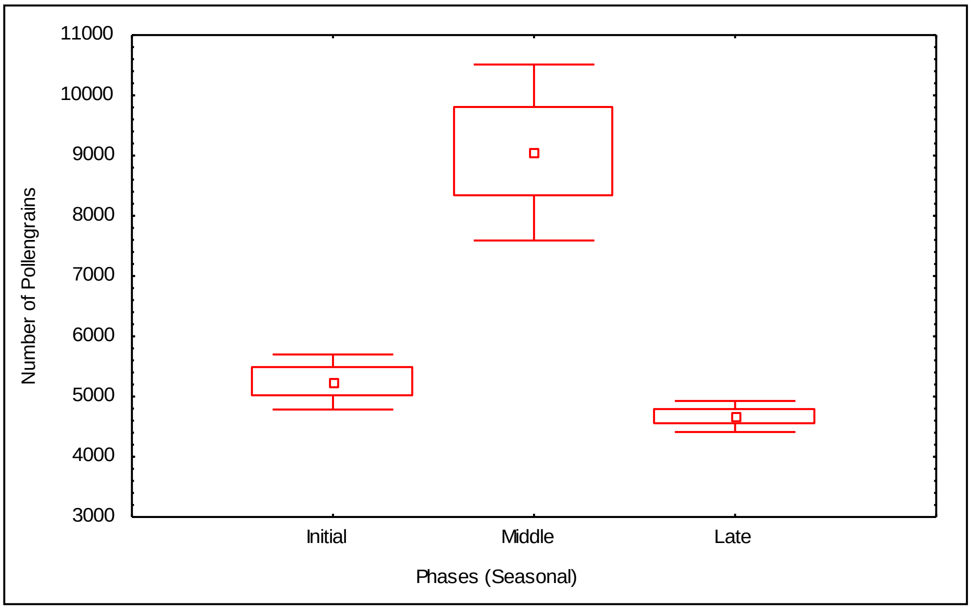


Figure.94: Mean pollen counts in different phases of the season



4.2.3.2. Pollen Removal

The mean number of pollen grains removed from staminate flowers varied by phases of the day and season. Pollen removal increased from IP [ip (1267±16.02); mp (2080.75±9.16); lp (469.08±4.16)]; to MP [ip (3394.41±30.11); mp (7182.66±22.44); lp (1066.33±9.99)] and then decreased to LP [ip (819.16±12.46); mp (1081.75±8.84); lp (322.66±4.27)]. In middle diurnal phase of middle seasonal phase maximum number of pollen grains (7182.66±22.44) were removed. In late diurnal phase of late seasonal phase minimum number of pollen grains (322.66±4.27) were removed. The number of pollen grains removed were significantly different in different phases of day such as IP (p=0.00) (Figure 95); MP (p=0.00) (Figure 96); LP (p=0.00) (Figure 97) and between seasonal phases (p=0.00) (Figure 98).

Figure.95: Mean pollen removal in diurnal phases (Initial seasonal phase)

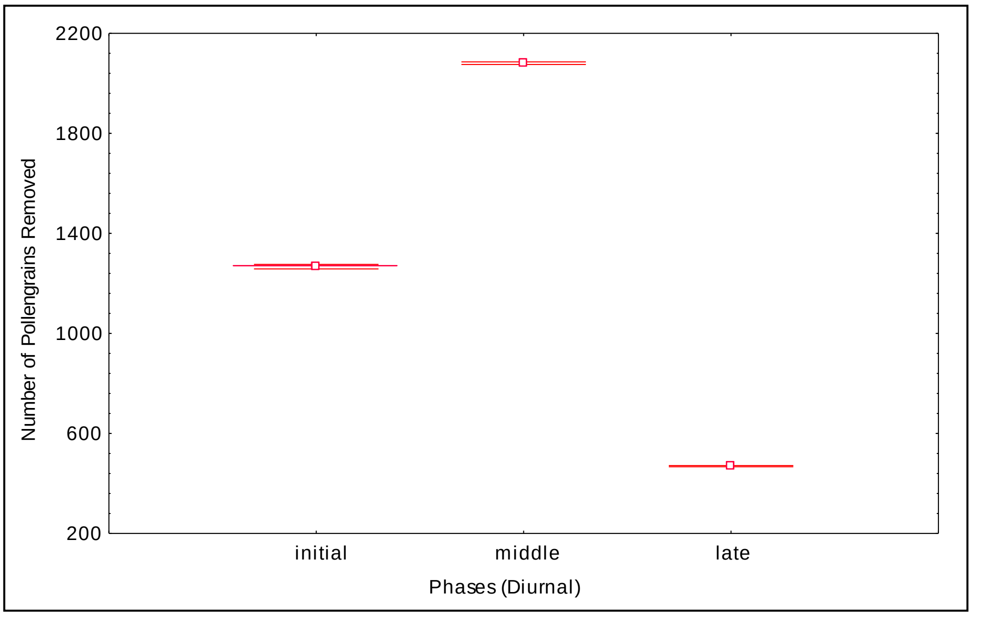


Figure.96: Mean pollen removal in diurnal phases (Middle seasonal phase)

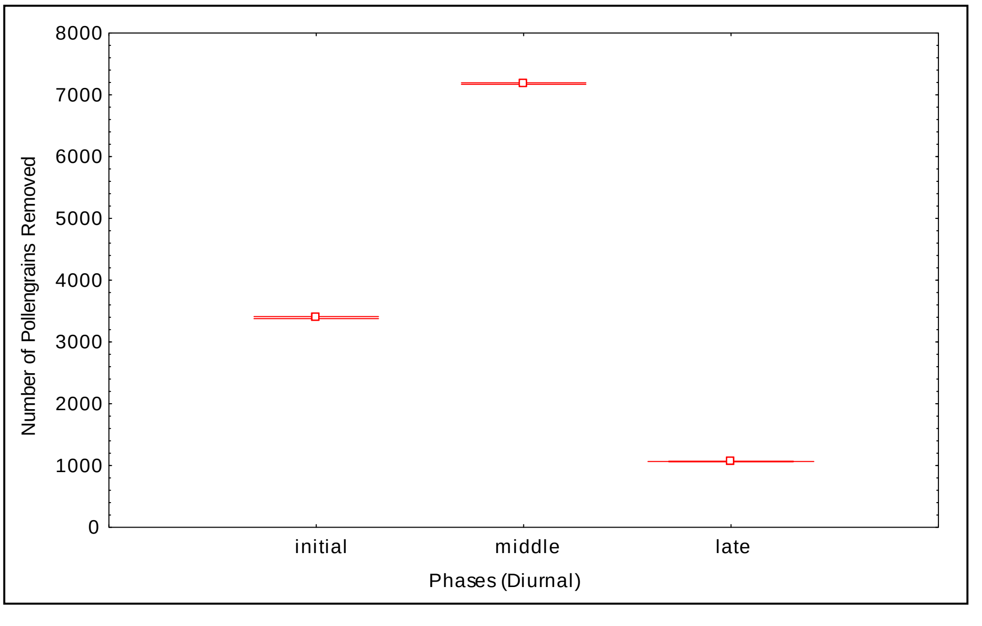


Figure.97: Mean pollen removal in diurnal phases (Late seasonal phase)

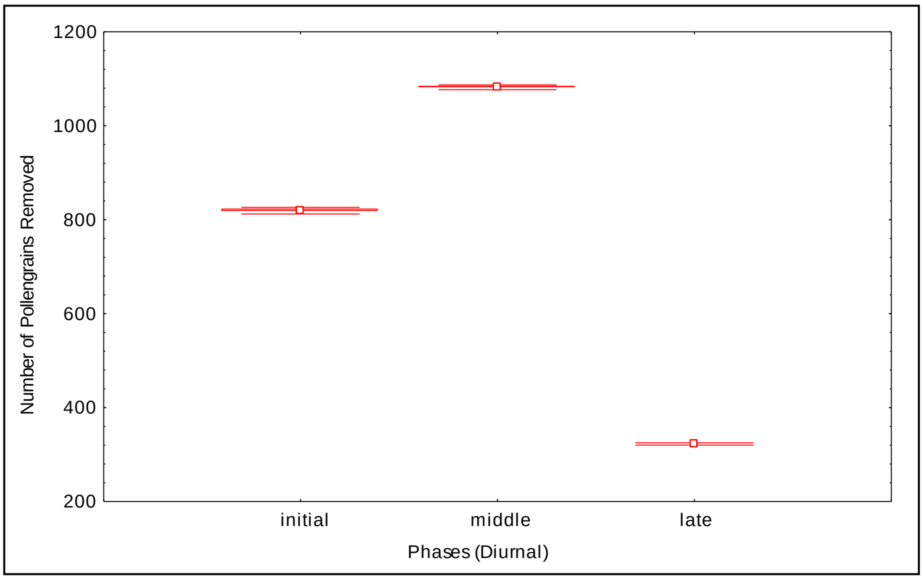
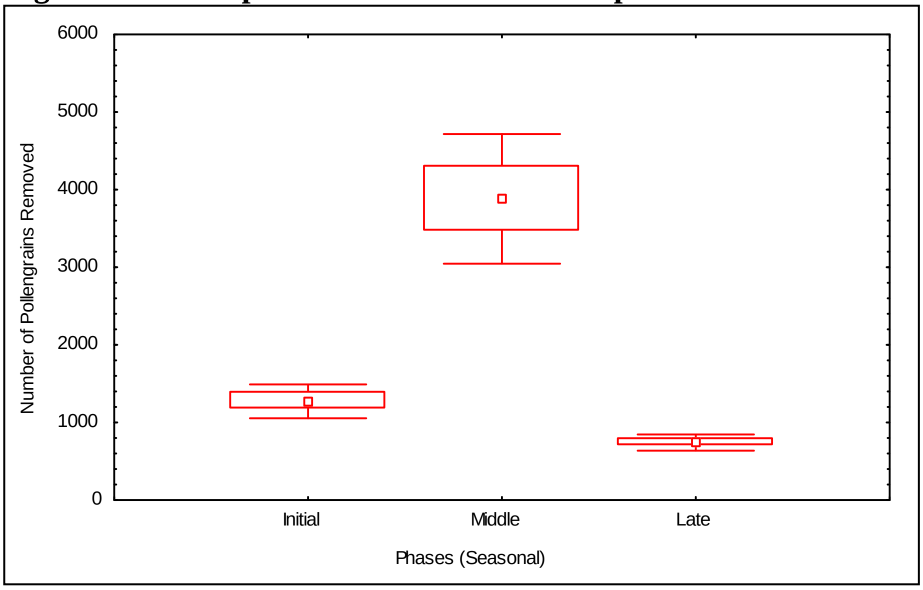


Figure.98: Mean pollen removal in different phases season



4.2.3.3. Pollen Deposition

The mean number of pollen grains deposited on stigma of pistillate flowers varied by phases of the day and season. Pollen deposition increased from IP [ip (556.91±9.39); mp (964±11.47); lp (158.08±5.11)]; to MP [ip (1423.66±53.69); mp (3440.41±14.63); lp (391.41±17.27)] and then decreased to LP [ip (300±21.63) mp (514.16±8.75); lp (99.5±5.11)].

Maximum pollen grains were deposited in the middle diurnal phase (3440.41±14.63) of middle phase of the season and minimum pollen grains were deposited in the late diurnal phase (99.5±5.11) of late phase of the season. The counts were significantly different in different phases of day such as IP (p=0.00) (Figure 99); MP (p=0.00) (Figure 100); LP (p=0.00) (Figure 101) and between seasonal phases (p=0.00) (Figure 102).

Figure.99: Mean pollen deposition in diurnal phases (Initial seasonal phase)

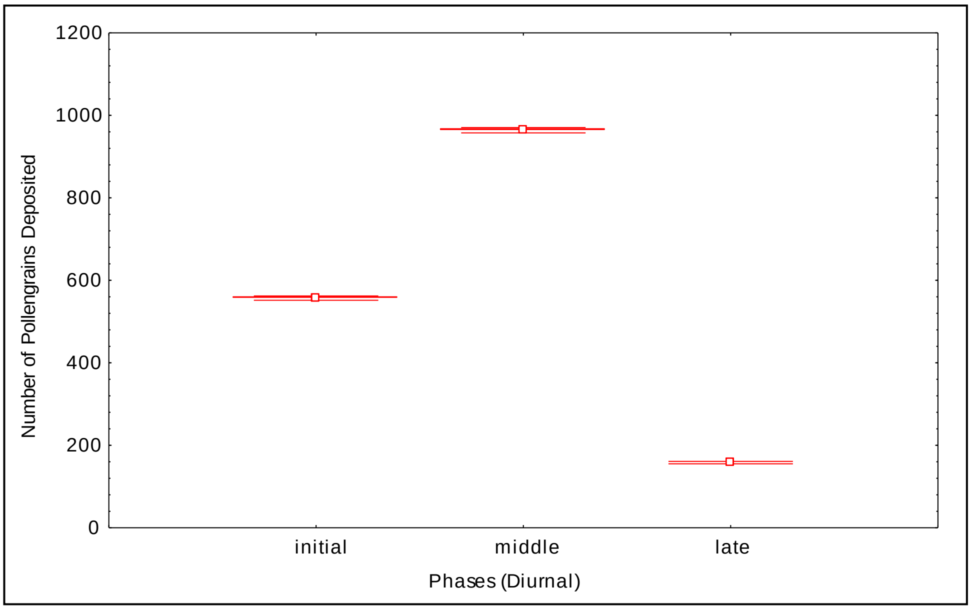


Figure.100: Mean pollen deposition in diurnal phases (Middle seasonal phase)

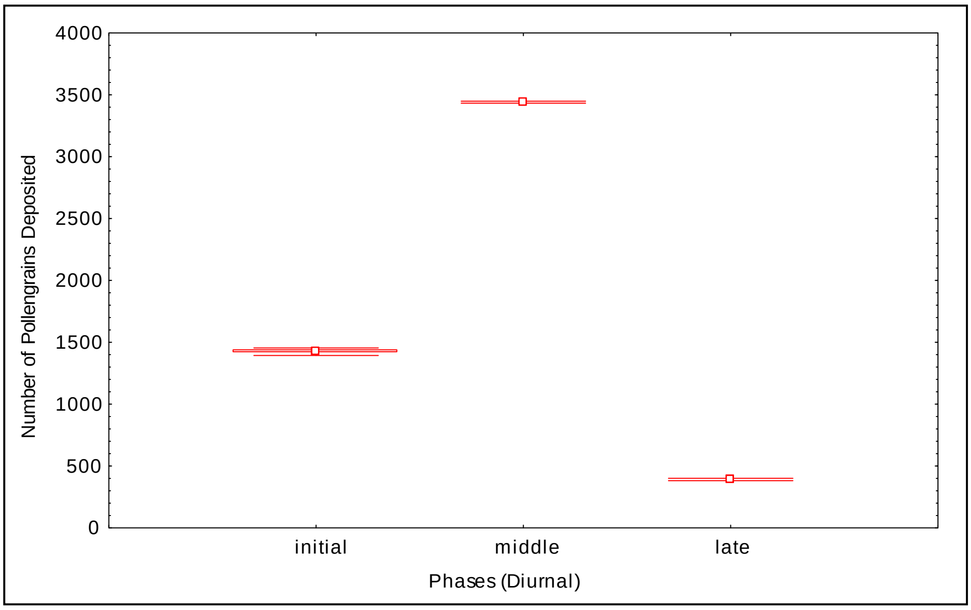


Figure.101: Mean pollen deposition in diurnal phases (Late seasonal phase)

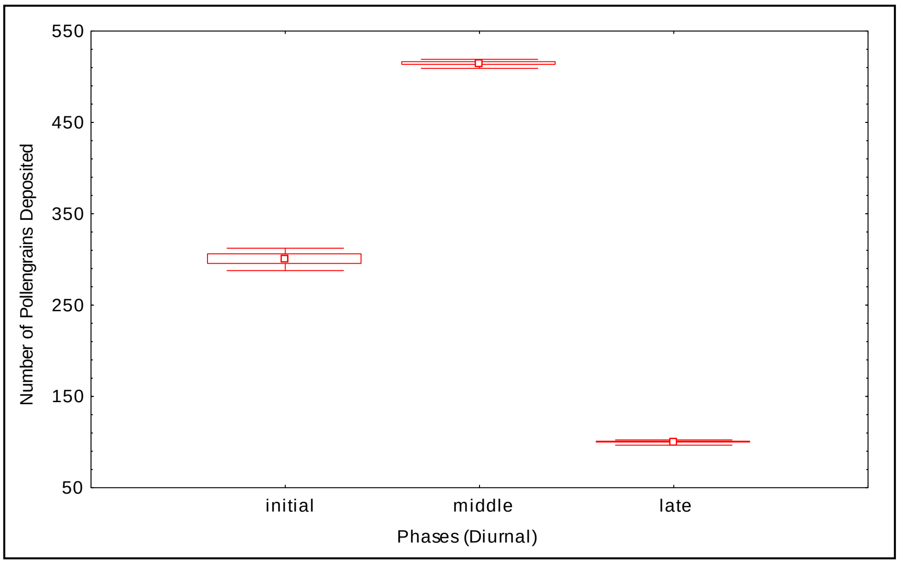
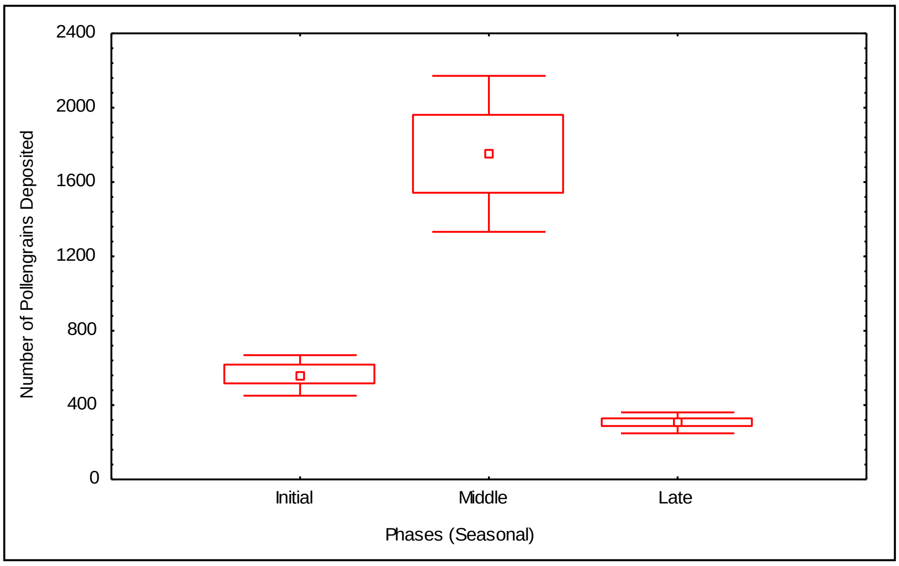


Figure.102: Mean pollen deposition in different phases season



4.2.3.4. Pollen Viability

Viability of pollen grains was found to decrease through diurnal phases of each season, IP [ip (758.75±6.98); mp (688.41±9.03); lp (625.50±9.95)]; MP [ip (3169.16±8.63); mp (2885.91±26.02); lp (2500.91±20.43)]; LP [ip (513.58±8.88); mp (458.08±7.79); lp (349.25±7.73)] and the variations in diurnal phases of each season were significantly different IP (p=0.00) (Figure 103); MP (p=0.00) (Figure 104); LP (p=0.00) (Figure 105). But viability increased from initial phase of the season to middle phase. Most viable pollen grains were observed in initial diurnal phase of middle seasonal phase (3169.16±8.63). Least number of viable pollen grains were observed in late diurnal phase (349.25±7.73) of late seasonal phase. Significant difference was found in the viability of pollen grains between the seasonal phases also (p=0.00) (Figure 106).

Figure.103: Mean pollen viability in diurnal phases (Initial seasonal phase)

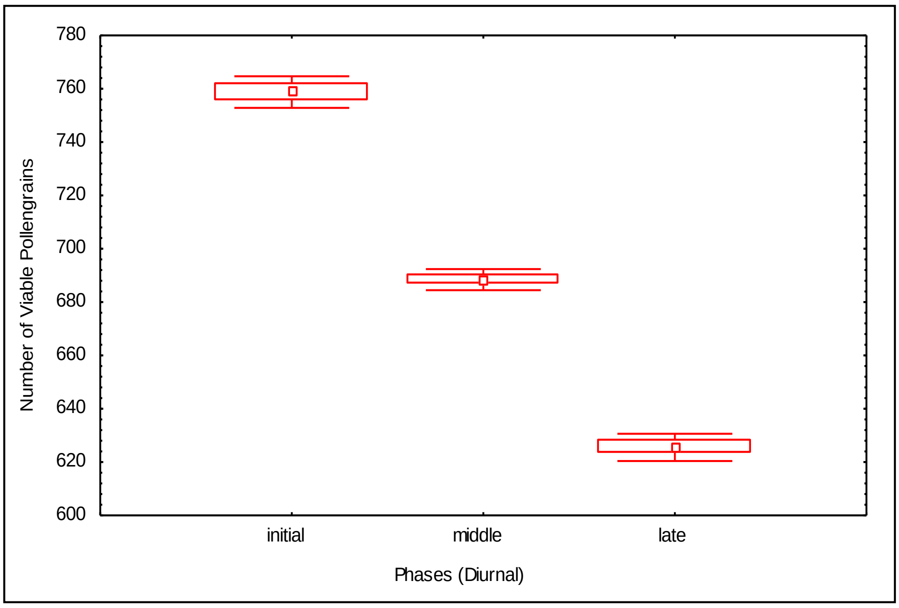


Figure.104: Mean pollen viability in diurnal phases (Middle seasonal phase)

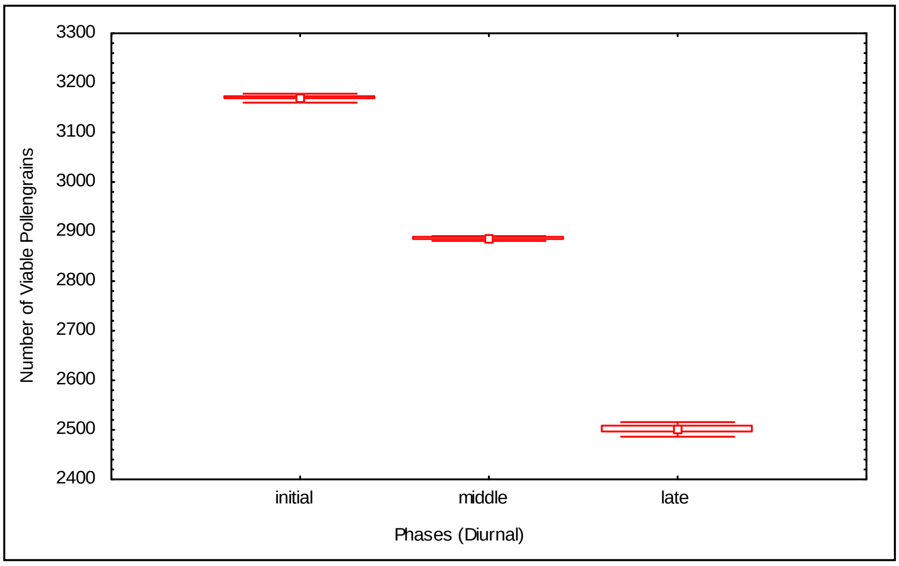


Figure.105: Mean pollen viability in diurnal phases (Late seasonal phase)

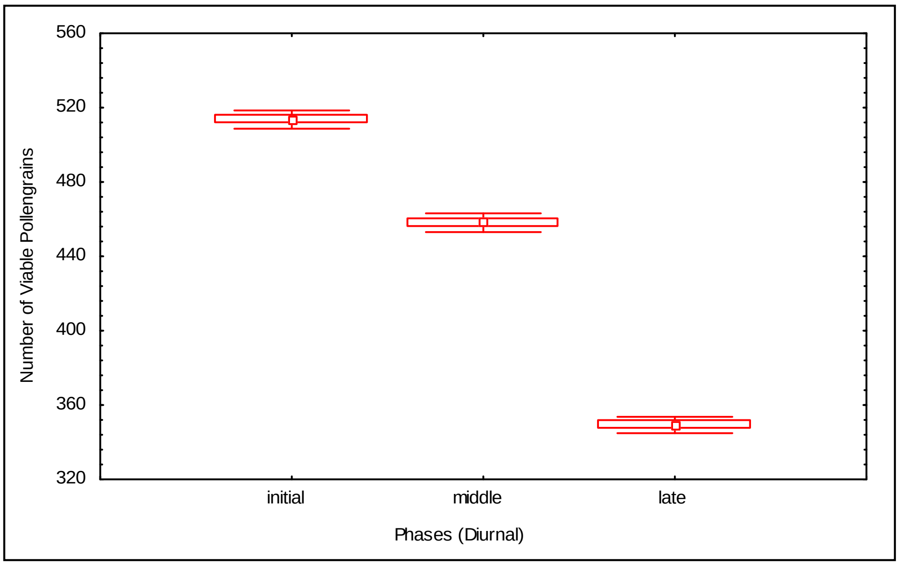
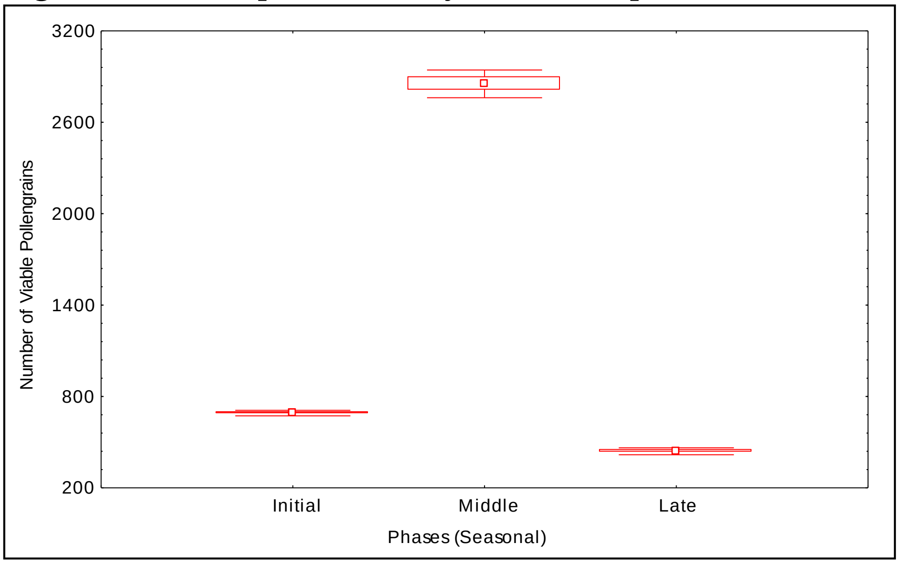


Figure.106: Mean pollen viability in different phases of the season



4.2.4. Pomology

4.2.4.1. Fruit Set

From the bagging experiment it was observed that percentage of fruit set increased from initial phase [IP (34.28%) : (ip)=10%; (mp)=18.57%; (lp)=5.71%] to middle phase [MP (41.42%): (ip)=12.85%;

(mp)=21.42%; (lp)=7.14%] and then decreased to late phase [LP (24.28%) : (ip)=8.57%; (mp)=10%; (lp)=5.71%] of the day and season. All non pollinated flowers were aborted (np=0). Highest fruit set was recorded in middle seasonal phase. Lowest fruit set was recorded in late seasonal phase. Percentage of fruits within seasonal phases such as IP (p=0.00) (Figure 107); MP (p=0.00) (Figure 108); LP (p=0.00) (Figure 109) and between the seasonal phases were significantly different (Figure 110).

Figure.107: Percentage of fruits in diurnal phases (Initial seasonal phase)

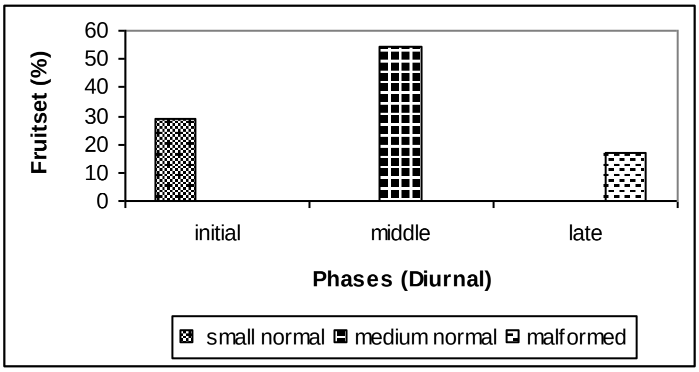


Figure.108: Percentage of fruits in diurnal phases (Middle seasonal phase)

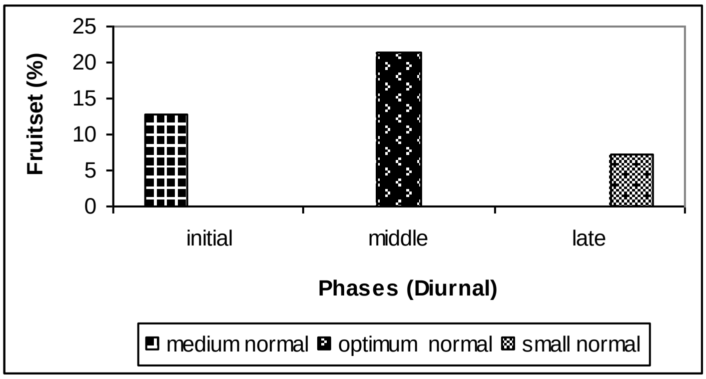


Figure.109: Percentage of fruits in diurnal phases (Late seasonal phase)

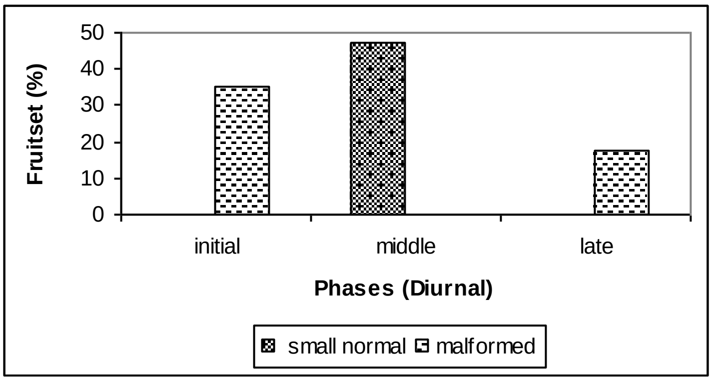
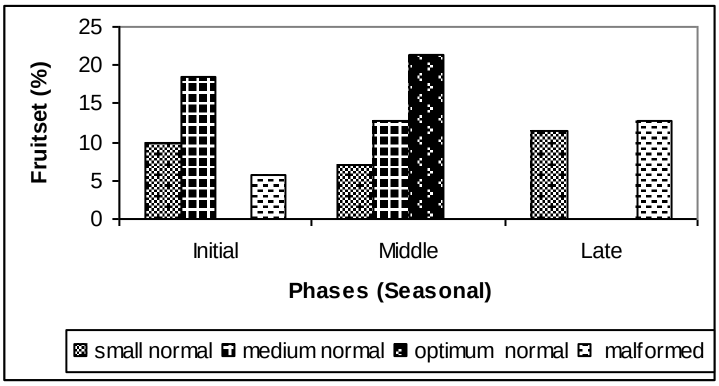


Figure.110: Percentage of fruits in different phases of season



4.2.4.2. Nature of Fruits

Fruits with varied shape and size were produced in the different phases of season. When size was measured in terms of length (l) and breadth (b) it was found that fruits formed in different diurnal and seasonal phases were differed in the maximum size they attained. By comparing each other fruits with lb ≤ 15 cm. x 4 cm. were included in small sized ones, ≤ 20 cm. x 6 cm. and ≤ 25 cm. x 8 cm. were included in the group of medium and optimum sized ones respectively. Also on the basis of shape the fruits were categorized into normal and malformed ones. So four categories like small normal, medium normal, optimum normal and malformed fruits were observed when size and shape were considered together for the assessment of nature of fruits [IP (ip)=10% small normal; (mp)=18.57% medium normal; (lp)=5.71% malformed; MP (ip)=12.85% medium normal; (mp)=21.42% optimum normal; (lp)=7.14% small normal; LP (ip)=8.57% malformed; (mp)=10% small normal; (lp)=5.71% malformed] (Plate 9). All non pollinated flowers were aborted in all phases. Majority of fruits formed in the initial and middle phase were normal shaped and in late phase were malformed. Size and shape of the fruits varied significantly within seasonal phases IP (p=0.00) (Figure 107); MP (p=0.00) (Figure 108); LP (p=0.00) (Figure.109) and between the seasonal phases (P=0.00) (Figure 110).

4.2.4.3. Weight of Fruits

Mean weight of fruits increased from initial phase [IP (ip)=129.58±114.57 gm.; (mp)=381.83±22.53 gm.; (lp)=19.166±28.31 gm.] to middle phase [MP (ip)=431.75±261.04 gm.; (mp)=1431.75±72.07 gm.; (lp)=51.91±64.18 gm.] and then decreased to late phase [Lp (ip)=69.91±73.08 gm.; (mp)=138.83±102.91 gm.; (lp)=9.08±16.44 gm.)] of the day and season. As non pollinated flowers were aborted no weights were recorded. In middle diurnal phase of middle seasonal phase the average weight of fruit was highest (1431.75±72.07 gm.). In late diurnal phase of late seasonal phase the average weight of fruit was lowest (9.08±16.44 gm).Weight of fruits within seasonal phases such as IP (p=0.00) (Figure 111); MP (p=0.00) (Figure 112); LP (p=0.00) (Figure 113) and between the seasonal phases were significantly different (P=0.00) (Figure 114).

Figure.111: Mean weight of fruits in diurnal phases (Initial seasonal phase)

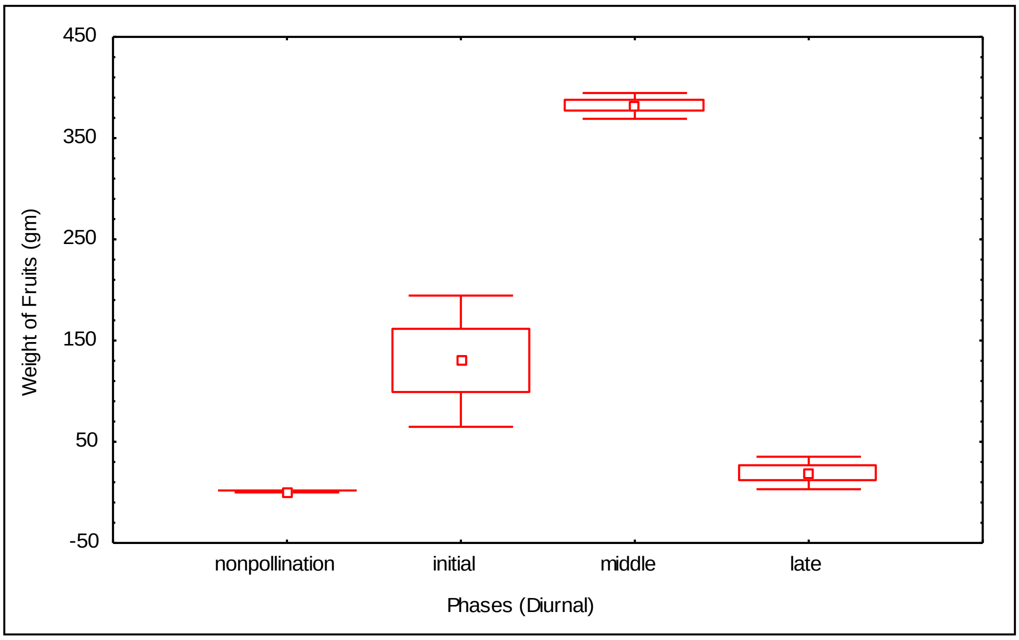


Figure.112: Mean weight of fruits in diurnal phases (Middle seasonal phase)

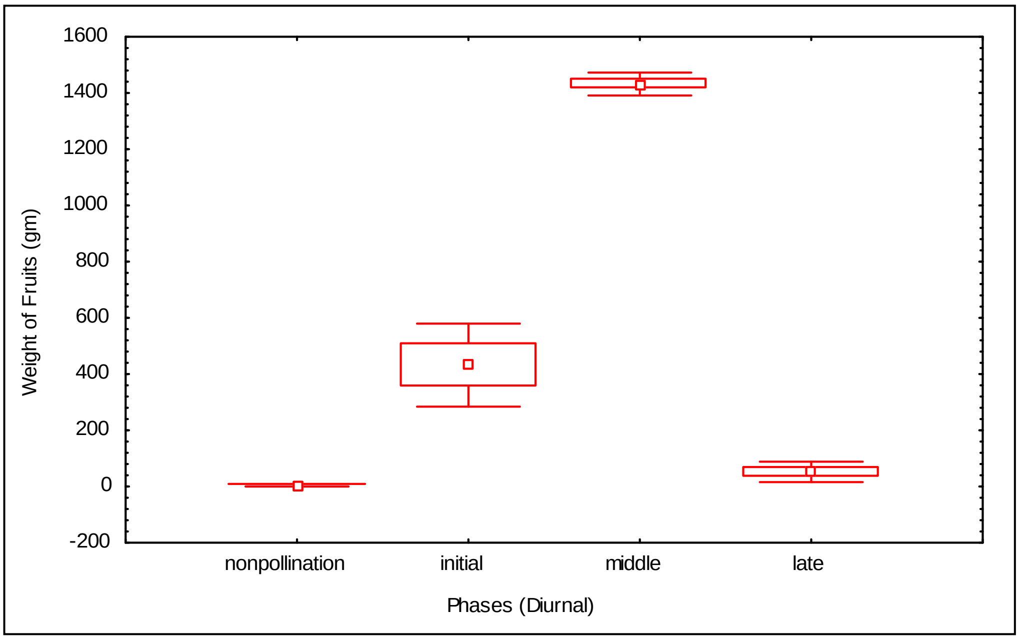


Figure.113: Mean weight of fruits in diurnal phases (Late seasonal phase)

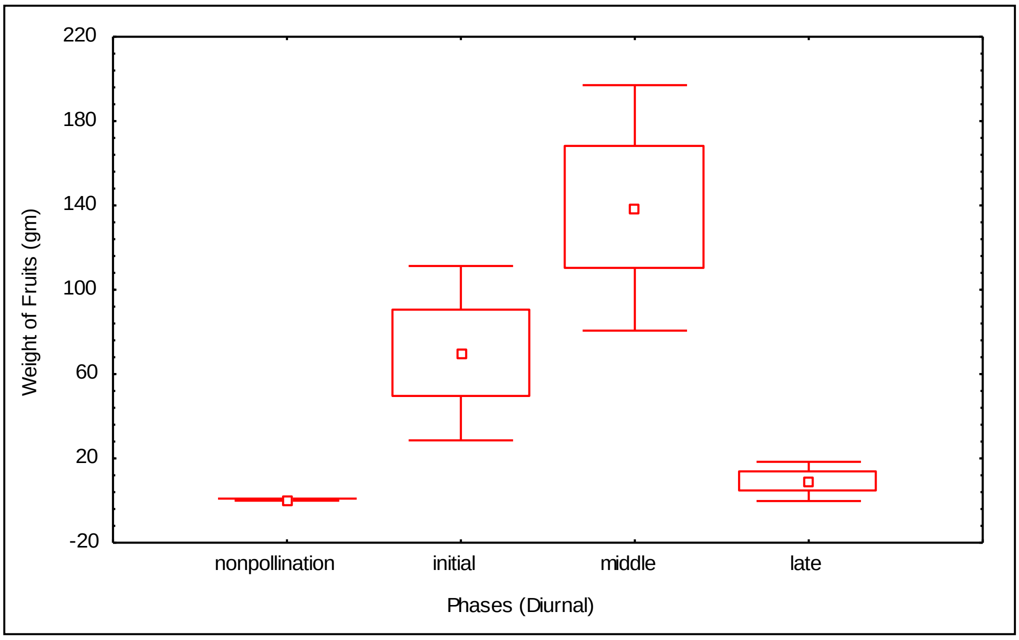
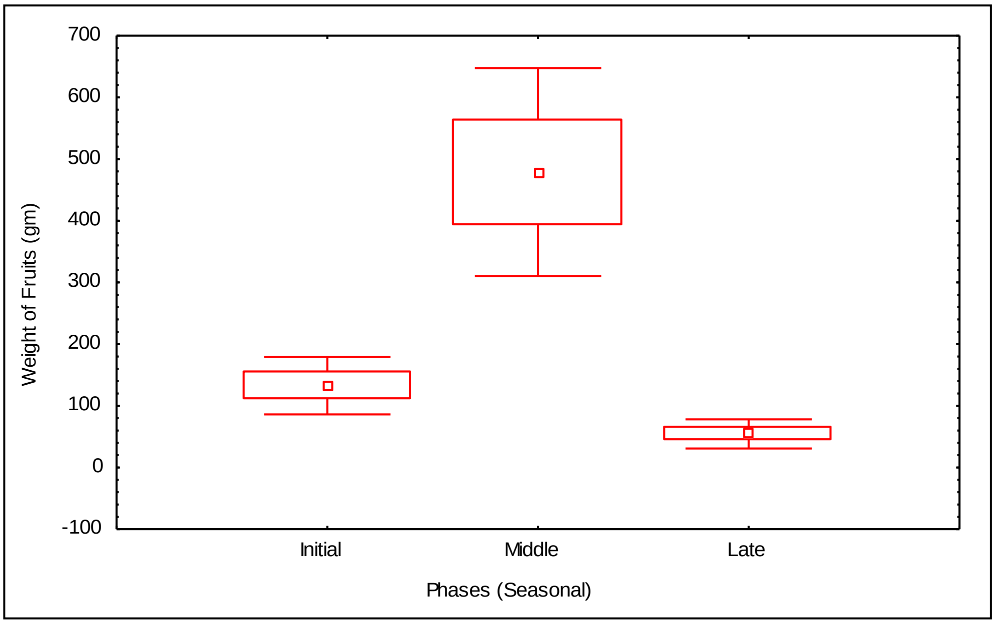


Figure.114: Mean weight of fruits in different seasonal phases



4.2.4.4. Number of Seeds

Mean number of seeds increased from initial phase of the season IP [ip=14.83±13.12; mp=45.25±3.74; lp=2.25±3.33] to middle phase of the season MP [ip=54.5±33.03; mp=182.16±14.32; lp=5.91±7.35] and then decreased to late phase LP [ip=7.41±7.75; mp=16.33±12.17; lp=1±1.80] of the season. As non pollinated flowers were aborted no seeds were found. Highest number of seeds were found in middle diurnal phase (182.16±14.32) of middle seasonal phase. In late diurnal phase of late seasonal phase less number of seeds (16.33±12.17) were found. Mean number of seeds within each seasonal phase such as IP (p=0.00) (Figure 115); MP (p=0.00) (Figure 116); LP (p=0.00) (Figure 117) and between the seasonal phases were significantly different (P=0.00) (Figure 118).

Figure.115: Mean number of seeds in diurnal phases (Initial seasonal phase)

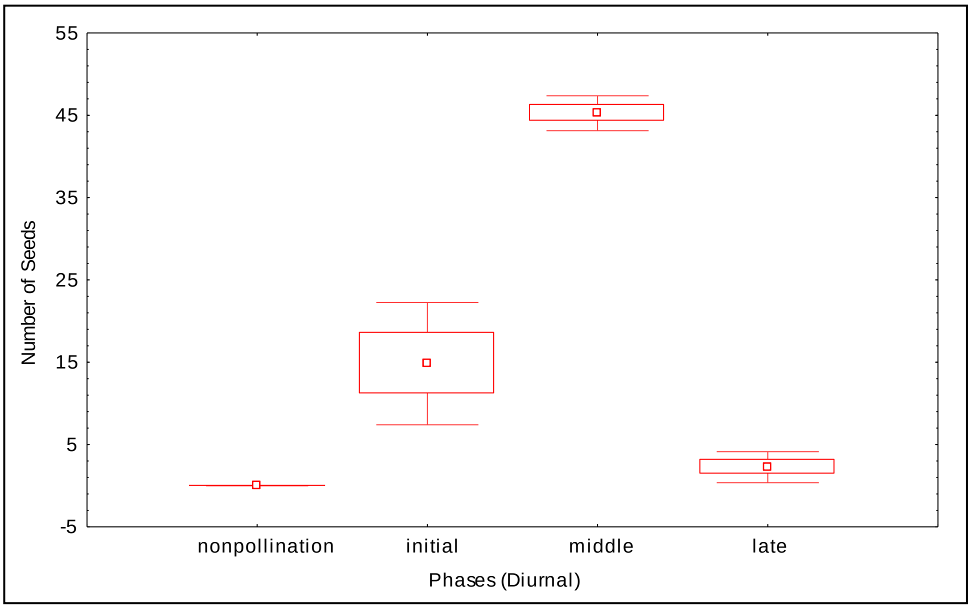


Figure.116: Mean number of seeds in diurnal phases (Middle seasonal phase)

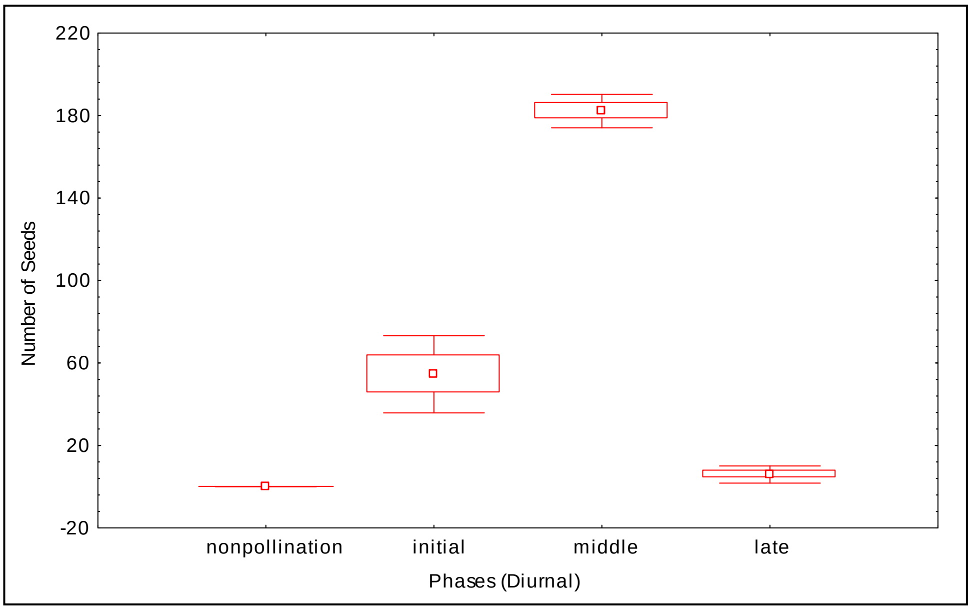


Figure.117: Mean number of seeds in diurnal phases (Late seasonal phase)

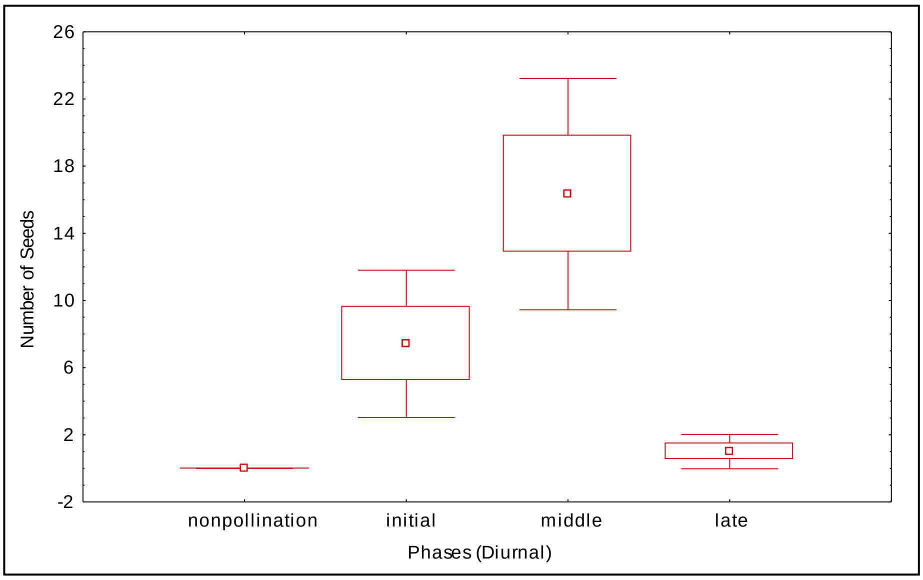
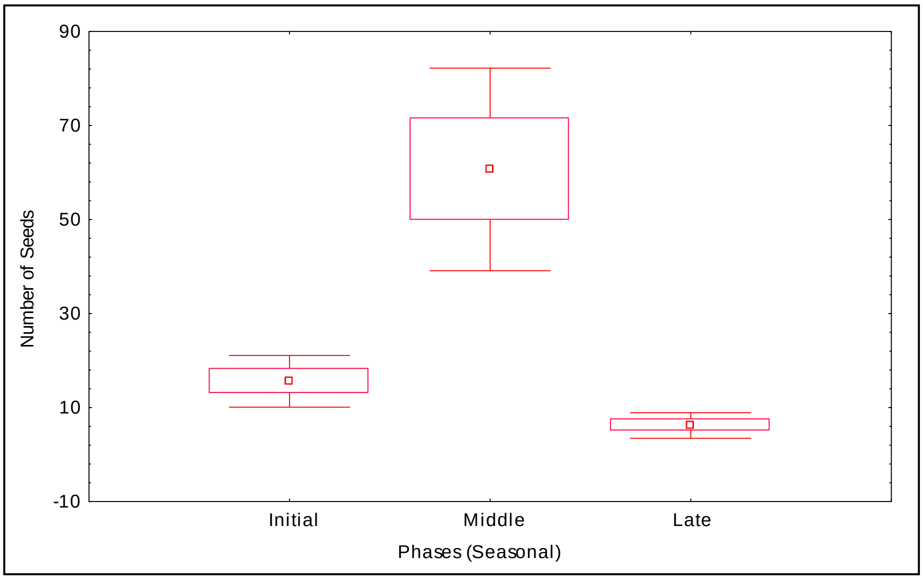


Figure.118: Mean number of seeds in different phases of season



4.2.4.5. Viability of Seeds

Mean number of viable seeds increased from initial phase of the season IP [ip=11.5±10.18; mp=36.58±3.05; lp=1.58±2.35] to middle phase of the season MP [ip=47±28.48; mp=168.41±13.93; lp=4.25±5.27] and then decreased to late phase LP [ip=3.91±4.10; mp=8.33±6.21; lp=0.5±0.90] of the season. As non pollinated flowers were aborted no viable seeds were recorded. Highest number of viable seeds were recorded in middle diurnal phase (168.41±13.93) of middle seasonal phase. In late diurnal phase of late seasonal phase lowest number of viable seeds (0.5±0.90) were recorded. Mean number of viable seeds within each seasonal phase such as IP (p=0.00) (Figure 119); MP (p=0.00) (Figure 120); LP (p=0.00) (Figure 121) and between the seasonal phases were significantly different (p=0.00) (Figure 122).

Figure.119: Mean number of viable seeds in diurnal phases (Initial seasonal phase)

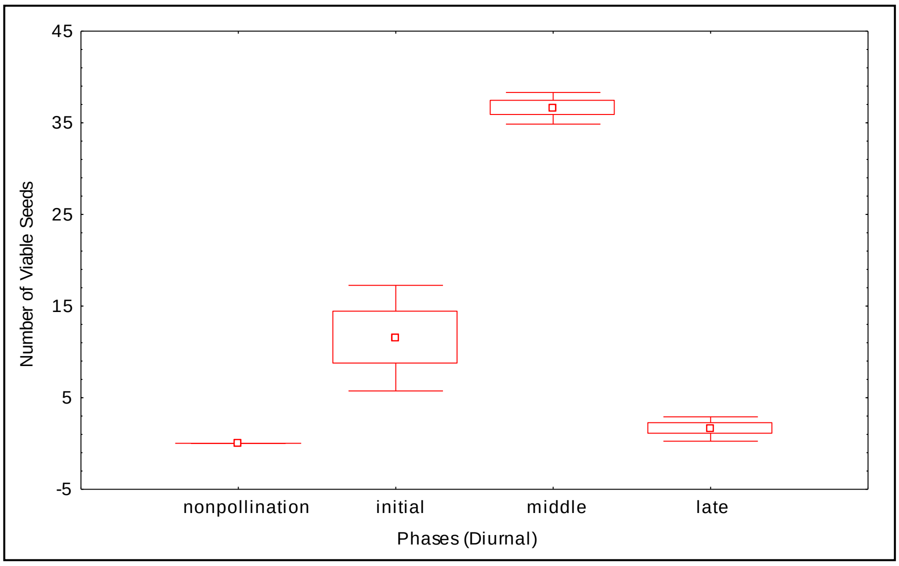


Figure.120: Mean number of viable seeds in diurnal phases (Middle seasonal phase)

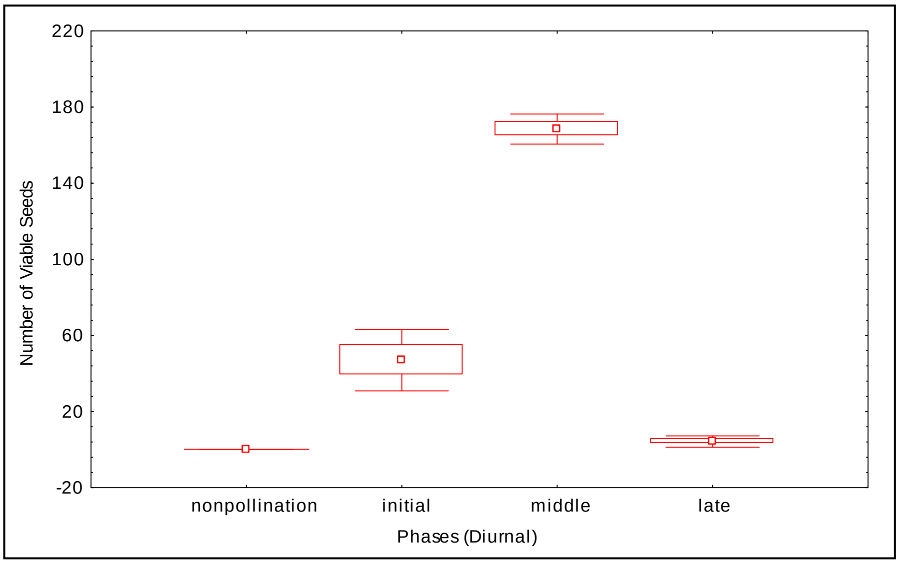


Figure.121: Mean number of viable seeds in diurnal phases (Late seasonal phase)

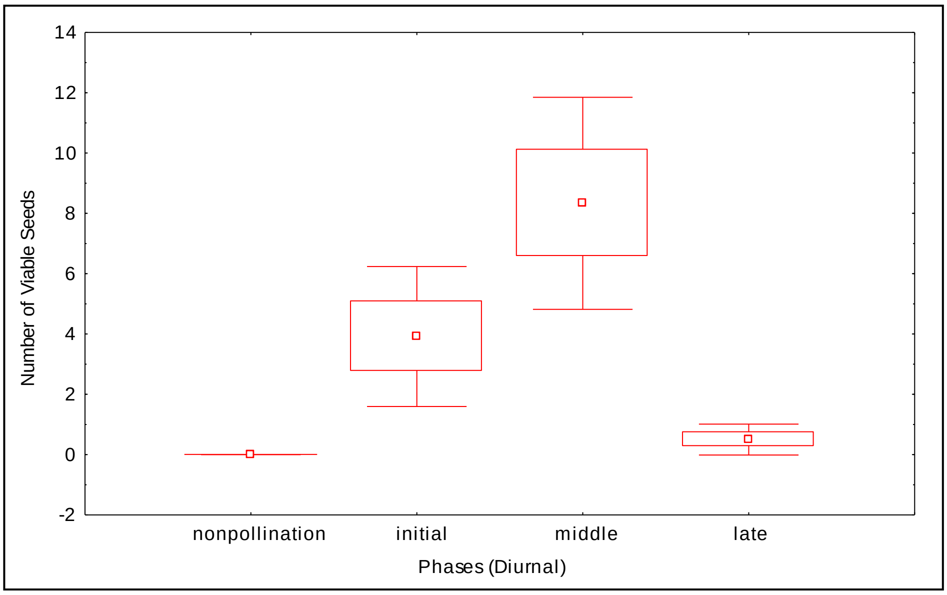
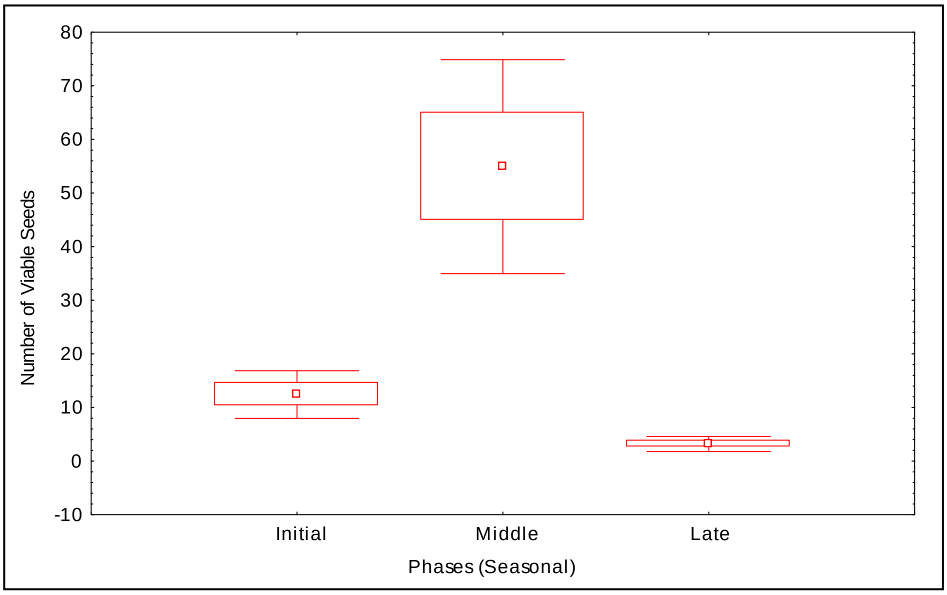


Figure.122: Mean number of viable seeds in different phases of season



4.2.5. Correlation

Positive correlation was observed between number of flowers and number of insects visited (r=0.96) (Figure 123), size of flowers and number of insects visited (r=0.99) (Figure 124), number of insects visited and number of pollen grains deposited (r=0.93) (Figure 125), duration of insect visit and number of pollen grains deposited (r=0.97) (Figure 126), number of pollen grains deposited and percentage of fruit set (r=0.84) (Figure 127), number of pollen grains deposited and weight of fruit (r=0.94) (Figure 128), number of pollen grains deposited and number of seeds (r=0.98) (Figure 129), and number of pollen grains deposited and number of seeds (r=0.93) (Figure 130).

Figure.123: Correlation between number of flowers / plant and number of insects visited

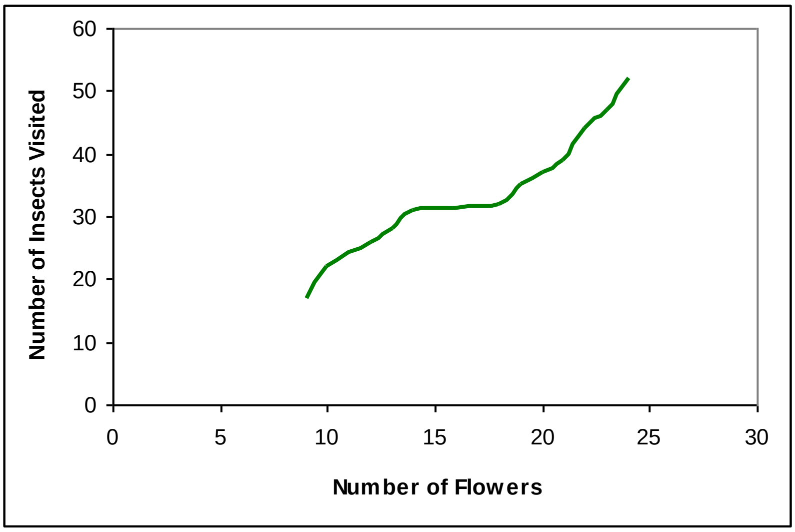


Figure.124: Correlation between size of flowers and number of insects visited

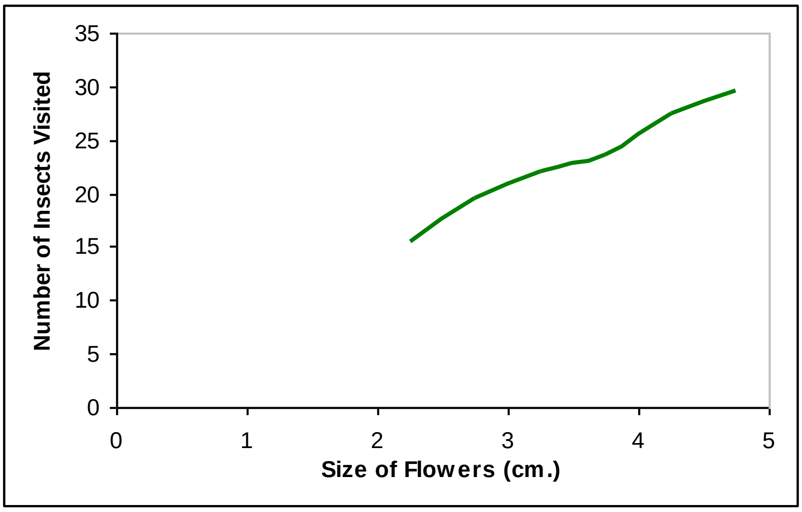


Figure.125: Correlation between number of insects visited and number of pollen grains deposited

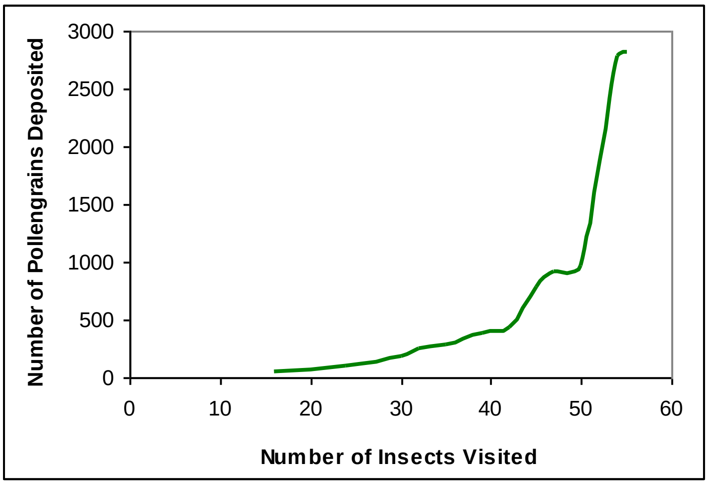


Figure.126: Correlation between duration of visit and number of pollen grains deposited

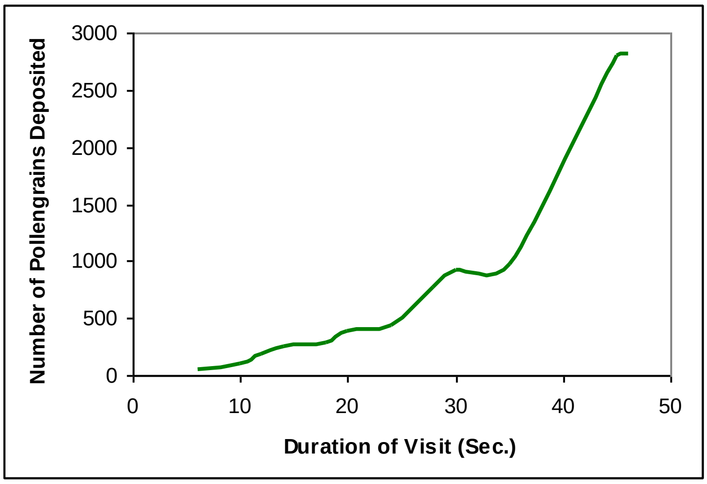


Figure.127: Correlation between number of pollen grains deposited and fruit set.

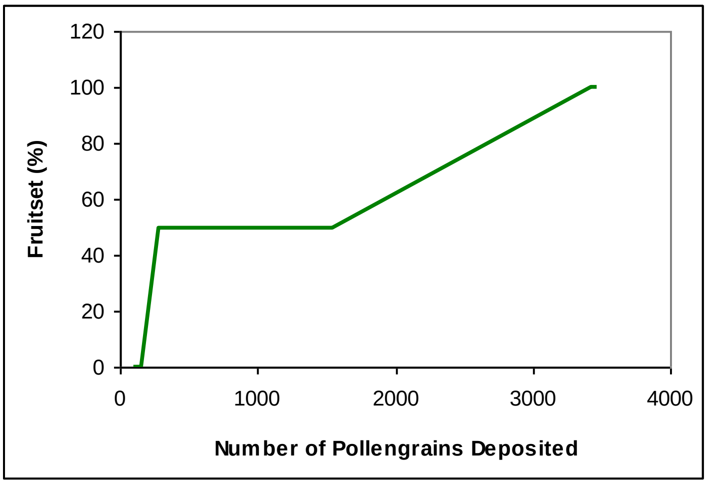


Figure.128: Correlation between number of pollen grains deposited and weight of fruit.

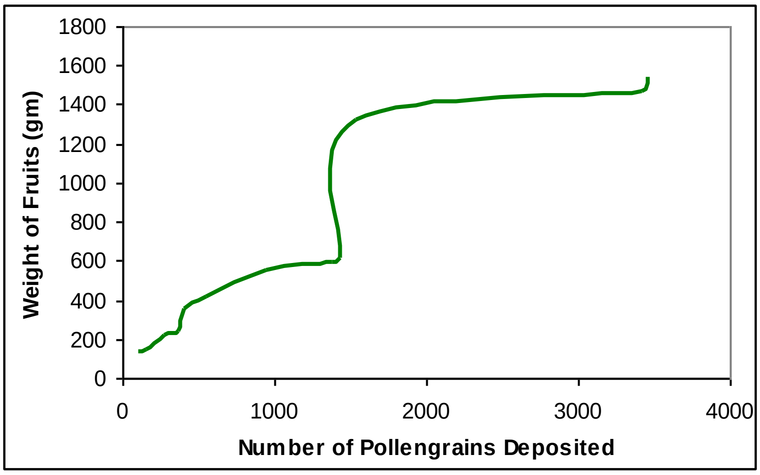


Figure.129: Correlation between number of pollen grains deposited and number seeds.

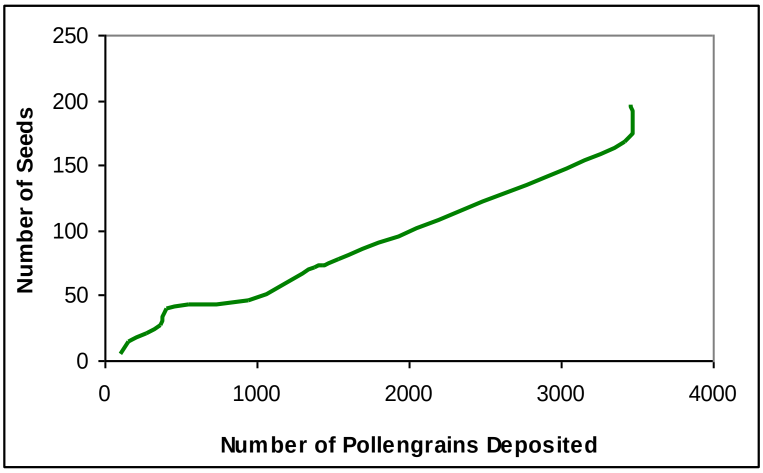
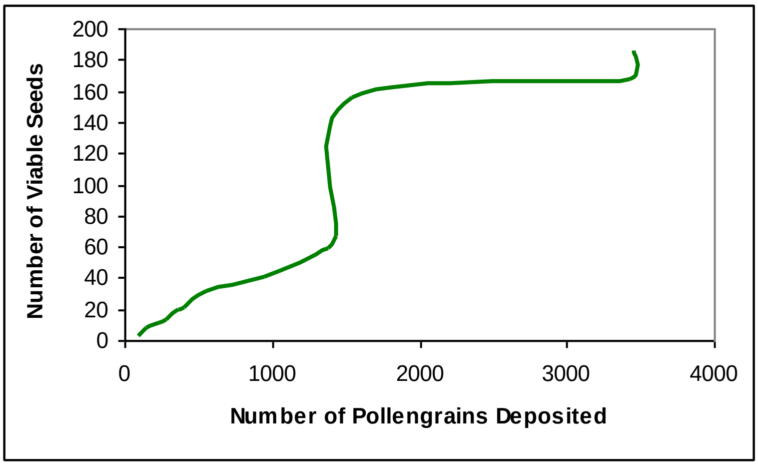


Figure.130: Correlation between number of pollen grains deposited and number of viable seeds.



4.3. Bittergourd

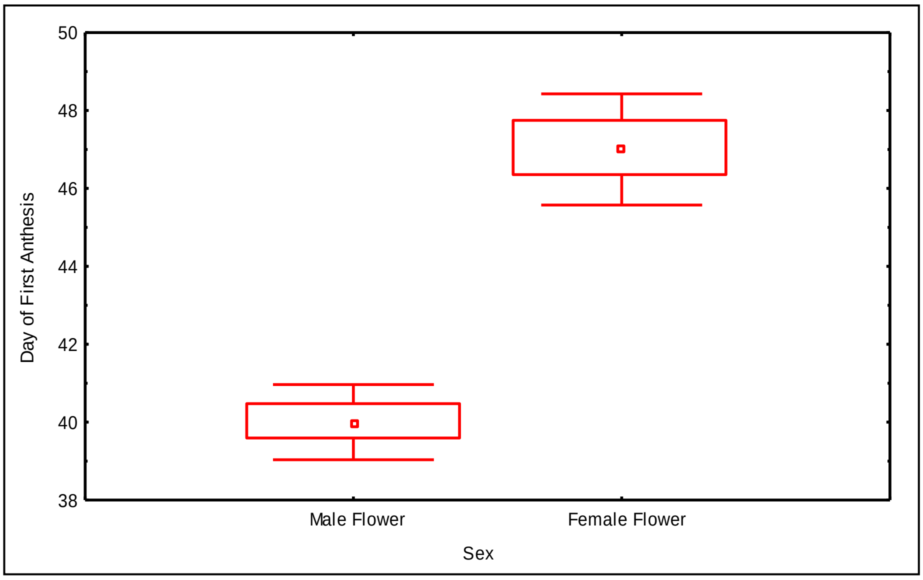
[*Momordica charantia* L.]

4.3.1. Phenology

4.3.1.1. Day of First Anthesis

It was observed that first male (♂) and female (♀) flower opened on 40± 1.71th and 47±2.52^{the} day respectively from the day of germination. Both male and female anthesis were significantly different (p=0.00) (Figure 131).

Figure.131: Day of first anthesis of male and female flowers of after germination



4.3.1.2. Flower Opening Time

Male (♂) flower anthesis commenced between 0317 h. and 0421 h. and female (♀) flower between 0301 h. and 0406 h. Significant difference was found between initiation of opening time of male (♂) and female (♀) flowers (p=0.00). Mean durations taken for full corolla expansion were 1.02±0.01 h. 1.21±0.07 h. by male (♂) and female (♀) flowers respectively and they showed significant difference (p=0.00).

4.3.1.3. Flower Closing Time

Male (♂) flower closing commenced between 1402 h. and 1506 h. female (♀) flower between and 1415 h. and 1519 h. Significant difference was found between initiation of closing time of male (♂) and female (♀) flowers (p=0.00). Mean durations taken for full petal constriction were 2.20±0.09 h., 2.01±0.00 h. by male (♂) and female (♀) flowers respectively and they showed significant difference (p=0.00).

4.3.1.4. Number of Flowers

Mean number of staminate (♂) and pistillate (♀) flowers produced per plant per day increased from initial phase (IP) (♂=8.06±2.00, ♀=1.42±0.49) to middle phase (MP) (♂=13.01±3.06, ♀=2.04±0.49) where maximum number of flowers were found and then decreased to late phase (LP) (♂=6.01±1.49, ♀=1.194±0.39) of the season where minimum number of flowers were found. Number of staminate (♂) and pistillate (♀) flowers within seasonal phases such as IP (p=0.00) (Figure 132); MP (p=0.00) (Figure 133); LP (p=0.00) (Figure 134) and the number of flowers between the seasonal phases were significantly different (P=0.00).

Figure.132: Mean number of male and female flowers produced /plant /day (Initial seasonal phase)

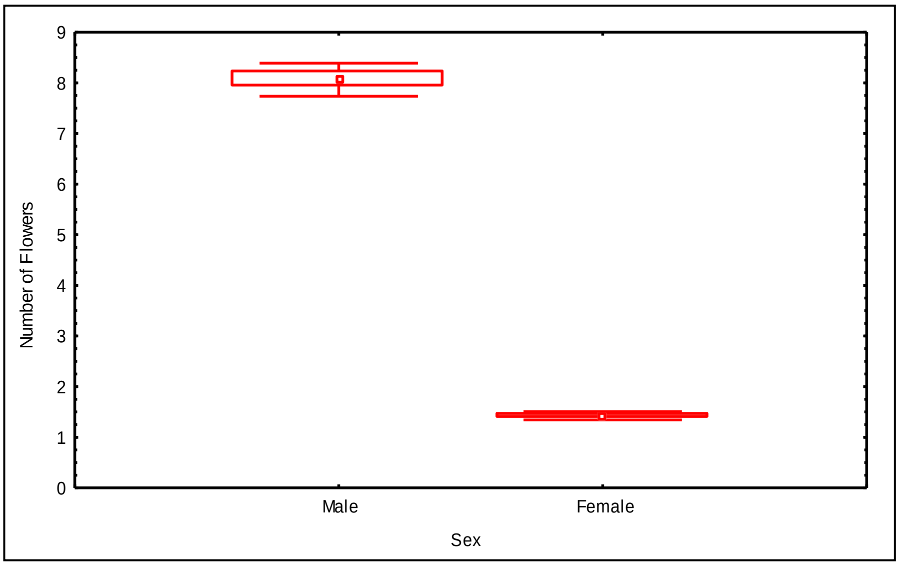


Figure.133: Mean number of male and female flowers produced /plant /day (Middle seasonal phase)

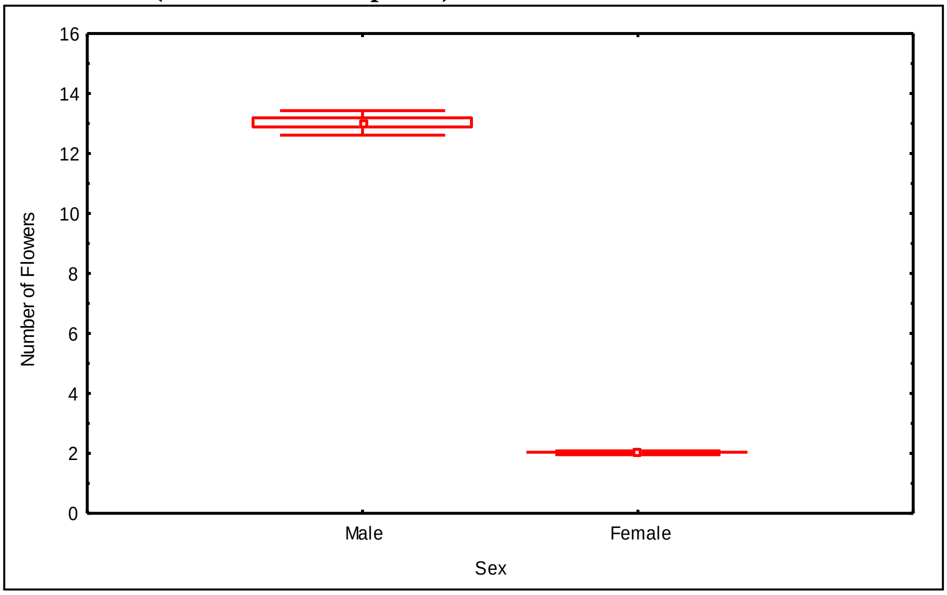
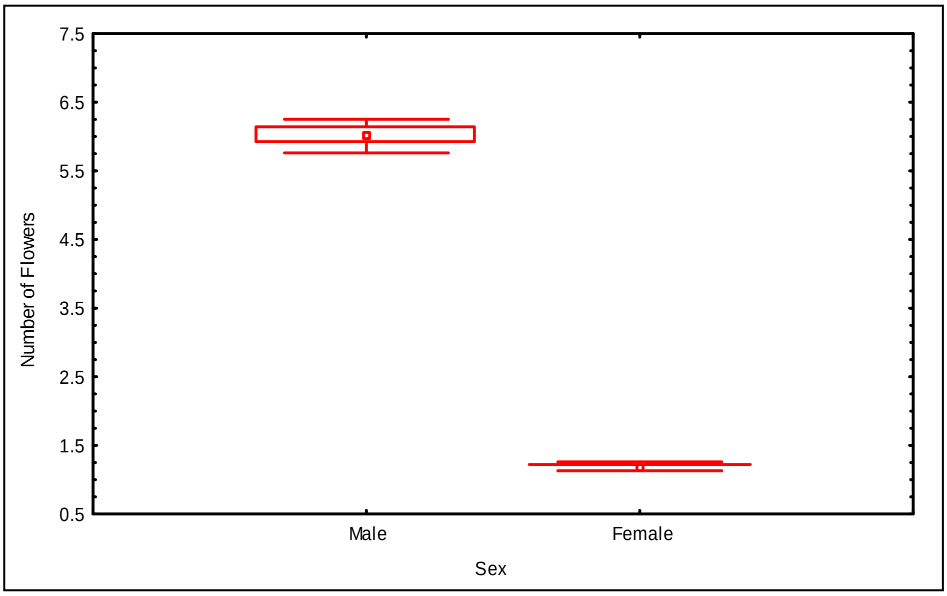


Figure.134: Mean number of male and female flowers produced /plant /day (Late seasonal phase)



4.3.1.5. Size /Dimension of Flower

Measurements showed that the mean size of staminate (♂) and pistillate (♀) flowers produced per plant per day increased from initial phase (IP) (♂=3.44±0.54 cm., ♀=2.94±0.54 cm.) to middle phase (MP)

(♂=4.60±0.50 cm., ♀=4.10±0.50 cm.) where maximum size was observed and then decreased to late phase (LP) (♂=3.13±0.46 cm., ♀=2.7±0.42 cm.) of the season where minimum size was observed. Size of staminate and pistillate flowers within seasonal phases such as IP (p=0.00) (Figure 135); MP (p=0.00) (Figure 136); LP (p=0.00) (Figure 137) and between the seasonal phases were significantly different (P=0.00).

Figure.135: Mean size of male and female flowers produced (Initial seasonal phase)

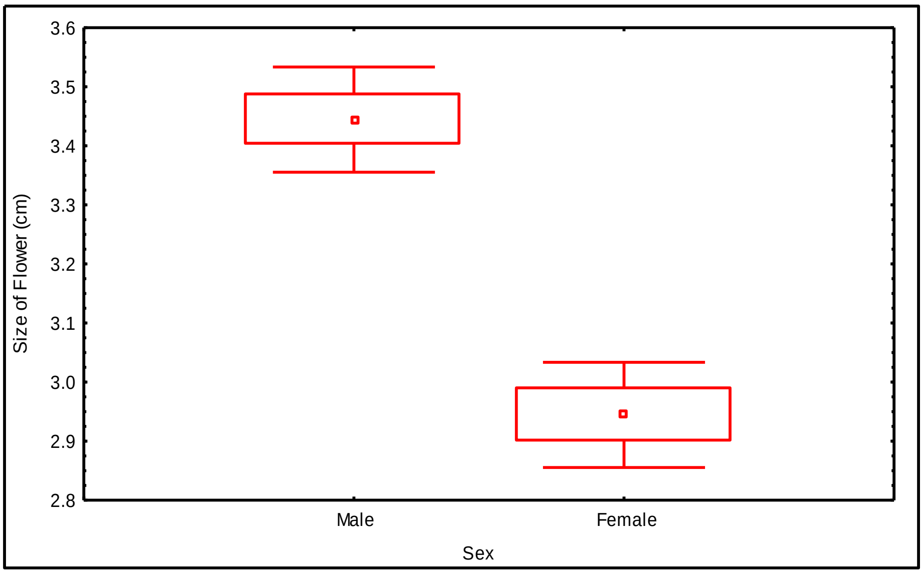


Figure.136: Mean size of male and female flowers produced (Middle seasonal phase)

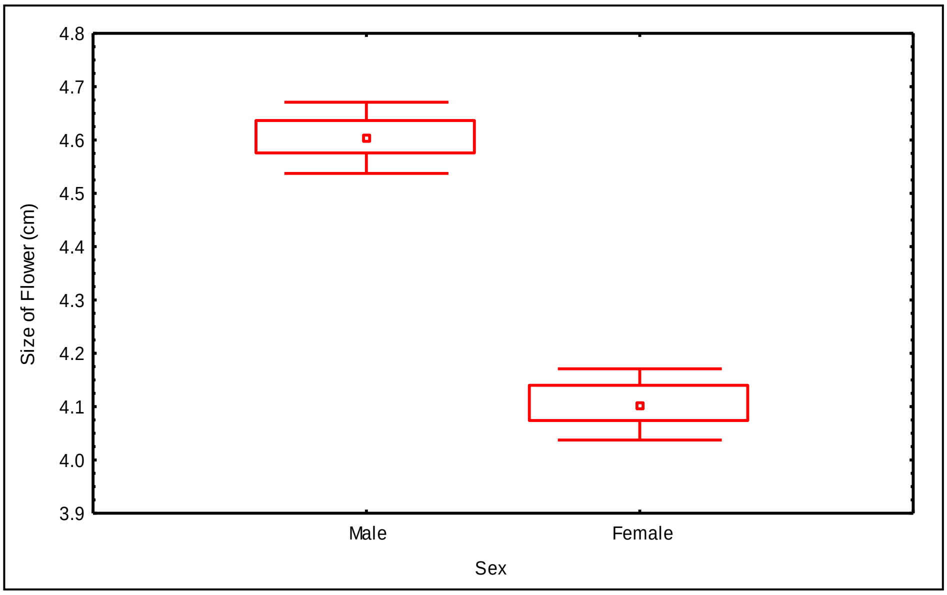
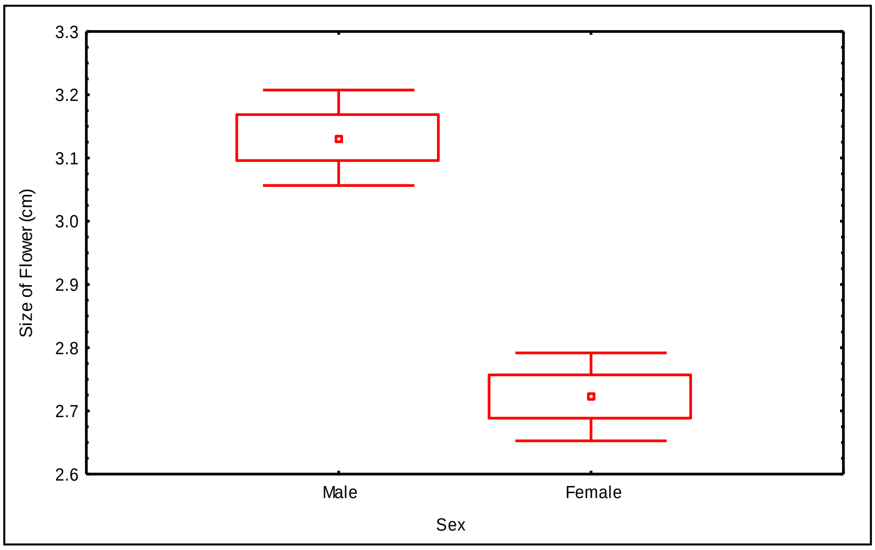


Figure.137: Mean size of male and female flowers produced (Late seasonal phase)



4.3.2. Entomology

4.3.2.1. Identification of Pollinators

A total of 16 insects were recorded from 3 orders during the study (Plate 7 and Plate 8). The most abundant order was the hymenoptera, including families Apidae, Halictidae, Xylocopidae followed by Coleoptera. Much less abundant was Lepidoptera. The list of pollinators of bittergourd observed during the study is given in Table 15.

Table.15: List of pollinators

Order	**Family**	**Species**
Hymenoptera	Apidae	*Ceratina heiroglyphica* Smith
		Apis cerana Fabricius
		Amegilla parhypate Lieftinck
		Apis dorsata Fabricius
		Apis florea Fabricius
		Braunsapis picitarsis Cameron
		Ceratina smaragdula Fabricius
	Halictidae	*Halictus taprobanae* Cameron
		Halictus timidus Smith
		Trigona iridipennis Smith
	Xylocopidae	*Xylocopa tenuiscapa* Westwood
		Xylocopa aestuans Linnaeus
Coleoptera	Chrysomelidae	*Aulacophora lewisii* Baly
		Aulacophora foveicollis Lucas
Lepidoptera	Sphingidae	*Cephonodes picus* Cramer
		Macroglossum troglodytus Boisduval

4.3.2.1.Floral Visitation (Dynamics of Pollinating behaviour)

4.3.2.1.1. Frequency of Pollinator Visit

The variety of insects encountered and the visits they made were more numerous in the MP than in IP and LP. It was observed that a mean of 18 and 15.08 hymenopterans and 4.41 and 3.5 coleopterans visited the male (♂) and female (♀) flowers /day respectively in the initial phase (IP) of the season. In middle phase (MP) a mean of 24 and 20.66 hymenopterans, 1.16 and 1.16 coleopterans and 0.58 and 0.5 lepidopterans visited the male (♂) and female (♀) flowers /day respectively. In late phase (LP) of the season a mean of 13.58 and 11.66 hymenopterans and 5.66 and 3.66 coleopterans visited the male (♂) and female (♀) flowers /day respectively. Variation in the case of different diurnal phases in each phase of the season was also observed. Higher frequency of visit was observed in middle diurnal phase of middle phase of season. Lowest frequency of visit was observed in late diurnal phase of late phase of season. The most dominant group was Hymenoptera followed by Coleoptera and Lepidoptera. Of these the *Ceratina heiroglyphica* was the most frequent visitor. It was followed by *Trigona iridipennis, Halictus timidus, Halictus taprobanae, and Apis cerana.* They were regular, consistent and made the higher number of visits compared to other insects, at all sites. Within each season, the visits of different insect groups varied with the flowering phase, the middle phase receiving the largest number of visits. Different orders of pollinators varied significantly over the day in each phase of the season IP (p=0.00) (Figure 138); MP (p=0.00) (Figure 139); LP (p=0.00) (Figure 140) (Table 16). Also the visitation frequency shown by different species changed significantly over the day IP (p=0.00) (Figure 141); MP (p=0.00) (Figure 142); LP (p=0.00) (Figure 143) (Table 17). But no significant difference was found in visitation frequency on staminate (♂) and pistillate (♀) flowers. IP (p=0.69); MP (p=0.77); LP (p=0.62). Diurnal phases in each seasonal phase also showed significant difference IP (p=0.00); MP (p=0.03); LP (p=0.00) in visitation frequency. Different seasonal phases also showed siginificant difference in visitation frequency (p=0.00).

Table.16: Frequency of pollinator (Order) visit /day

Order	Sex of flower	Initial Phase (IP)			Middle Phase (MP)			Late Phase (LP)		
		ip	mp	lp	ip	mp	lp	ip	mp	lp
Hymenoptera	♂	6.25	9.66	2.08	7.16	12.41	4.41	4.41	8.16	1
	♀	5.25	8.25	1.58	6	11.33	3.33	3.58	7.66	0.41
Coleoptera	♂	1.41	1.17	1.83	0.41	0.16	0.58	1.75	1.66	2.25
	♀	1.25	1	1.58	0.41	0.16	0.58	1.25	1.16	1.25
Lepidoptera	♂	0	0	0	0.58	0	0	0	0	0
	♀	0	0	0	0.5	0	0	0	0	0

IP - Initial phase of season
MP - Middle phase of season
LP - Late phase of season
ip - initial phase of day
mp - middle phase of day
lp - late phase of day
♂ -Male flower
♀ -Female flower

Figure.138: Frequency of pollinator (Order) visit /day (Initial seasonal phase)

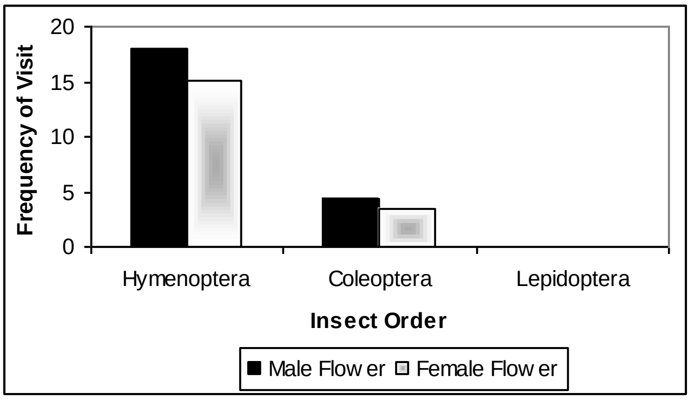


Figure.139: Frequency of pollinator (Order) visit /day (Middle seasonal phase)

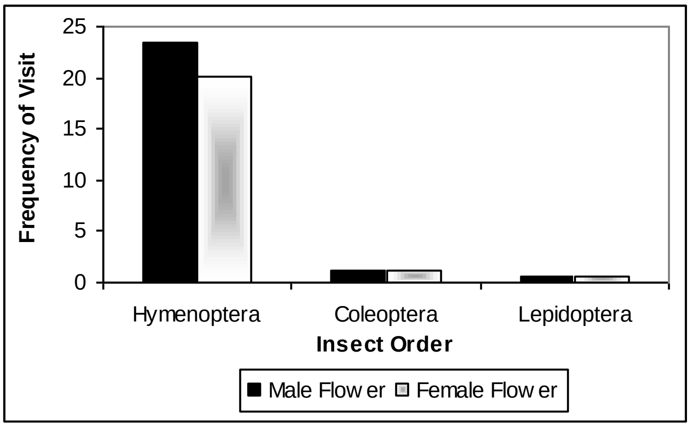


Figure.140: Frequency of pollinator (Order) visit /day (Late seasonal phase)

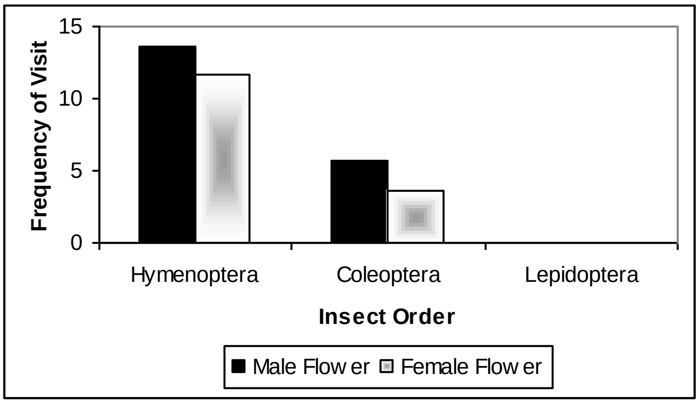


Table.17: Frequency of pollinator (Species) visit /day

Species	Sex of flower	Initial Phase (IP)			Middle Phase (MP)			Late Phase (LP)		
		ip	mp	lp	ip	mp	lp	ip	mp	lp
Ceratina heiroglyphica	♂	4.33	7.33	1.25	5	8.66	2.58	3	6.16	0.5
	♀	3.91	6.25	1	4.25	7.91	1.75	2.41	5.91	0.08
Apis cerana	♂	0.33	0.5	0.16	0.41	0.5	0.33	0.25	0.41	0.08
	♀	0.25	0.41	0.08	0.33	0.5	0.33	0.16	0.33	0.08
Amegilla parhypate	♂	0	0	0	0.08	0	0	0	0	0
	♀	0	0	0	0.08	0	0	0	0	0
Braunsapis picitarsis	♂	0	0	0	0	0.33	0	0	0	0
	♀	0	0	0	0	0.25	0	0	0	0
Apis florea	♂	0	0	0	0	0.16	0	0	0	0
	♀	0	0	0	0	0.16	0	0	0	0
Ceratina smaragdula	♂	0	0	0	0	0.25	0	0	0	0
	♀	0	0	0	0	0.25	0	0	0	0
Apis dorsata	♂	0	0	0	0	0.08	0	0	0	0
	♀	0	0	0	0	0.08	0	0	0	0
Halictus timidus	♂	0.5	0.58	0.25	0.58	0.66	0.58	0.33	0.5	0.16
	♀	0.33	0.5	0.16	0.41	0.58	0.41	0.33	0.41	0.08
Halictus taprobanae	♂	0.41	0.58	0.16	0.41	0.66	0.33	0.33	0.5	0.08
	♀	0.33	0.5	0.16	0.33	0.58	0.33	0.25	0.41	0.08
Trigona iridipennis	♂	0.66	0.66	0.25	0.66	0.83	0.58	0.5	0.58	0.16
	♀	0.41	0.58	0.17	0.58	0.75	0.5	0.41	0.58	0.08
Xylocopa aestuans	♂	0	0	0	0	0.16	0	0	0	0
	♀	0	0	0	0	0.16	0	0	0	0
Xylocopa tenuiscapa	♂	0	0	0	0	0.08	0	0	0	0
	♀	0	0	0	0	0.08	0	0	0	0
Apis lewisii	♂	0.75	0.75	0.91	0.25	0.08	0.33	1.08	1	1.33
	♀	0.66	0.66	0.66	0.25	0.08	0.33	0.66	0.66	0.66
Aulacophora foveicollis	♂	0.66	0.41	0.91	0.17	0.08	0.25	0.66	0.66	0.91
	♀	0.58	0.33	0.58	0.16	0.08	0.25	0.58	0.5	0.58
C.ephonodes picus	♂	0	0	0	0.25	0	0	0	0	0
	♀	0	0	0	0.16	0	0	0	0	0
Macroglossum troglodytus	♂	0	0	0	0.33	0	0	0	0	0
	♀	0	0	0	0.33	0	0	0	0	0

IP - Initial phase of season
MP - Middle phase of season
LP - Late phase of season

ip - initial phase of day
mp - middle phase of day
lp - late phase of day

♂ -Male flower
♀ -Female flower

Figure.141: Frequency of pollinator (Species) visit /day (Initial seasonal phase)

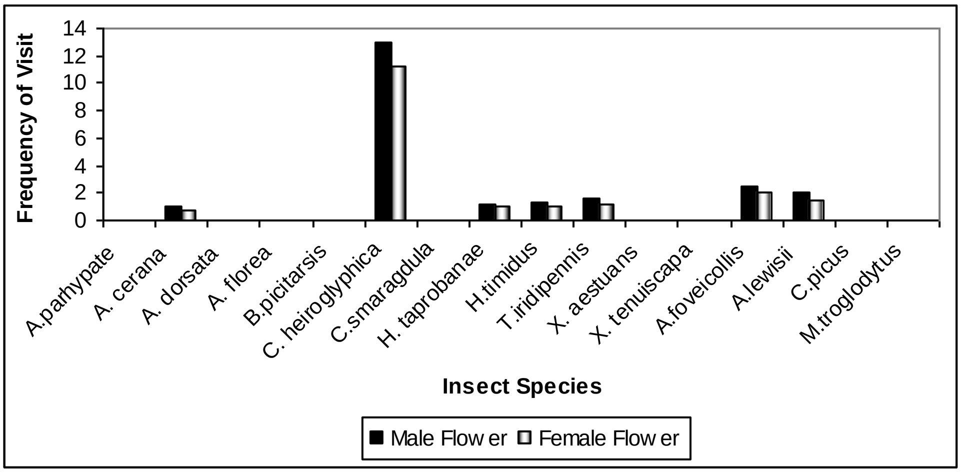


Figure.142: Frequency of pollinator (Species) visit /day (Middle seasonal phase)

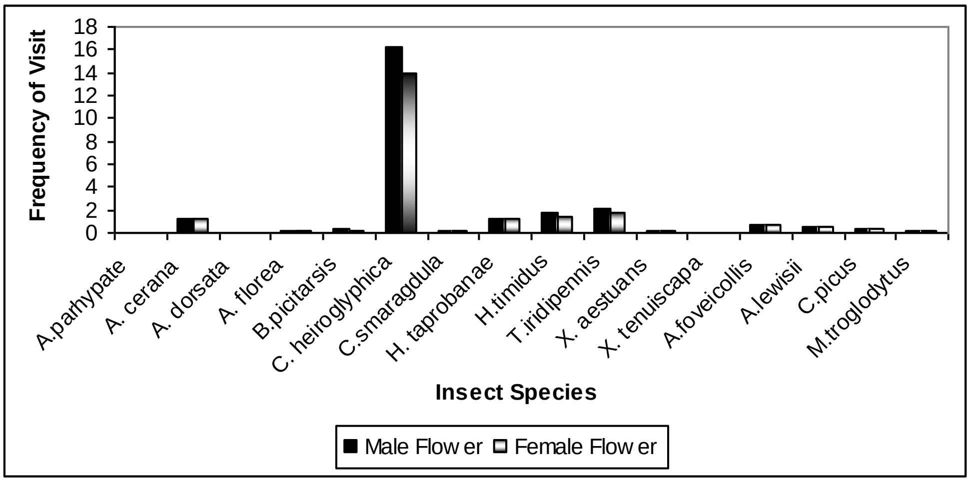
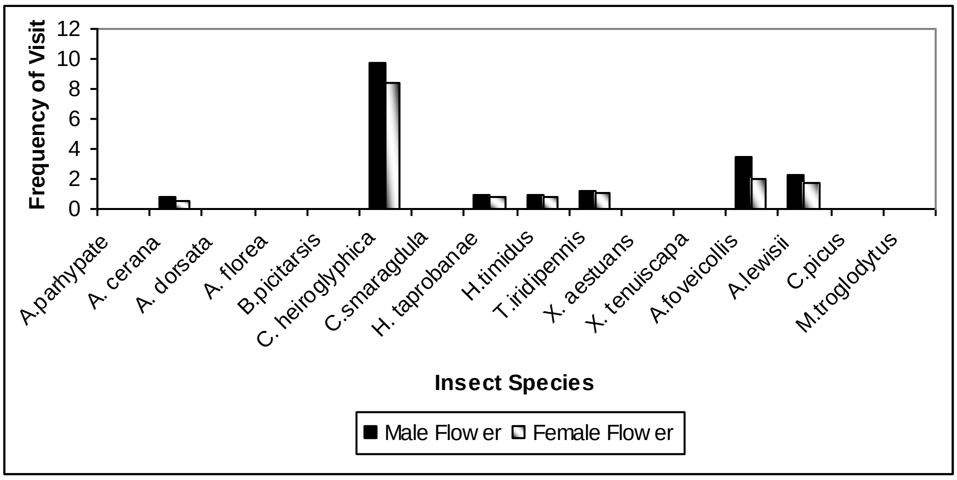


Figure.143: Frequency of pollinator (Species) visit /day (Late seasonal phase)



4.3.2.1.2. Mean Number of Flowers Visited by Pollinators

Mean number of male (♂) and female (♀) flowers visited was increased from initial phase of the season (IP) to middle phase of the season, (MP) and decreased to late of the season (LP). There was significant difference in the way these components changed in number over the day and season. Hymenopterans visited a mean of 33.83 male (♂) flowers and 27.16 female (♀) flowers and coleopterans visited 10.91 male (♂) flowers and 8.75 female (♀) flowers /day in the initial phase (IP) of the season. In middle phase (MP) a mean of 47.08 male (♂) flowers and 38.66 female (♀) flowers were visited by hymenopterans, 2.75 male (♂) flowers and 2.25 female (♀) flowers by coleopterans and 0.58 male (♂) flowers and 0.58 female (♀) flowers by lepidopterans /day. In late phase (LP) of the season it was a mean of 21.83 male (♂) flowers and 16.75 female (♀) flowers by hymenopterans and 9.66 male (♂) flowers and 7.16 female (♀) flowers by coleopterans /day. Variation in number of flowers visited in different diurnal phases in each phase of the season was also observed. Maximum number of flowers were visited in the middle diurnal phase of middle seasonal phase and minimum number of flowers were visited in the late diurnal phase of late seasonal phase. Hymenopterans visited highest number of flowers. Mean number of flowers visited by different orders [IP (p=0.01) (Figure 144); MP (p=0.00) (Figure 145) and LP (p=0.00) (Figure 146)] (Table 18) and different species of pollinators varied significantly [IP (p=0.01) (Figure 147); MP (p=0.01) (Figure 148); LP (p=0.00) (Figure 149) (Table 19)] of season. But there was no significant difference in mean number of male (♂) and female flowers visited by different insects [IP (p=0.24); MP (p=0.48); LP (p=0.53). And there was also significant difference in mean number of flowers visited by pollinators in different diurnal phases of the season [IP (p=0.03); MP (p=0.01); LP (p=0.02)].

Significant difference in the mean number of flowers visited by pollinators was also found between different phases of the season (p=0.00).

Table.18: Mean number of flowers visited by pollinators (Order) /day

Order	Sex of flower	Initial Phase (IP)			Middle Phase (MP)			Late Phase (LP)		
		ip	mp	lp	ip	mp	lp	ip	mp	lp
Hymenoptera	♂	11.41	17	5.41	15.58	23.5	8	7.83	11.41	2.58
	♀	9	14.75	3.41	12.16	20.75	5.75	6.58	9.25	0.91
Coleoptera	♂	4	4.08	2.83	1	1.08	0.66	3.33	3.58	2.75
	♀	3.25	3.58	1.91	0.83	0.83	0.58	2.58	2.75	1.83
Lepidoptera	♂	0	0	0	0.58	0	0	0	0	0
	♀	0	0	0	0.58	0	0	0	0	0

IP - Initial phase of season ip - initial phase of day ♂ -Male flower
MP - Middle phase of season mp - middle phase of day ♀ -Female flower
LP - Late phase of season lp - late phase of day

Figure.144: Mean number of flowers visited by pollinators (Order) /day (Initial seasonal phase)

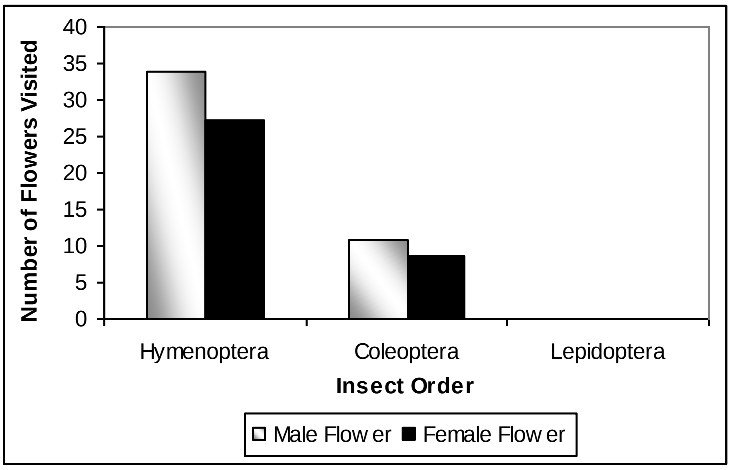


Figure.145: Mean number of flowers visited by pollinators (Order) /day (Middle seasonal phase).

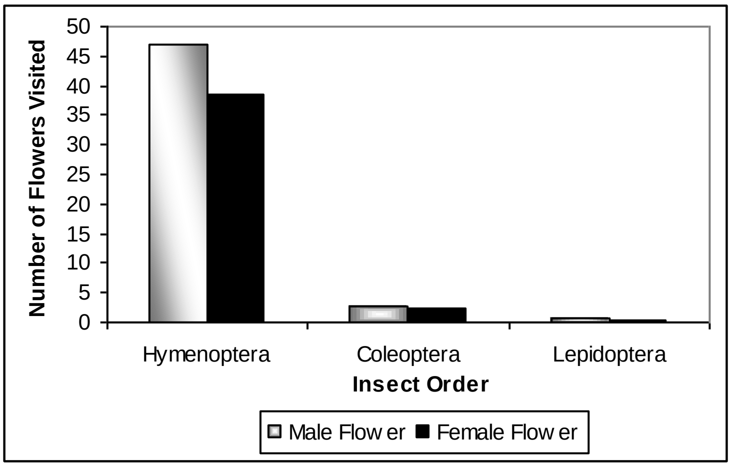


Figure.146: Mean number of flowers visited by pollinators (Order) /day (Late seasonal phase)

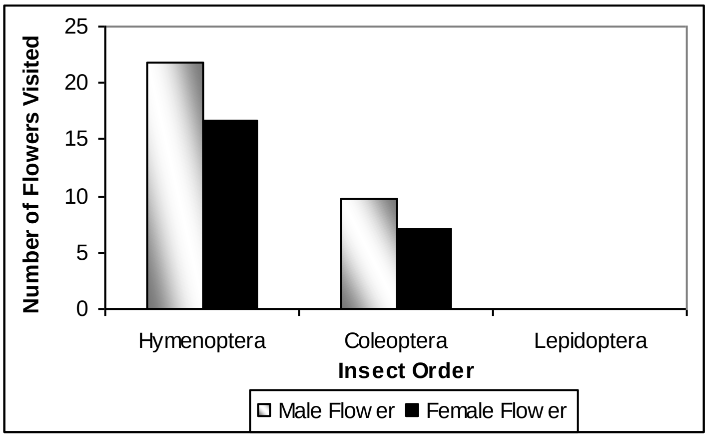


Table.19: Mean number of flowers visited by pollinators (Species)/day

Species	Sex of flower	Initial Phase (IP)			Middle Phase (MP)			Late Phase (LP)		
		ip	mp	lp	ip	mp	lp	ip	mp	lp
Ceratina heiroglyphica	♂	5.41	8.16	2.25	7.58	9.25	4.41	4.33	6.25	1.41
	♀	4.33	7.08	1.91	6.25	8.08	3.16	4.08	5.75	0.25
Apis cerana	♂	1.16	1.25	0.33	1.16	2.25	0.58	0.5	1	0.16
	♀	0.75	0.91	0.16	0.75	1.91	0.41	0.33	0.58	0.16
Amegilla parhypate	♂	0	0	0	0.33	0	0	0	0	0
	♀	0	0	0	0.33	0	0	0	0	0
Braunsapis picitarsis	♂	0	0	0	0	0.58	0	0	0	0
	♀	0	0	0	0	0.41	0	0	0	0
Apis florea	♂	0	0	0	0	0.33	0	0	0	0
	♀	0	0	0	0	0.25	0	0	0	0
Ceratina smaragdula	♂	0	0	0	0	0.75	0	0	0	0
	♀	0	0	0	0	0.58	0	0	0	0
Apis dorsata	♂	0	0	0	0	0.08	0	0	0	0
	♀	0	0	0	0	0.08	0	0	0	0
Halictus timidus	♂	1.33	2.66	1.16	2.25	2.75	1.16	0.75	1.25	0.41
	♀	1.08	2.17	0.41	1.91	2.58	0.66	0.58	0.83	0.16
Halictus taprobanae	♂	1.25	1.33	0.5	1.83	2.83	0.66	0.75	1.25	0.16
	♀	0.66	1.17	0.41	0.75	2.58	0.5	0.41	0.58	0.16
Trigona iridipennis	♂	2.25	3.58	1.17	2.41	4	1.16	1.5	1.66	0.41
	♀	2.17	3.41	0.5	2.16	3.75	1	1.16	1.5	0.16
Xylocopa aestuans	♂	0	0	0	0	0.5	0	0	0	0
	♀	0	0	0	0	0.33	0	0	0	0
Xylocopa tenuiscapa	♂	0	0	0	0	0.16	0	0	0	0
	♀	0	0	0	0	0.16	0	0	0	0
Apis lewisii	♂	2.58	2.66	1.5	0.58	0.58	0.41	2.08	2.25	1.5
	♀	1.91	2.25	1.08	0.5	0.5	0.33	1.33	1.41	1.08
Aulacophora foveicollis	♂	1.41	1.41	1.33	0.41	0.5	0.25	1.25	1.33	1.25
	♀	1.33	1.33	0.83	0.33	0.33	0.25	1.25	1.33	0.75
C.ephonodes picus	♂	0	0	0	0.25	0	0	0	0	0
	♀	0	0	0	0.25	0	0	0	0	0
Macroglossum troglodytus	♂	0	0	0	0.33	0	0	0	0	0
	♀	0	0	0	0.33	0	0	0	0	0

IP - Initial phase of season ip - initial phase of day ♂ -Male flower
MP - Middle phase of season mp - middle phase of day ♀ -Female flower
LP - Late phase of season lp - late phase of day

Figure.147: Mean number of flowers visited by pollinators (Species) /day (Initial seasonal phase)

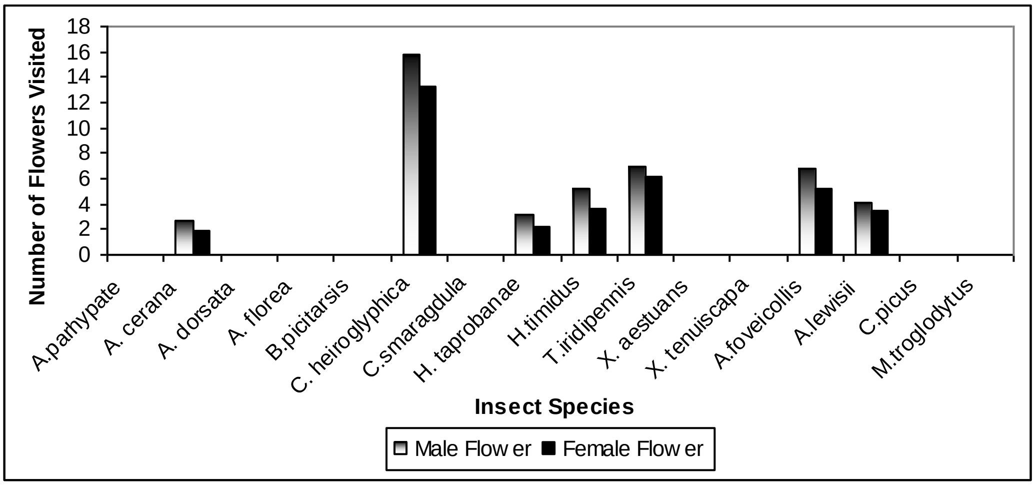


Figure.148: Mean number of flowers visited by pollinators (Species) /day (Middle seasonal phase)

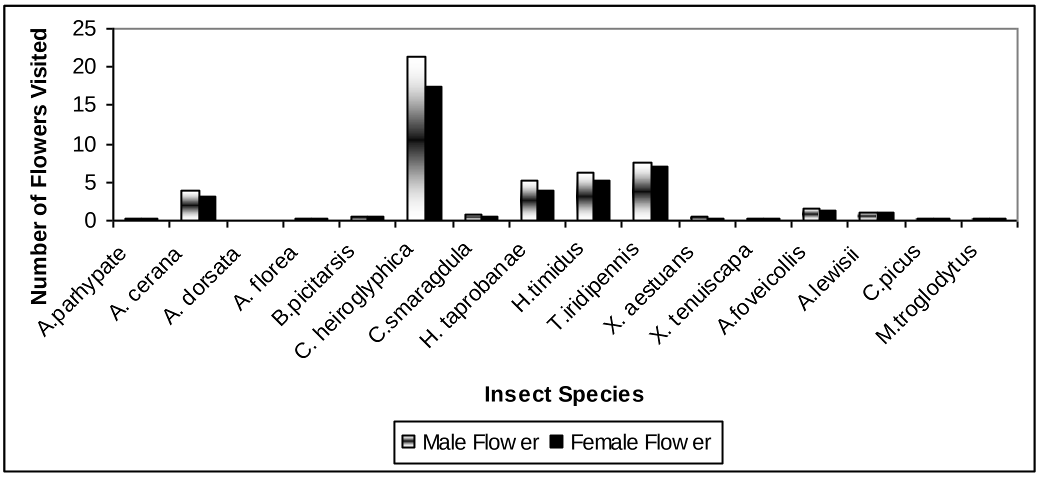
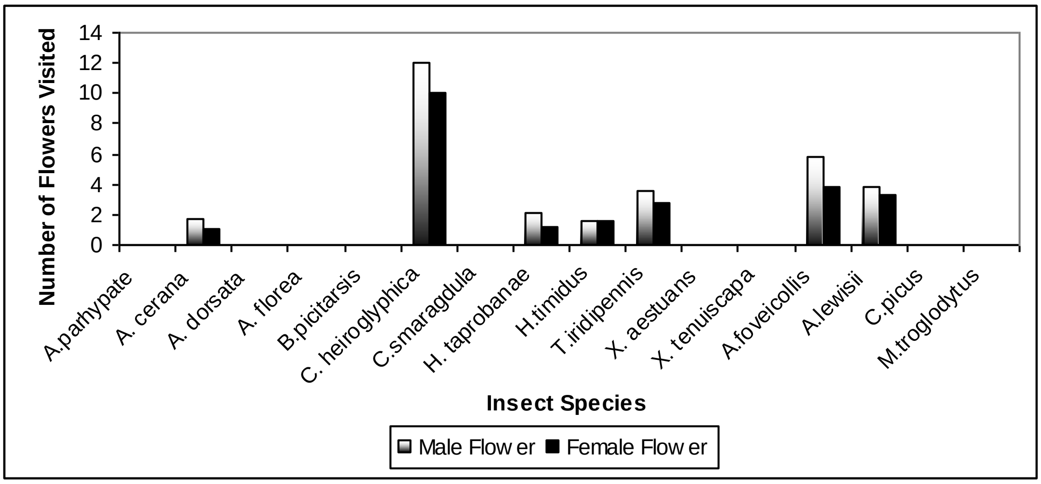


Figure.149: Mean number of flowers visited by pollinators (Species) /day (Late seasonal phase)



4.3.2.1.3. Mean Duration of Pollinator Visit

Duration of visit on each flower was also recorded in seconds (sec.) to provide data on the average time spent on male (♂) and female (♀) flowers by different insects. It was observed that mean duration of pollinator visit increased from initial phase (IP) to middle phase (MP) and decreased to late phase (LP) of the season. But the mean duration of visit decreased from initial to late in diurnal phases of each seasonal phase The pollinators took longest duration in initial diurnal phase of middle seasonal phase and shortest duration in late diurnal phase of late seasonal phase. Mean duration of visit taken by hymenopterans was 30.08 sec. on male (♂) flowers and 22.41 sec. on female (♀) flowers and by coleopterans was 7.41 sec. on male (♂) flowers and 6.16 sec. on female (♀) flowers /day in the initial phase (IP) of the season. In middle phase (MP) 37.83 sec. on male (♂) flowers and 28 sec. on female (♀) flowers were taken by hymenopterans, 3.5 sec. on male (♂) flowers and 2.5 sec. on female (♀) flowers by coleopterans and 0.83 sec. on male (♂) flowers and 0.75 sec. on female (♀) flowers by lepidopterans /day. In late phase (LP) of the season it was 22.41 sec. on male (♂) flowers and 15 sec. on female (♀) flowers by hymenopterans and 6.75 sec. on male (♂) flowers and 5.08 sec. on female (♀) flowers by coleopterans /day. Variation in mean duration of visit taken by different orders in different diurnal phases in each phase of the season was also observed. The mean duration taken by different orders in IP ($p=0.01$) (Figure 150); MP ($p=0.03$) (Figure 151) and LP ($p=0.00$) (Figure 152] (Table 20) and different species of pollinators in all phases of season varied significantly [IP ($p=0.00$) (Figure 153); MP ($p=0.00$) (Figure 154); LP ($p=0.00$) (Figure 155)] (Table 21). No significant difference in mean duration of visit to male (♂) and female (♀) flowers [IP ($p=0.22$); MP ($p=0.32$); LP ($p=0.62$)] was found. But the duration of visit during diurnal phases of each season [IP ($p=0.00$); MP ($p=0.00$); LP ($p=0.00$)] varied significantly. Seasonal phases also showed significant difference in mean duration of visit (p=0.00).

Table.20: Mean duration of pollinator (Order) visit in seconds

Order	Sex of flower	Initial Phase (IP)			Middle Phase (MP)			Late Phase (LP)		
		ip	mp	lp	ip	mp	lp	ip	mp	lp
Hymenoptera	♂	14.08	9.91	6.08	15.66	14.16	8	10.25	8	4.16
	♀	11	7.75	3.66	12	10.41	5.58	7.25	5.41	2.33
Coleoptera	♂	3.5	2	1.91	1.83	0.83	0.83	3	1.91	1.83
	♀	3.25	1.58	1.33	1.66	0.41	0.41	2.33	1.5	1.25
Lepidoptera	♂	0	0	0	0.83	0	0	0	0	0
	♀	0	0	0	0.75	0	0	0	0	0

IP - Initial phase of season
MP - Middle phase of season
LP - Late phase of season

ip - initial phase of day
mp - middle phase of day
lp - late phase of day

♂ -Male flower
♀ -Female flower

Figure.150: Mean duration of visit on flowers by pollinators (Order) in seconds (Initial seasonal phase)

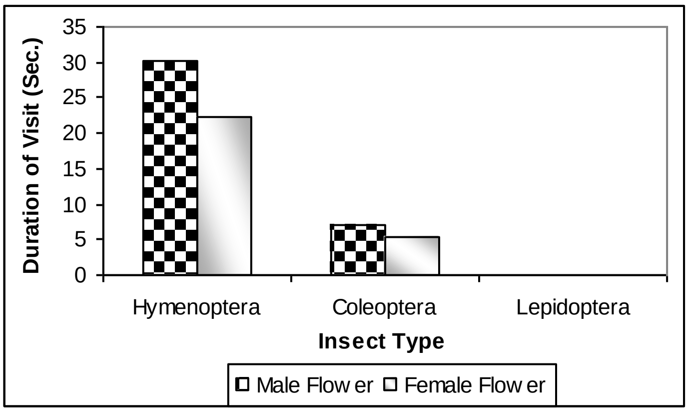


Figure.151: Mean duration of visit on flowers by pollinators (Order) in seconds (Middle seasonal Phase)

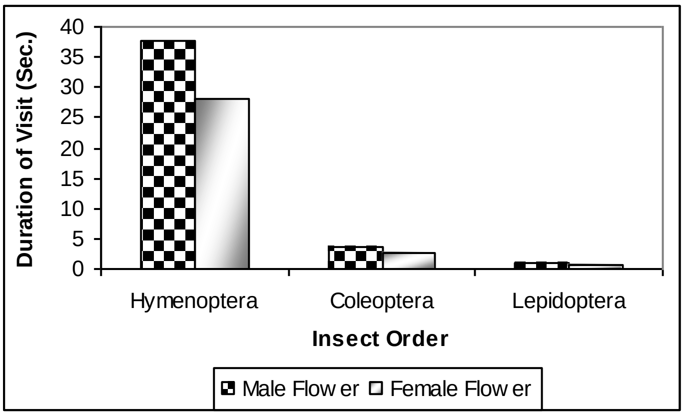


Figure.152: Mean duration of visit on flowers by pollinators (Order) in seconds (Late seasonal Phase)

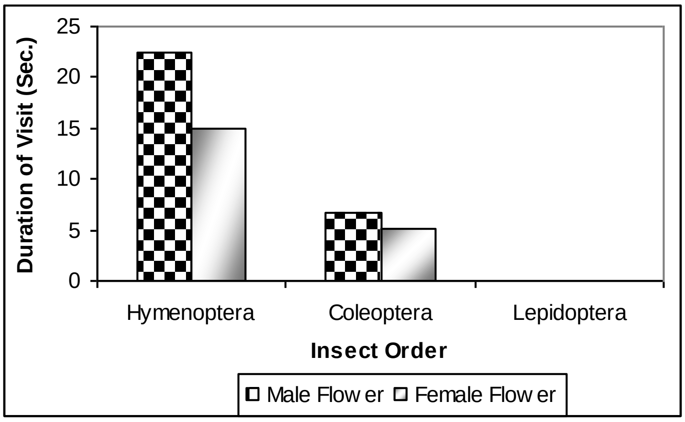


Table.21: Mean duration of pollinator (Species) visit in seconds

Species	Sex of flower	Initial Phase (IP)			Middle Phase (MP)			Late Phase (LP)		
		ip	mp	lp	ip	mp	lp	ip	mp	lp
Ceratina heiroglyphica	♂	6.91	4.66	3.66	7.5	5.5	4.08	5.41	4.25	2.75
	♀	5.83	3.83	2.83	6.16	4.83	3.33	4.25	3	1.83
Apis cerana	♂	1.5	1	0.41	1.58	1	0.5	0.66	0.66	0.16
	♀	0.83	0.83	0.08	0.91	0.83	0.33	0.41	0.41	0.08
Amegilla parhypate	♂	0	0	0	0.16	0	0	0	0	0
	♀	0	0	0	0.08	0	0	0	0	0
Braunsapis picitarsis	♂	0	0	0	0	0.58	0	0	0	0
	♀	0	0	0	0	0.5	0	0	0	0
Apis florea	♂	0	0	0	0	0.41	0	0	0	0
	♀	0	0	0	0	0.25	0	0	0	0
Ceratina smaragdula	♂	0	0	0	0	0.41	0	0	0	0
	♀	0	0	0	0	0.33	0	0	0	0
Apis dorsata	♂	0	0	0	0	0.16	0	0	0	0
	♀	0	0	0	0	0.08	0	0	0	0
Halictus timidus	♂	1.66	1.5	0.58	2.16	1.66	1.25	1	0.91	0.41
	♀	1.16	1.08	0.25	1.66	1.08	0.58	0.58	0.58	0.16
Halictus taprobanae	♂	1.5	1	0.5	1.75	1.41	0.75	1	0.66	0.25
	♀	0.66	0.66	0.25	0.66	0.66	0.5	0.5	0.41	0.08
Trigona iridipennis	♂	2.5	1.75	0.91	2.5	2.5	1.41	2.16	1.5	0.58
	♀	2.5	1.33	0.25	2.5	1.5	0.83	1.5	1	0.16
Xylocopa aestuans	♂	0	0	0	0.33	0	0	0	0	0
	♀	0	0	0	0.25	0	0	0	0	0
Xylocopa tenuiscapa	♂	0	0	0	0.16	0	0	0	0	0
	♀	0	0	0	0.08	0	0	0	0	0
Apis lewisii	♂	2.08	1.08	1.08	1.16	0.41	0.41	1.83	1.08	1
	♀	1.83	0.91	0.66	1.16	0.25	0.25	1.16	0.91	0.66
Aulacophora foveicollis	♂	1.41	0.91	0.83	0.66	0.41	0.41	1.16	0.83	0.83
	♀	1.41	0.66	0.66	0.5	0.16	0.16	1.16	0.58	0.58
C.ephonodes picus	♂	0	0	0	0.33	0	0	0	0	0
	♀	0	0	0	0.33	0	0	0	0	0
Macroglossum troglodytus	♂	0	0	0	0.5	0	0	0	0	0
	♀	0	0	0	0.41	0	0	0	0	0

IP - Initial phase of season ip - initial phase of day ♂ -Male flower
MP - Middle phase of season mp - middle phase of day ♀ -Female flower
LP - Late phase of season lp - late phase of day

Figure.153: Mean duration of visit on flowers by pollinators (Species) in seconds (Initial seasonal phase)

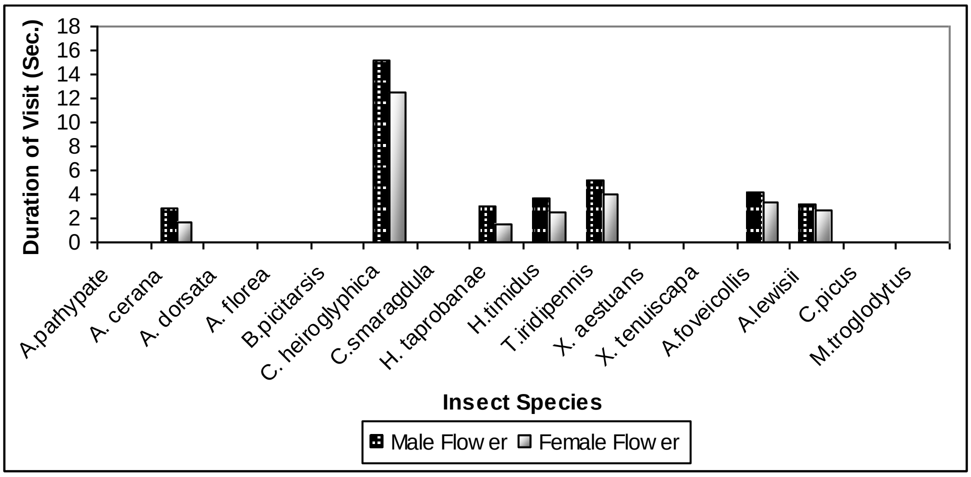


Figure.154: Mean duration of visit on flowers by pollinators (Species) in seconds (Middle seasonal phase)

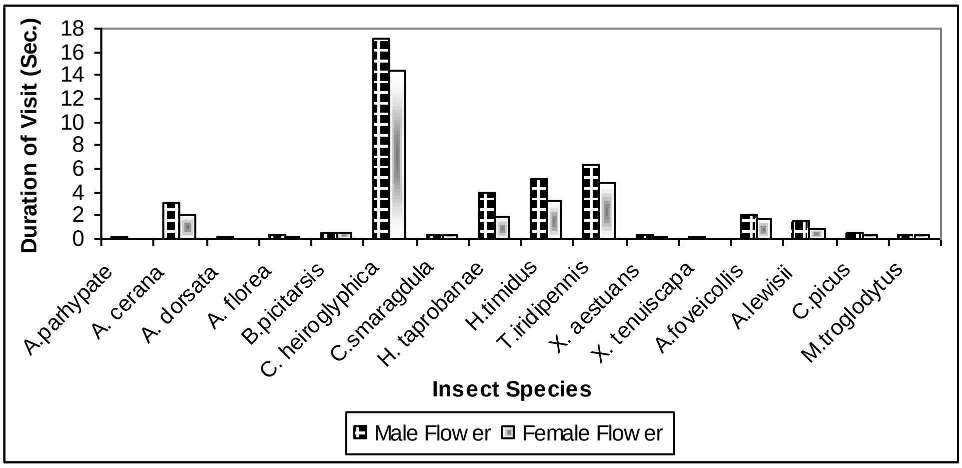
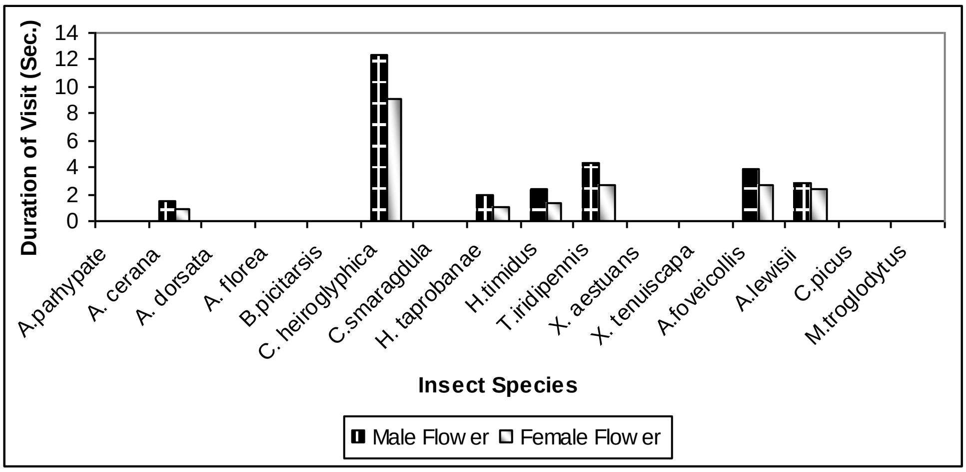


Figure.155: Mean duration of visit on flowers by pollinators (Species) in seconds (Late seasonal phase)



4.3.3. Palynology

4.3.3.1. Pollen Count

The mean number of pollen grains produced by staminate flowers varied by phases of the season. It was highest in middle phase (MP) (16861.08±55.86) than in initial phase (IP) (7899.58±15.82) and late phase (LP) (6703.66±14.27) of the season. At anthesis staminate flowers contained maximum pollen grains /flower and the number of pollen grains remaining on anthers decreased over time of day IP [ip (7899.58±15.82); mp (6186.33±4.47); lp (3727.33±13.43)]; MP [ip (16861.08±55.86); mp (12526±4.39); lp (3338.33±68.55)] LP [ip (6703.66±14.27); mp (5518.5±3.61); lp (3876.25±12.98)]. The mean number of pollen grains produced was highest in the initial diurnal phase (16861.08±55.86) of middle seasonal phase and lowest in the late diurnal phase (3876.25±12.98) of late seasonal phase. The counts were significantly different in diurnal phases of each seasonal phase such as IP (p=0.00) (Figure 156); MP (p=0.00) (Figure 157); LP (p=0.00) (Figure 158). Mean pollen counts between the seasonal phases were also significantly different (P=0.00) (Figure 159).

Figure.156: Mean pollen counts in diurnal phases (Initial seasonal phase)

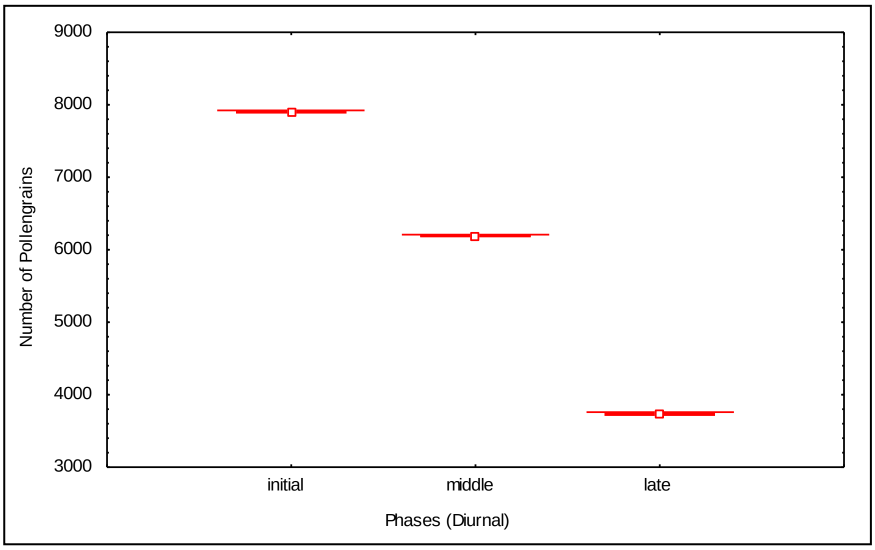


Figure.157: Mean pollen counts in diurnal phases (Middle seasonal phase)

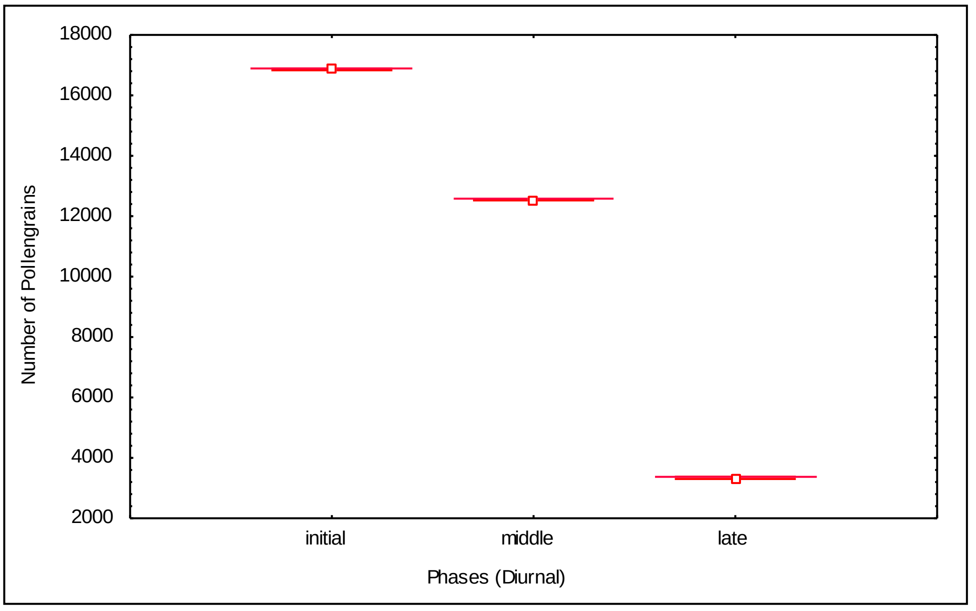


Figure.158: Mean pollen counts in diurnal phases (Late seasonal phase)

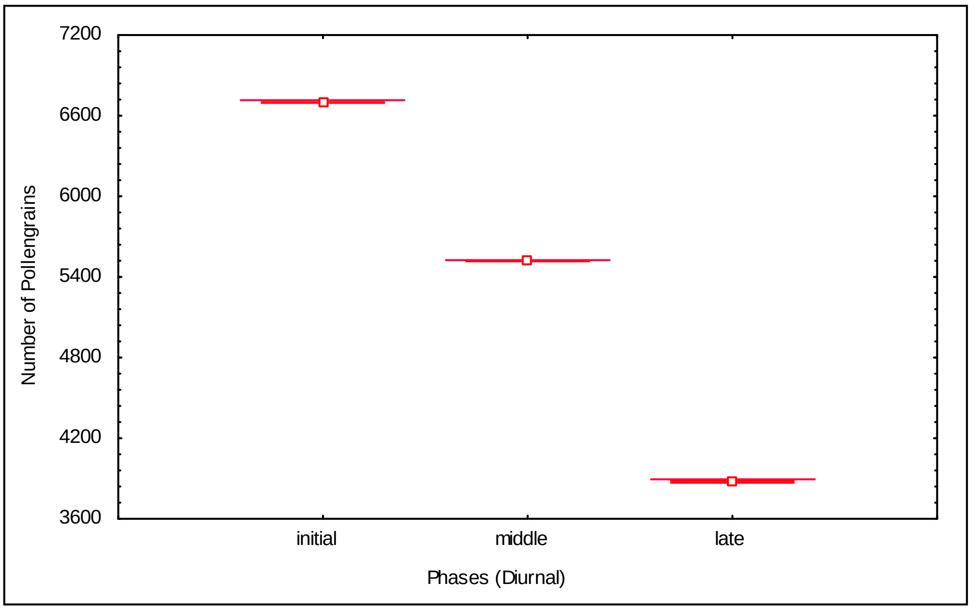
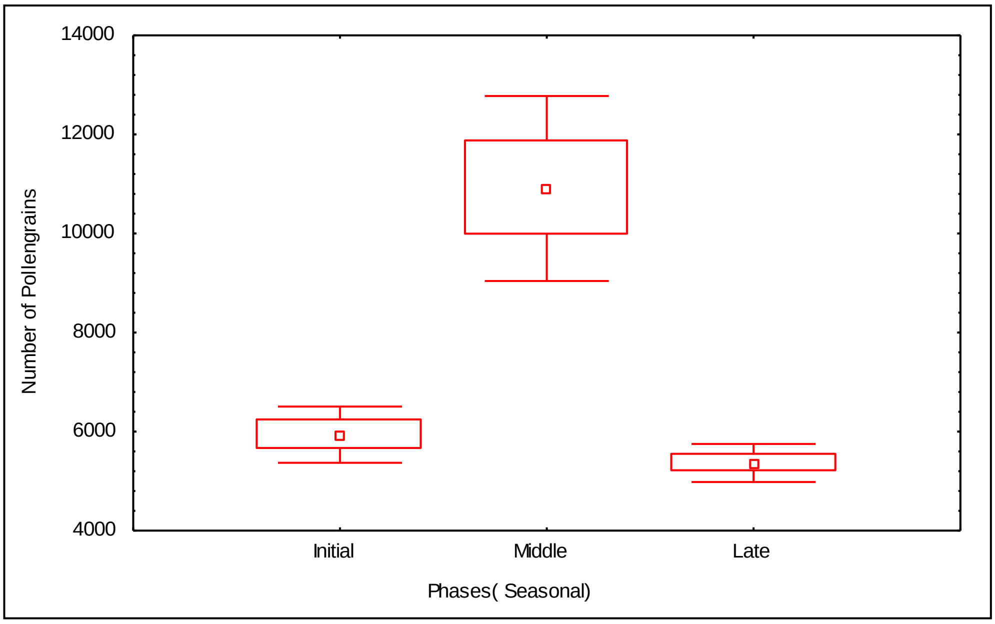


Figure.159: Mean pollen counts in different phases of the season



4.3.3.2. Pollen Removal

The mean number of pollen grains removed from staminate flowers varied by phases of the day and season. Pollen removal increased from IP [ip (1713.25±20.29); mp (2459±9.01); lp (585±5.37)]; to MP [ip (4335.08±60.02); mp (9187.66±64.21); lp (1413.58±14.06)] and then decreased to LP [ip (1185.16±17.81); mp (1642.25±9.44); lp (415.33±6.63)]. In middle diurnal phase of middle seasonal phase maximum number of pollen grains (9187.66±64.21) were removed. In late diurnal phase of late seasonal phase minimum number of pollen grains (415.33±6.63) were removed. The counts were significantly different in diurnal phases of each season such as IP ($p=0.00$) (Figure 160); MP ($p=0.00$) (Figure 161); LP ($p=0$) (Figure 162) and between the seasonal phases ($p=0.00$) (Figure 163).

Figure.160: Mean pollen removal in diurnal phases (Initial seasonal phase)

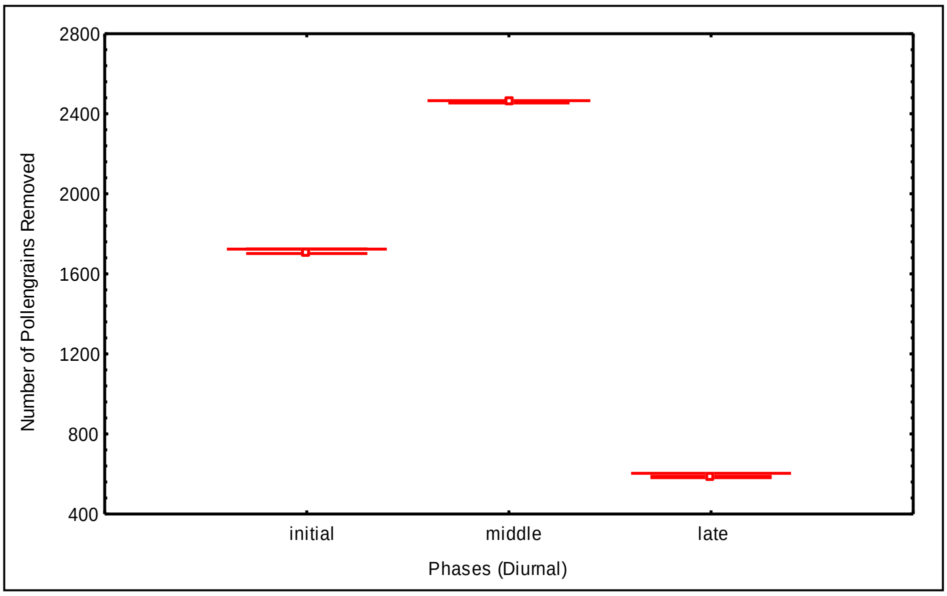


Figure.161: Mean pollen removal in diurnal phases (Middle seasonal phase)

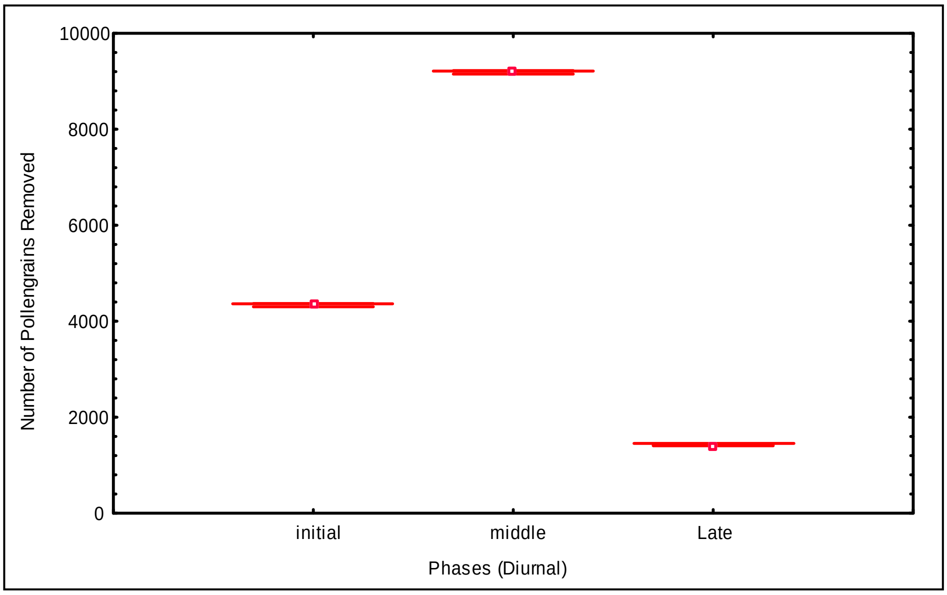


Figure.162: Mean pollen removal in diurnal phases (Late seasonal phase)

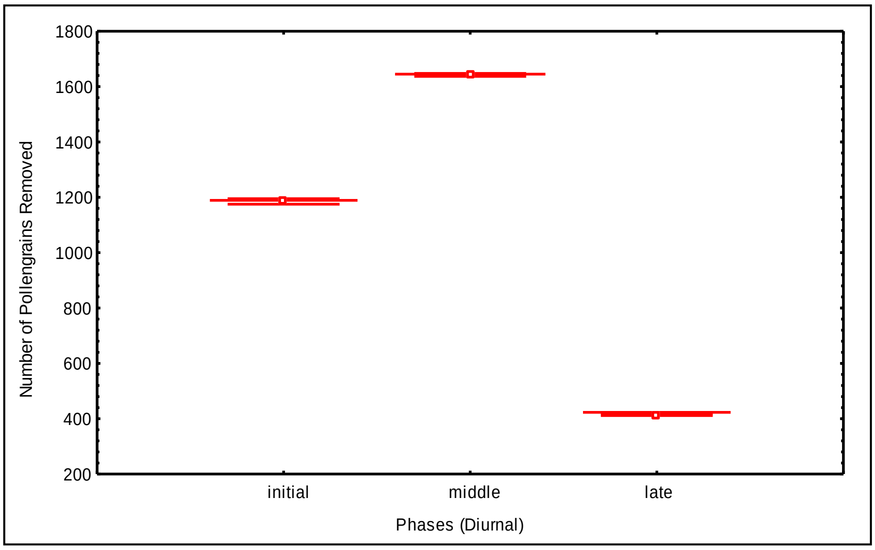
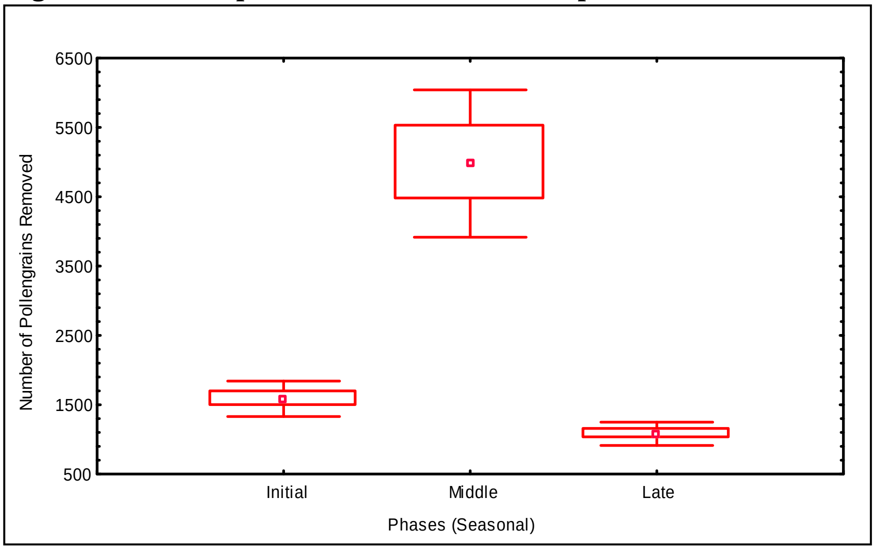


Figure.163: Mean pollen removal in different phases season



4.3.3.3. Pollen Deposition

The mean number of pollen grains deposited on stigma of pistillate flowers varied by phases of the day and season. Pollen deposition increased from IP [ip (728.91±12.88); mp (1190.16±5.61); lp (223.75±9.11)]; to MP [ip (1901.16±21.80); mp (4564.66±22.45); lp (552.91±22.28)] and then decreased to LP [ip (482.83±9.73); mp (751.91±10.73); lp (150.08±8.47)].

Maximum pollen grains were deposited in the middle diurnal phase (4564.66±22.45) of middle phase of the season and minimum pollen grains were deposited in the late diurnal phase (150.08±8.47) of late phase of the season. The counts were significantly different in diurnal phases such as IP (p=0.00) (Figure 164); MP (p=0.00) (Figure 165); LP (p=0.00) (Figure 166) and between the seasonal phases (p=0.00) (Figure 167).

Figure.164: Mean pollen deposition in diurnal phases (Initial seasonal phase)

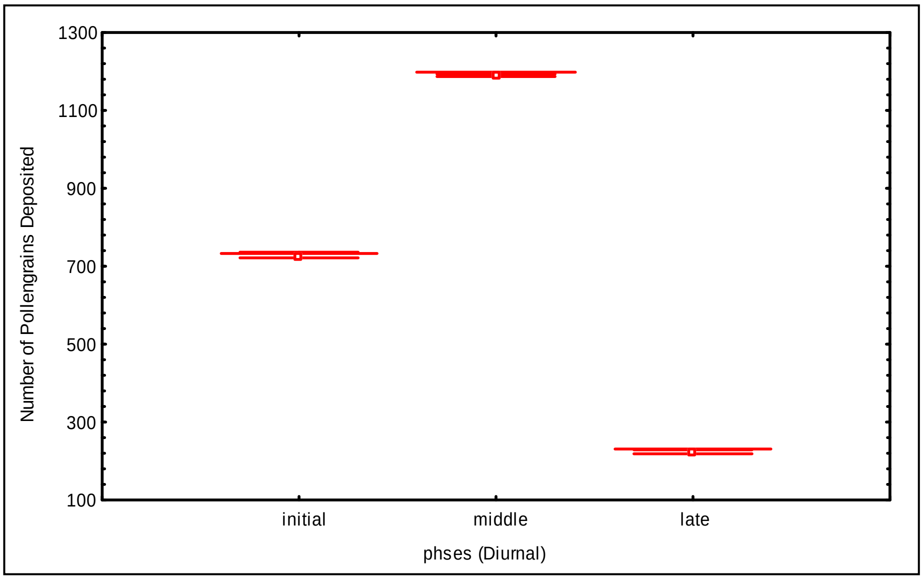


Fig.165: Mean pollen deposition in diurnal phases (Middle seasonal phase)

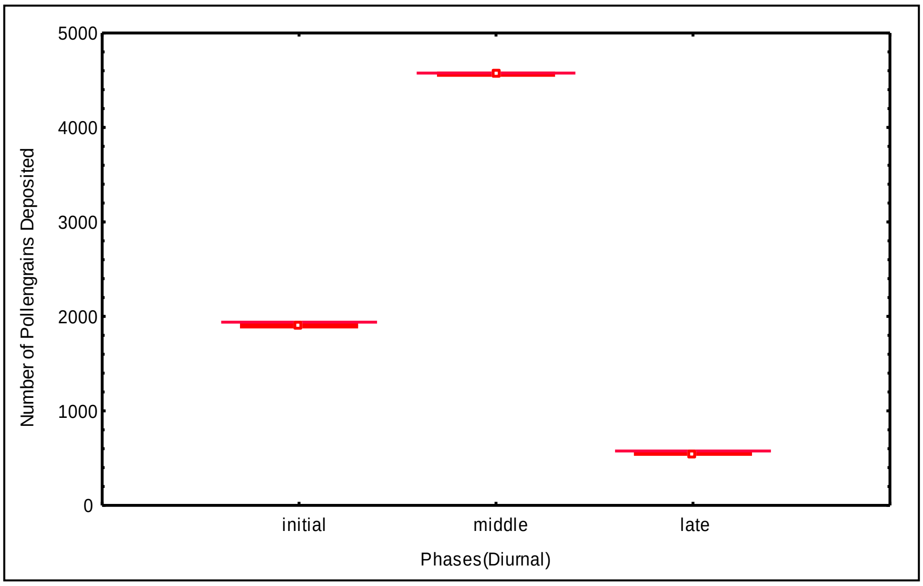


Figure.166: Mean pollen deposition in diurnal phases (Late seasonal phase)

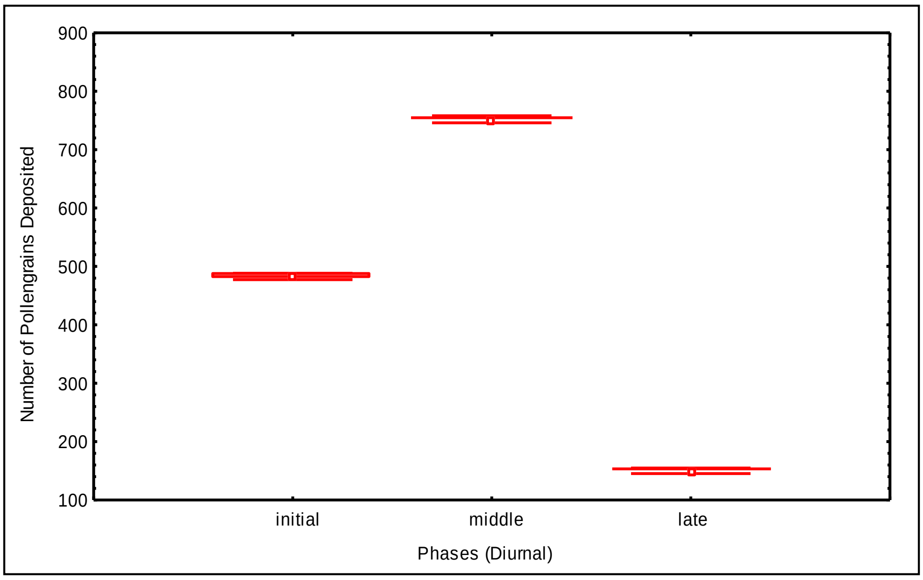
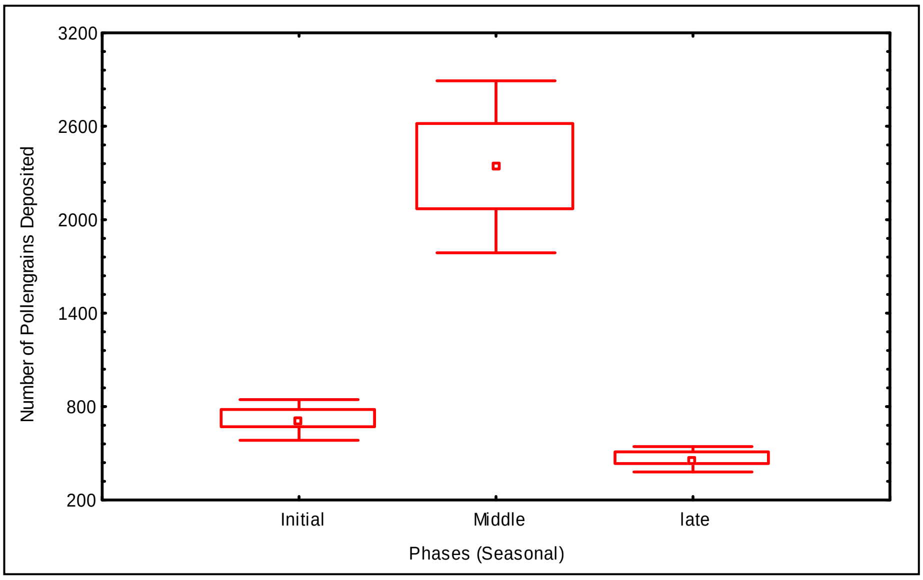


Figure.167: Mean pollen deposition in different seasonal phases



4.3.3.4. Pollen Viability

Viability of pollen grains was found to decrease through diurnal phases of each season, IP [ip (965.5±13.10); mp (883.75±10.06); lp (816.33±7.32)]; MP [ip (4062.5±21.67); mp (3761.66±22.18); lp (3208.83±12.97)]; LP [ip (748.91±9.48); mp (684.08±9.83); lp (550.91±10.31)] and the variations in diurnal phases of each season were significantly different IP (p=0.00) (Figure 168); MP (p=0.00) (Figure 169); LP (p=0.00) (Figure 170). Viability increased from initial phase of the season to middle phase. Most viable pollen grains were observed in initial diurnal phase of middle phase of the season (4062.5±21.67). In late diurnal phase of late seasonal phase least number of viable pollen grains were found (550.91±10.31). Significant difference was found in the viability of pollen grains between the seasonal phases also (p=0.00) (Figure 171).

Figure.168: Mean pollen viability in diurnal phases (Initial seasonal phase)

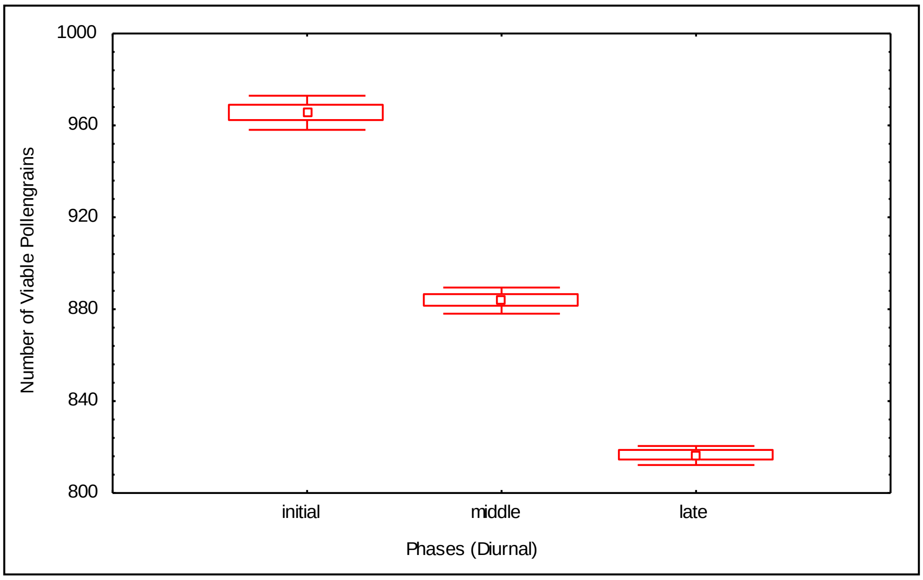


Figure.169: Mean pollen viability in diurnal phases (Middle seasonal phase)

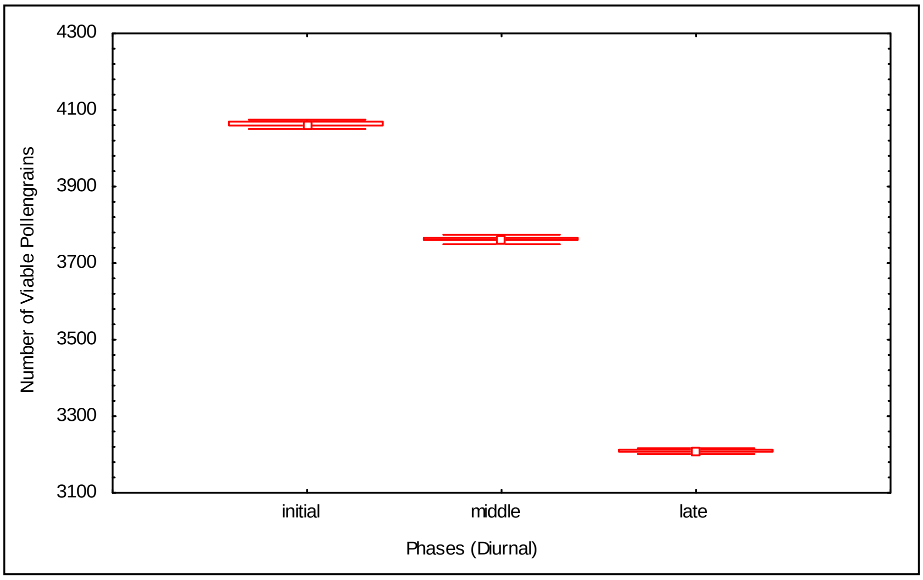


Figure.170: Mean pollen viability in diurnal phases (Late seasonal phase)

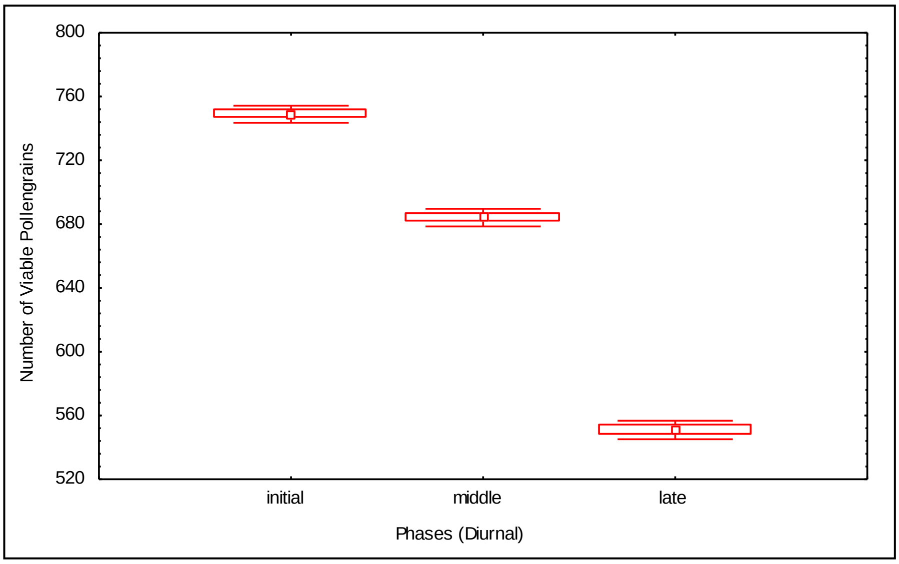
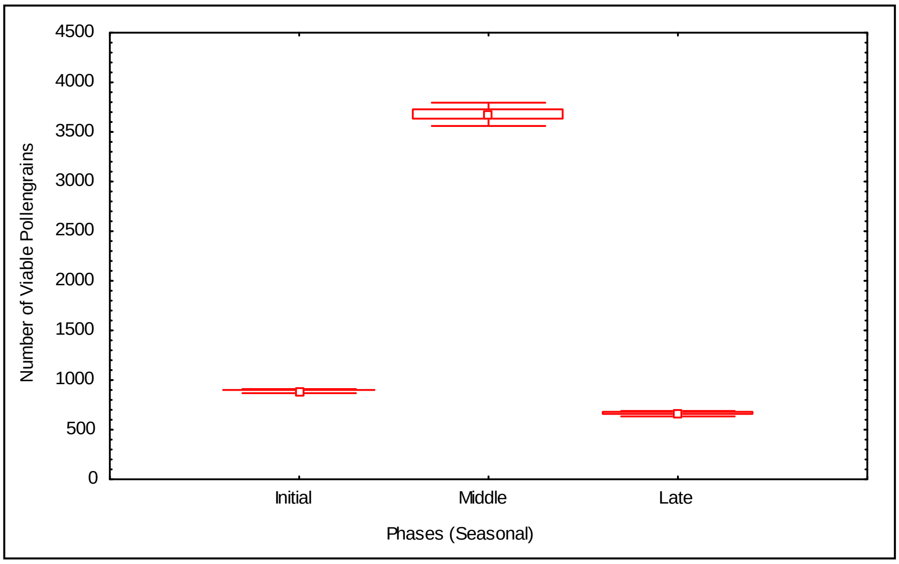


Figure.171: Mean pollen viability in different phases of the season



4.3.4. Pomology

4.3.4.1. Fruit Set

From the bagging experiment it was observed that percentage of fruit set increased from initial phase [IP (33.33%) : (ip)=10.25%; mp=16.66%; lp=6.41%)] to middle phase [MP (41.02%) : (ip)=12.82%;

(mp)=20.51%; lp=7.69%)] and then decreased to late phase [LP (25.64%) [(ip)=8.97%; mp=11.53%; lp=5.12%)]. All non pollinated flowers were aborted (np=0). Highest fruit set was recorded in middle phase of middle seasonal phase (20.51%). Lowest fruit set was recorded in late phase of late seasonal phase (5.12%). Percentage of fruits within each seasonal phase such as IP (Figure 172); MP (Figure 173); LP (Figure 174) and between the seasonal phases were significantly different (Figure 175).

Figure.172: Percentage of fruits in diurnal phases (Initial seasonal phase)

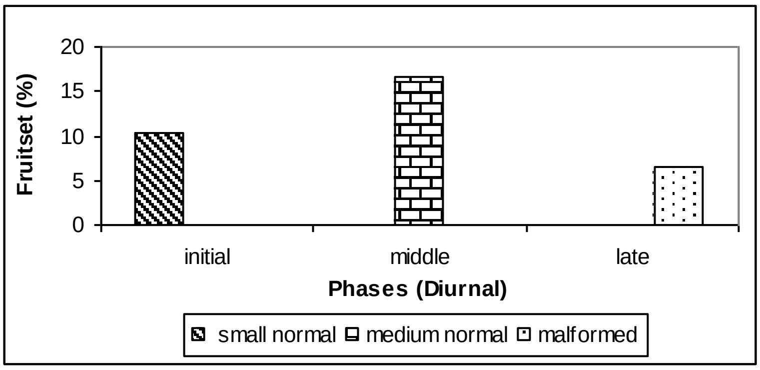


Figure.173: Percentage of fruits in diurnal phases (Middle seasonal phase)

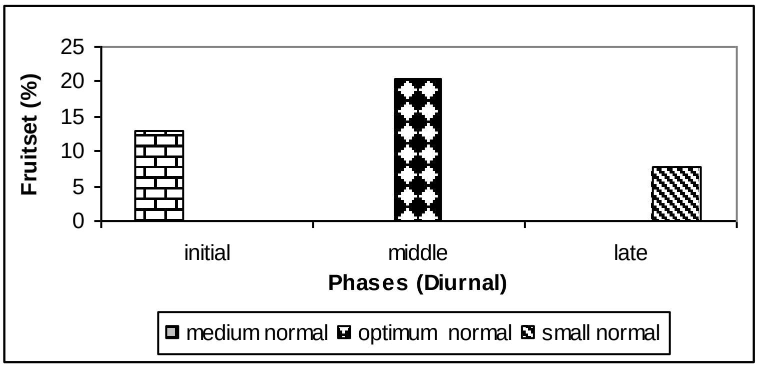


Figure.174: Percentage of fruits in diurnal phases (Late seasonal Phase)

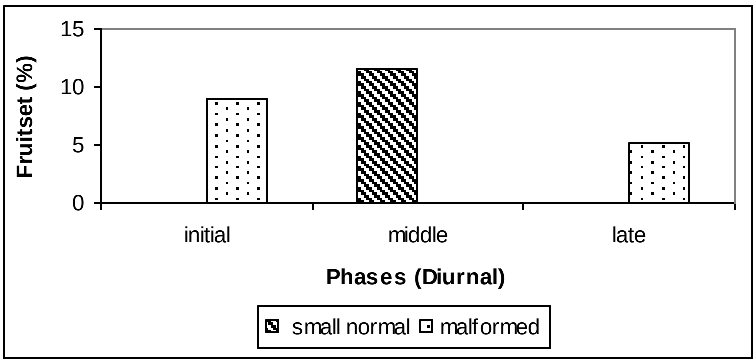
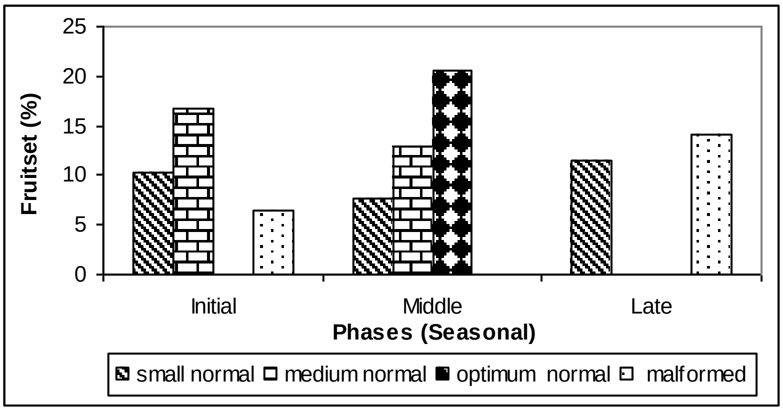


Figure.175: Percentage of fruits in different phases of season



4.3.4.2. Nature of Fruits

Fruits with varied shape and size were produced in the different phases of season. When size was measured in terms of length (l) and breadth (b) it was found that fruits formed in different diurnal and seasonal phases were varied in the maximum size they attained. By comparing each other fruits with lb $\leq$ 10 cm. x 3 cm. were included in small sized ones, 16 cm. x 4 cm. and $\leq$ 20 cm. x 6 cm. were included in the group of medium sized and optimum sized ones respectively. Also on the basis of shape the fruits were categorized into normal and malformed ones. So four categories like small normal, medium normal, optimum normal and malformed fruits were observed when size and shape were considered together for the assessment of nature of fruits [IP (ip)=10.25% small normal, (mp)=16.66% medium normal, (lp)=6.41% malformed; MP (ip)=12.82% medium normal, (mp)=20.51% optimum normal, (lp)=7.69% small normal; LP (ip)=8.97% malformed, (mp)=11.53% small normal, (lp)=5.12% malformed] (Plate 10). All non pollinated flowers were aborted in all phases. Majority of fruits formed in the initial and middle phase were normal shaped and in late phase were malformed. Size and shape of the fruits varied significantly within seasonal phases such as IP (p=0.00)

(Figure 172); MP (p=0.00) (Figure 173); LP (p=0.00) (Figure 174) and between the seasonal phases (p=0.00) (Figure 175).

4.3.4.3. Weight of Fruits

Mean weight of fruits increased from initial phase [IP: (ip)=15.41±11.42 gm.; (mp)=39.33±2.26 gm.; (lp)=2.41±3.02 gm.] to middle phase [MP:(ip)=55.33±26.01 gm.; (mp)=156.91±8.63 gm.; (lp)=8.58±9.01 gm.] and then decreased to late phase [LP: (ip)=9.33±8.26gm.; (mp)=18.91±11.50 gm.; (lp)=1.58±.2.35 gm.] of the day and season. As non pollinated flowers were aborted no weights were recorded. In middle diurnal phase of middle seasonal phase the average weight of fruit was highest (156.91±8.63 gm.). In late diurnal phase of late seasonal phase the average weight of fruit was lowest (1.58±.2.35 gm.).Weight of fruits within seasonal phases such as IP (p=0.00) (Figure 176); MP (p=0.00) (Figure 177); LP (p=0.00) (Figure 178) and between the seasonal phases were significantly different (P=0.00) (Figure 179).

Figure.176: Mean weight of fruits in diurnal phases (Initial seasonal phase)

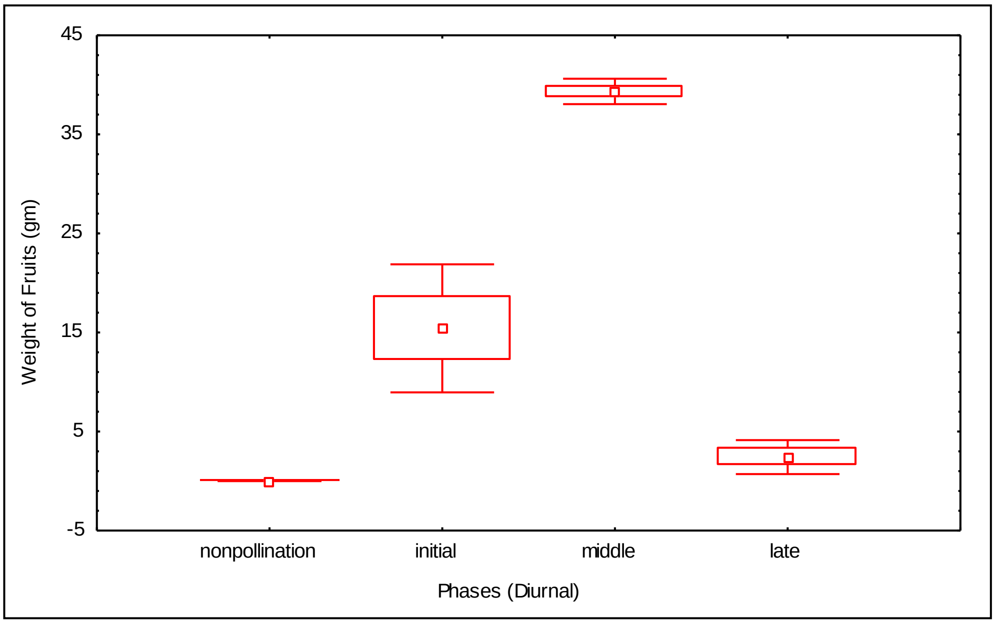


Figure.177: Mean weight of fruits in diurnal phases (Middle seasonal phase)

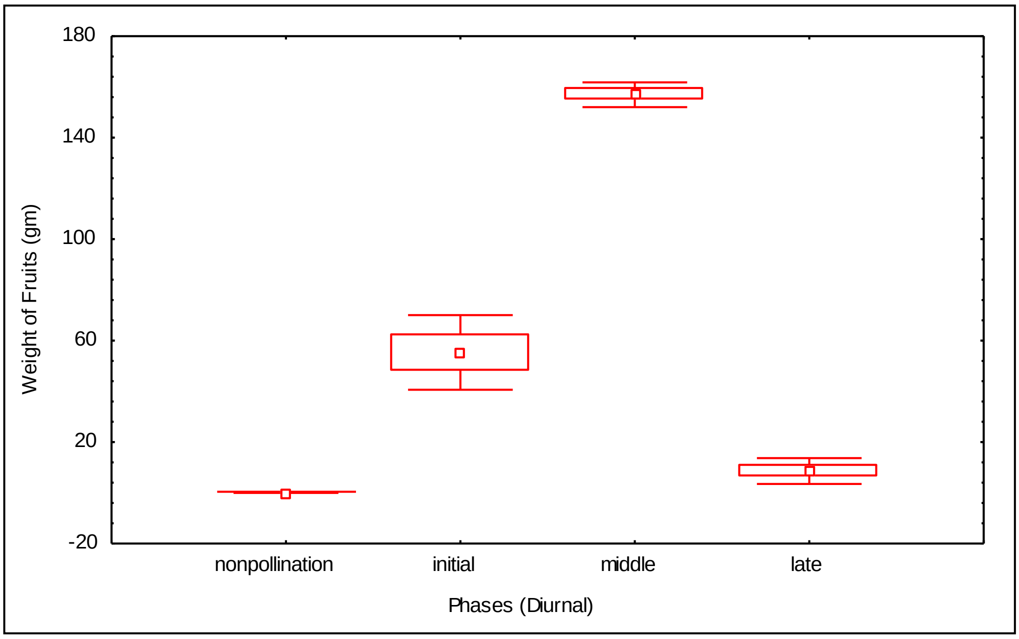


Figure.178: Mean weight of fruits in diurnal phases (Late seasonal phase)

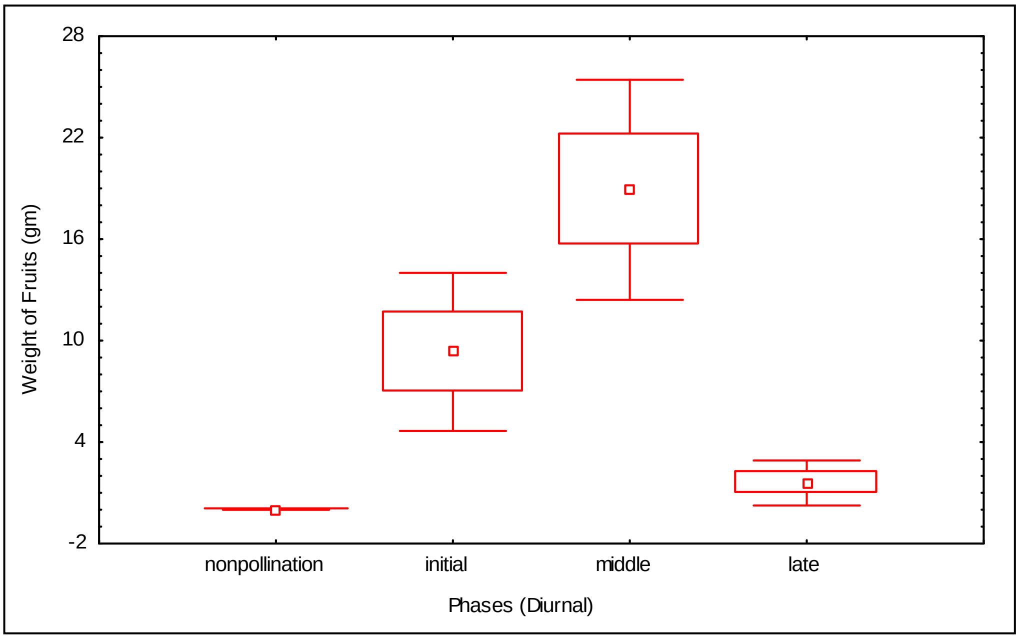
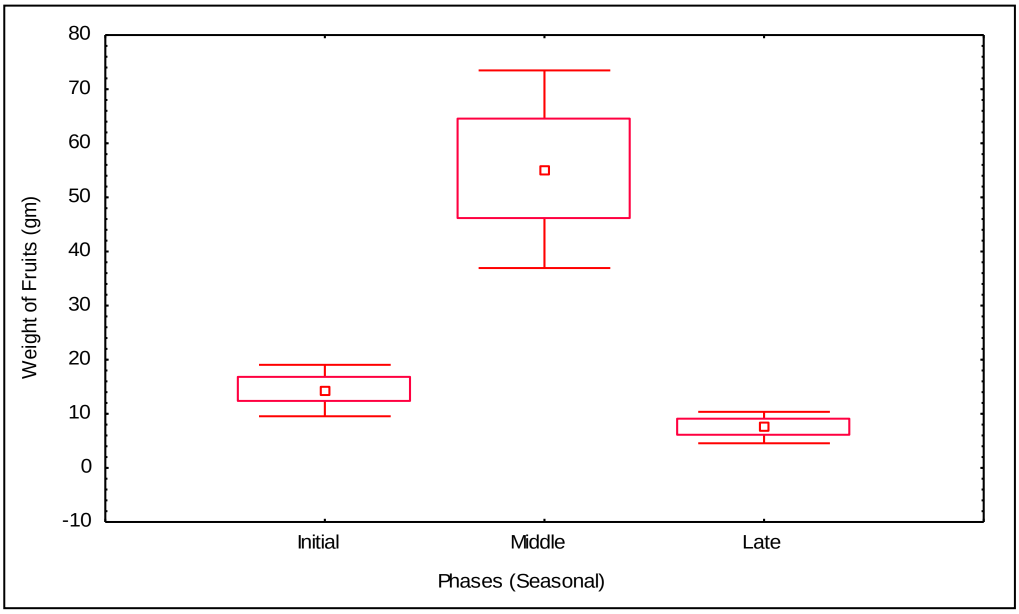


Figure.179: Mean weight of fruits in different phases of season



4.3.4.4. Number of Seeds

Mean number of seeds increased from initial phase of the season IP [ip=2.00±1.47; mp=5.16±0.93; lp=0.41±0.51] to middle phase of the season MP [ip=6.91±3.31; mp=20.75±2.30; lp=0.83±0.93] and then decreased to late phase LP [ip=1.16±1.0; mp=2.25±1.35; lp=0.33±0.49] of the season. As non pollinated flowers were aborted no seeds were recorded. Highest number of seeds were recorded in middle diurnal phase (20.75±2.30) of middle seasonal phase. In late diurnal phase of late seasonal phase lowest number of seeds (0.33 ±0.49) were recorded. Mean number of seeds within each seasonal phase such as IP (p=0.00) (Figure 180); MP (p=0.00) (Figure 181); LP (p=0.00) (Figure 182) and between the seasonal phases were significantly different (P=0.00) (Figure 183).

Figure.180: Mean number of seeds in diurnal phases (Initial seasonal phase)

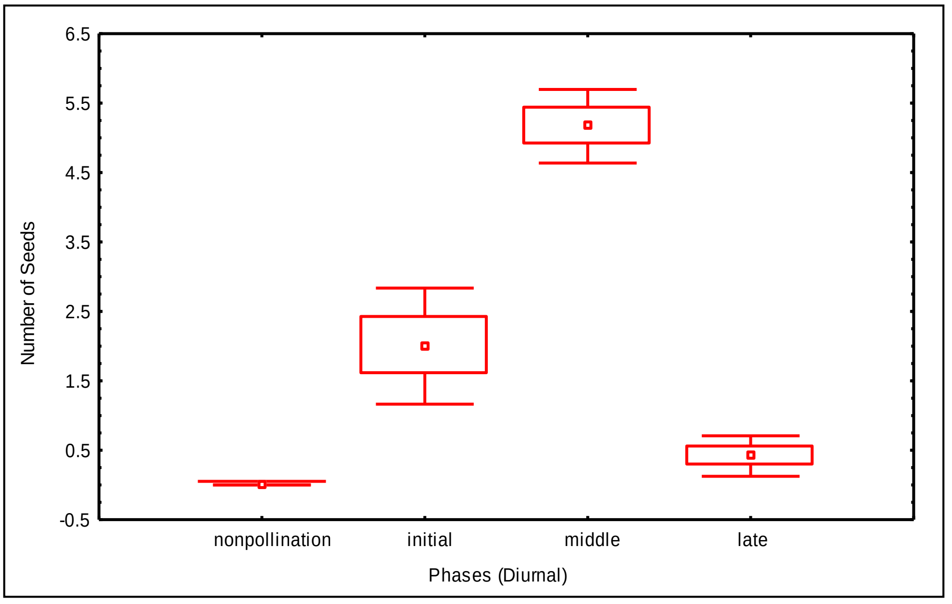


Figure.181: Mean number of seeds in diurnal phases (Middle seasonal phase)

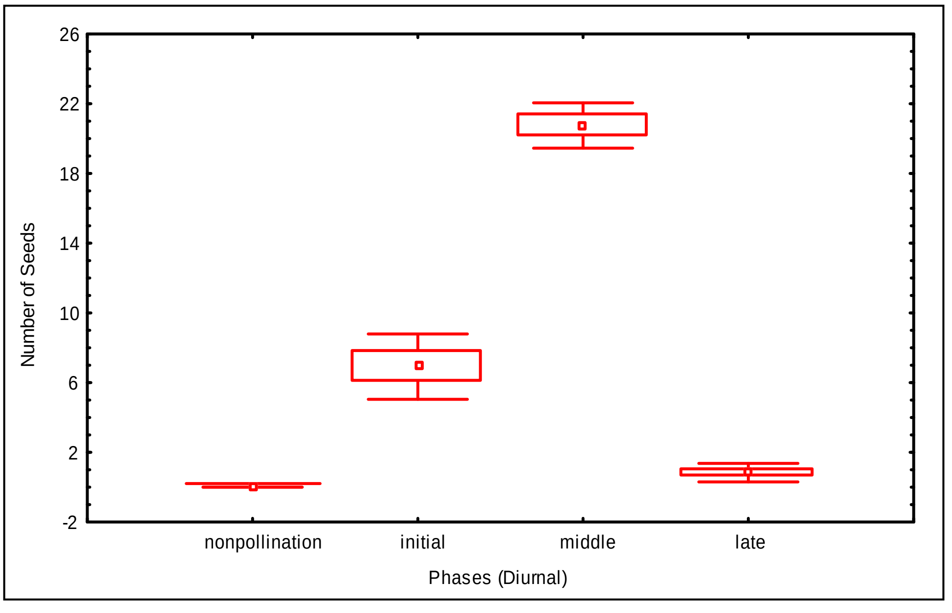


Figure.182: Mean number of seeds in diurnal phases (Late seasonal phase)

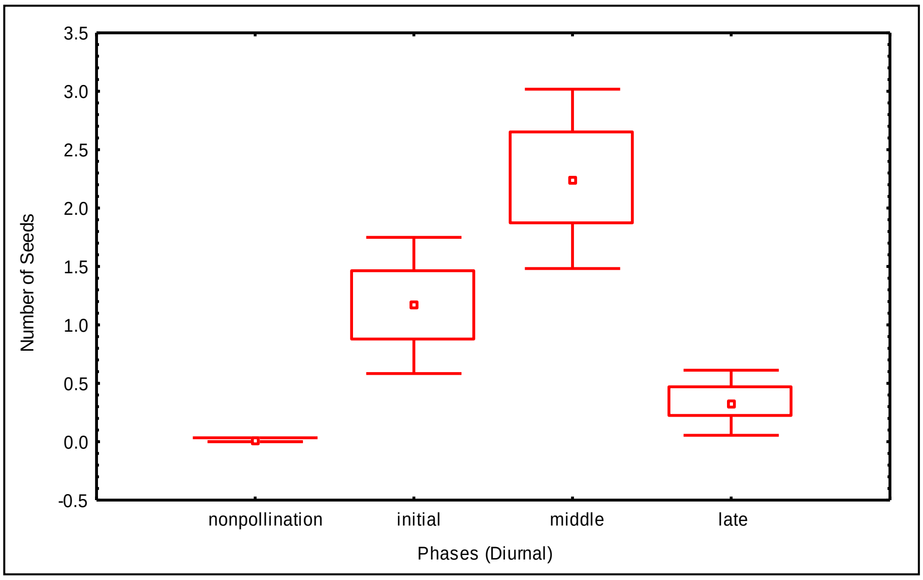
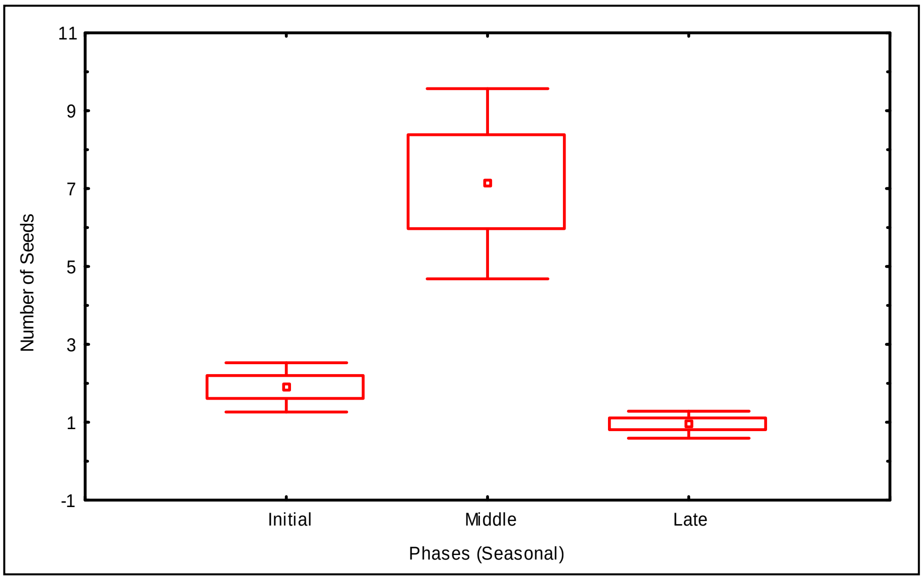


Figure.183: Mean number of seeds in different phases of season



4.3.4.5. Viability of Seeds

Mean number of viable seeds increased from initial phase, IP [ip=1.83±1.40; mp=4.25±0.75; lp=0.33±0.49] to middle phase, MP [ip=6.08±2.91; mp=19.33±1.96; lp=0.75±0.86] and then decreased to late phase, LP [ip=0.58±0.51; mp=1.33±0.88; lp=0.08±0.28] of the day and season. Maximum viable seeds were recorded in middle diurnal phase (19.33±1.96) of middle seasonal phase. In late diurnal phase of late seasonal phase minimum number of viable seeds (0.08±0.28) were found. As non pollinated flowers were aborted no viable seeds were recorded. Number of viable seeds within each seasonal phase such as IP (p=0.00) (Figure 184); MP (p=0.00) (Figure 185); LP (p=0.00) (Figure 186) and between the seasonal phases were significantly different (p=0.00) (Figure 187).

Figure.184: Mean number of viable seeds in diurnal phases (Initial seasonal phase)

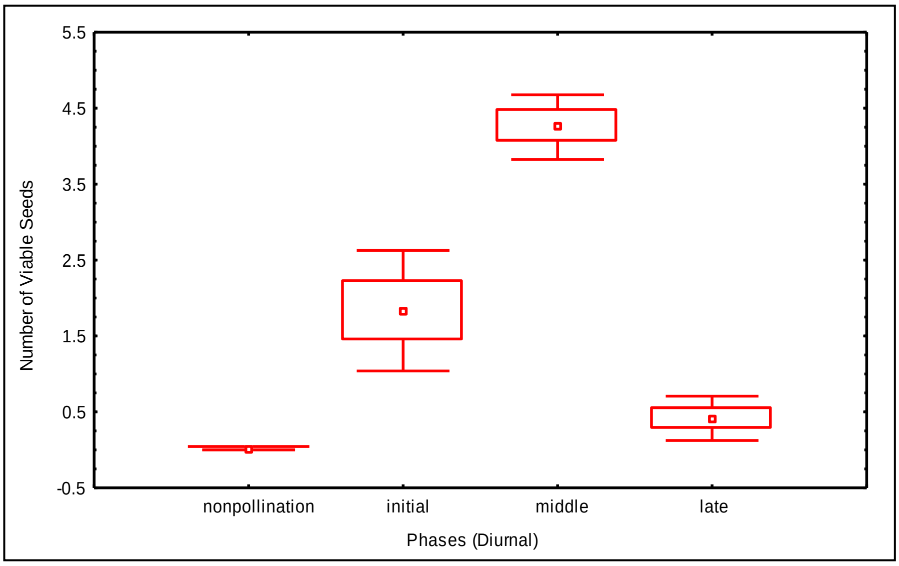


Figure.185: Mean number of viable seeds in diurnal phases (Middle seasonal phase)

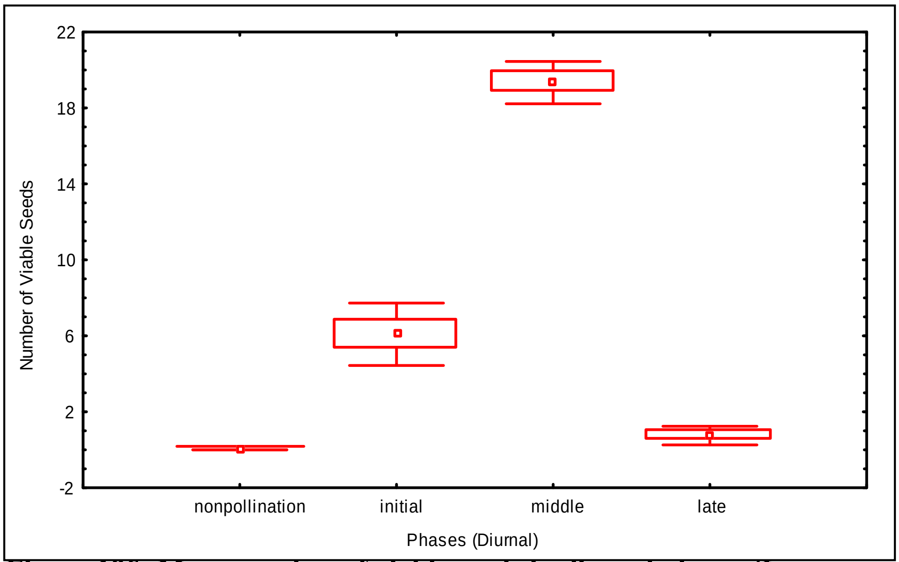


Figure.186: Mean number of viable seeds in diurnal phases (Late seasonal phase)

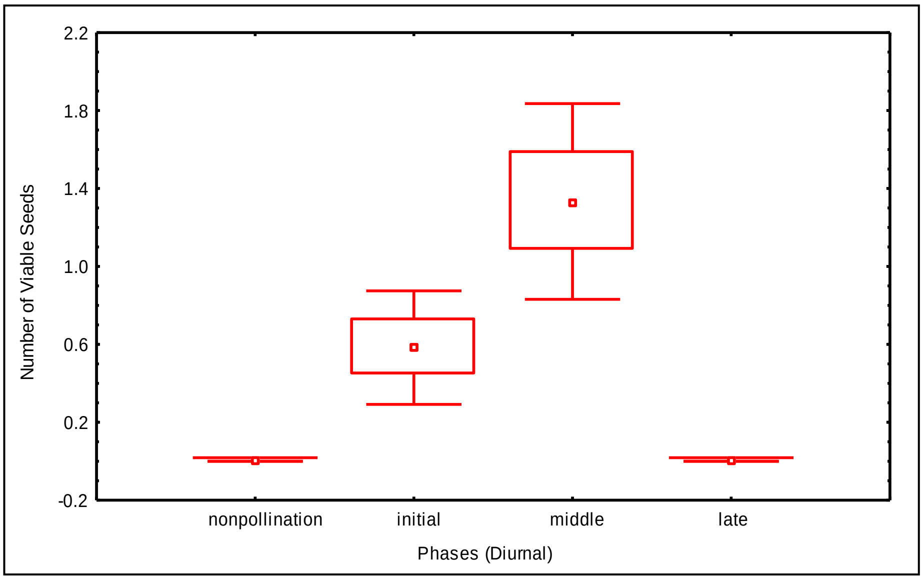
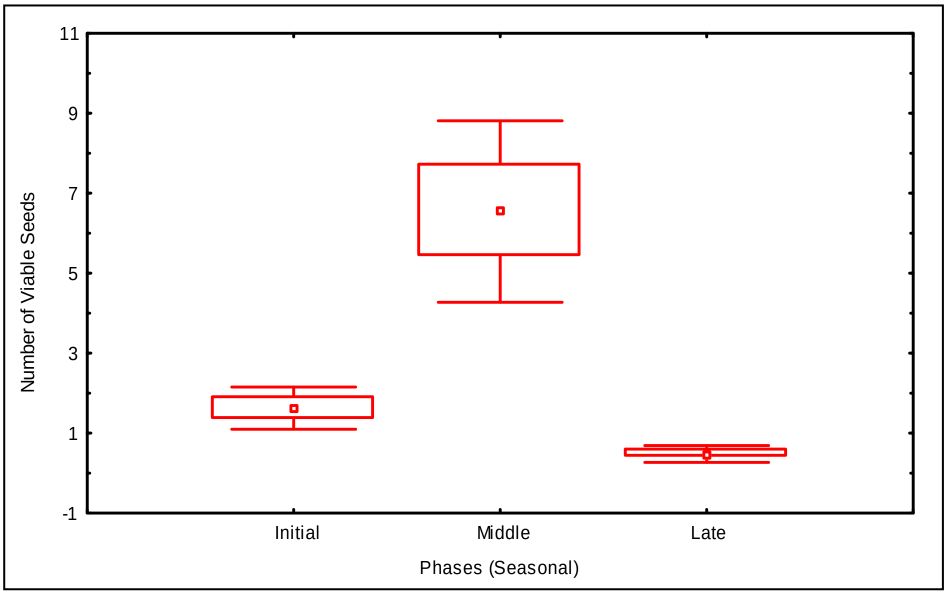


Figure.187: Mean number of viable seeds in different phases of season



4.3.5. Correlation

Positive correlation was observed between number of flowers and number of insects visited (r=0.99) (Figure 188), size of flowers and number of insects visited (r=0.99) (Figure 189), number of insects visited and number of pollen grains deposited (r=0.93) (Figure 190), duration of insect visit and number of pollen grains deposited (r=0.88) (Figure 191), number of pollen grains deposited and percentage of fruit set (r=0.95) (Figure 192), number of pollen grains deposited and weight of fruit (r=0.88) (Figure 193), number of pollen grains deposited and number of seeds (r=0.94) (Figure 194) and number of pollen grains deposited and number of seeds (r=0.87) (Figure 195).

Figure.188: Correlation between number of flowers /plant and number of insects visited

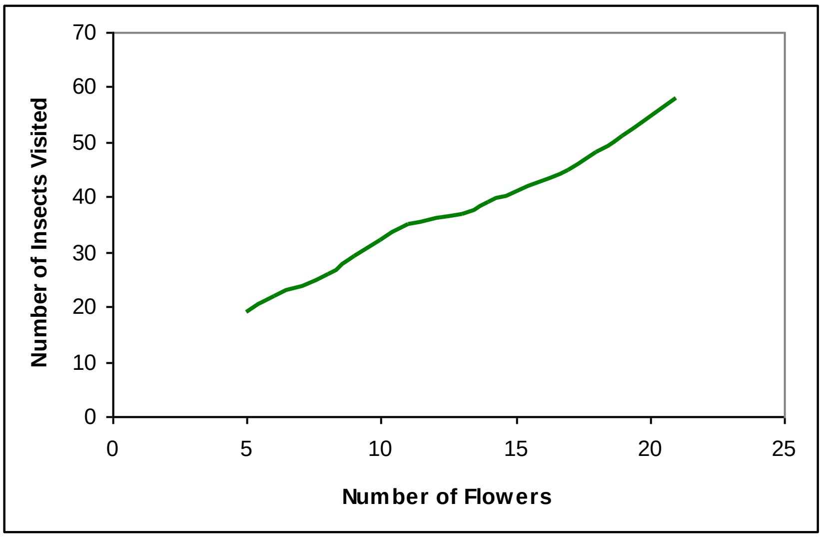


Figure.189: Correlation between size of flowers and number of insects visited

Figure.190: Correlation between number of insects visited and number of pollen grains deposited

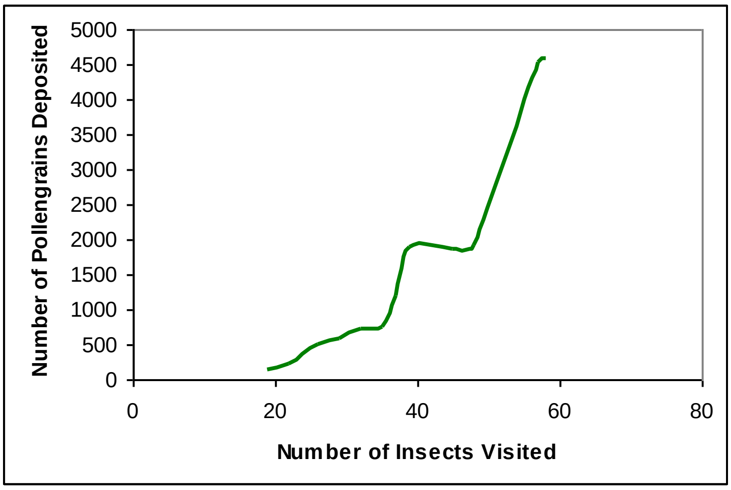


Figure.191: Correlation between duration of visit and number of pollen grains deposited

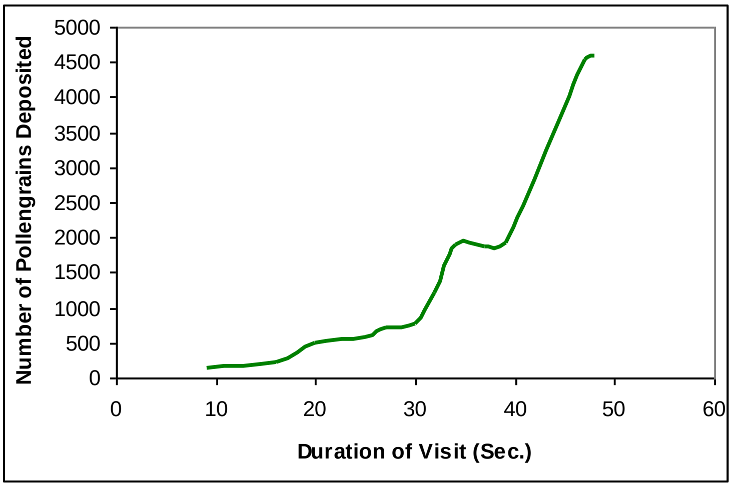


Figure.192: Correlation between number of pollen grains deposited and fruit set

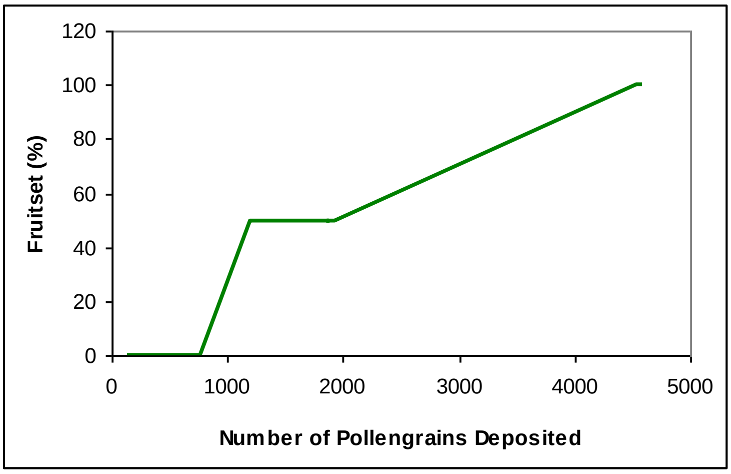


Figure.193: Correlation between number of pollen grains deposited and weight of fruit

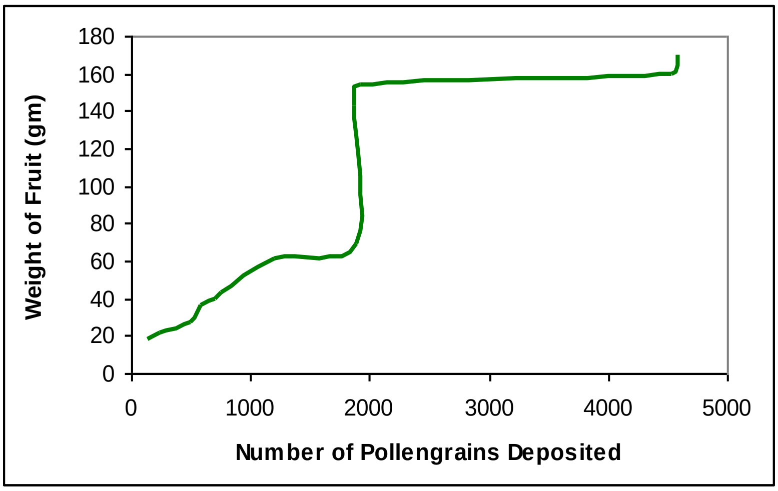


Figure.194: Correlation between number of pollen grains deposited and number of seeds

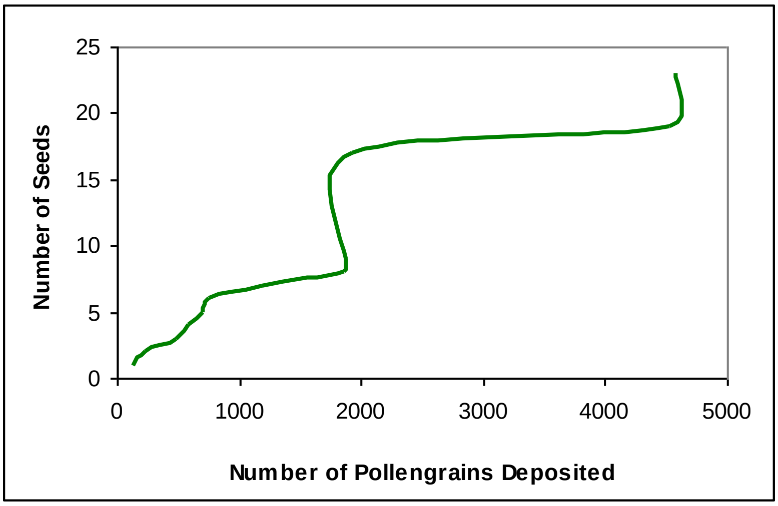


Figure.195: Correlation between number of pollen grains deposited and number of viable seeds

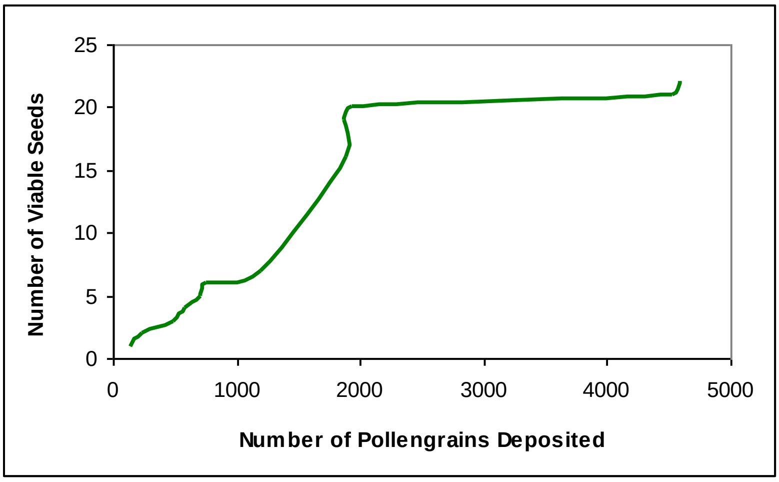


Plate 10

Bittergourd Fruit

Bittergourd Nonpollinated Ovary

Bittergourd Malformed Fruit

Ashgourd Fruit

Ashgourd Nonpollinated Ovary

Ashgourd Malformed Fruit

4.4. Ashgourd

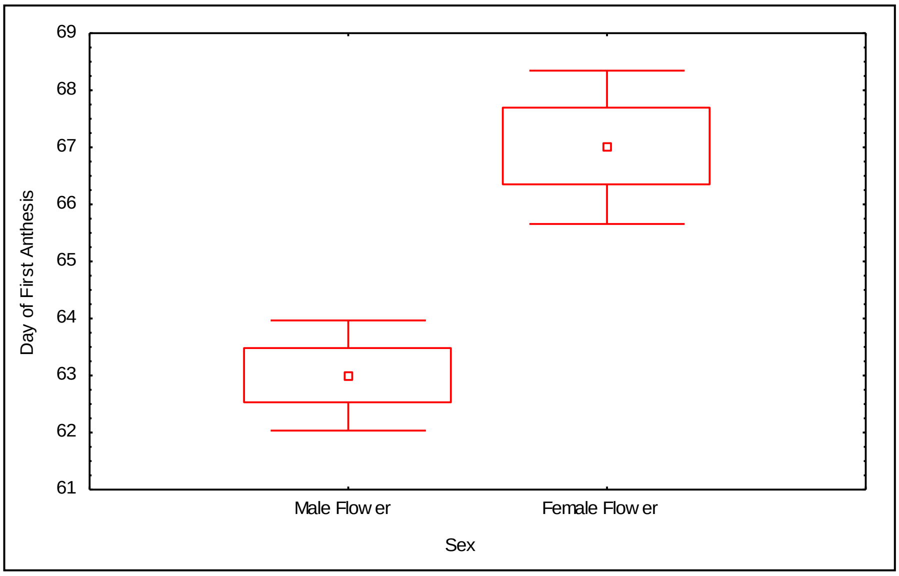
[*Benincasa hispida* Thunb. and Cogn.]

4.4.1. Phenology

4.4.1.1. Day of First Anthesis

It was observed that first male (♂) and female (♀) flower opened on 64.34±0.7th and 69.00±0.82th day respectively from the day of germination. Both male and female anthesis were significantly different (p=0.00) (Figure 196).

Figure.196: Day of first anthesis of male and female flowers of after germination



4.4.1.2. Flower Opening Time

Male flower (♂) anthesis commenced between 0516 h. and 0623 h. and female (♀) flower between 0501 h. and 0609 h. The times at which male (♂) and female (♀) flowers opened were significantly different (p=0.00). Mean durations taken for full corolla expansion were 1.01±0.00 h. and 1.2±0.07 h. by male (♂) and female (♀) flowers respectively and they showed significant difference (p=0.02).

4.4.1.3. Flower Closing Time

Male flower (♂) closing commenced between 1701 h. and 1805 h. and female flower (♀) between 1715 and 1820 h. The times at which male (♂) and female (♀) flowers closed were significantly different (p=0.00). Mean durations taken for full petal constriction were 2.16±0.10 h., 2.01±0.01 h. by male (♂) and female (♀) flowers respectively and showed significant difference (p=0.00).

4.4.1.4. Number of Flowers

Mean number of staminate (♂) and pistillate (♀) flowers produced per plant per day increased from initial phase (IP) (♂=5.60±1.8, ♀=1.43±0.49) to middle phase (MP) (♂=9.67±2.62, ♀=2.02±0.37), where maximum number of flowers were observed and then decreased to late phase LP (♂=3.64±0.88, ♀=1.16±0.37) of the season where minimum number of flowers were observed. Number of staminate (♂) and pistillate (♂) flowers within seasonal phases such as IP (p=0.00) (Figure 197); MP (p=0.00) (Figure 198); LP (p=0.00) (Figure 199) and between the seasonal phases were significantly different (P=0.00).

Figure.197: Mean number of male and female flowers produced /plant /day (Initial seasonal phase)

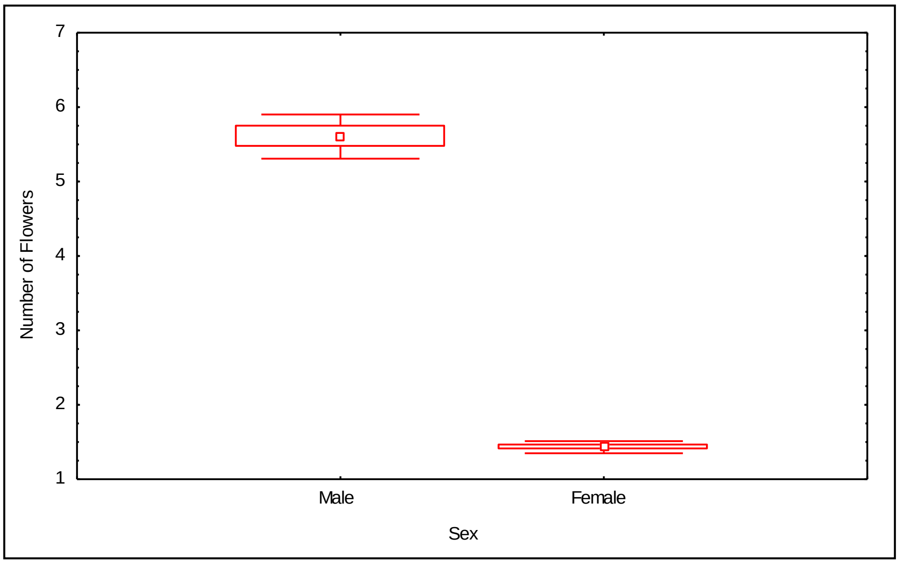


Figure.198: Mean number of male and female flowers produced /plant /day (Middle seasonal phase)

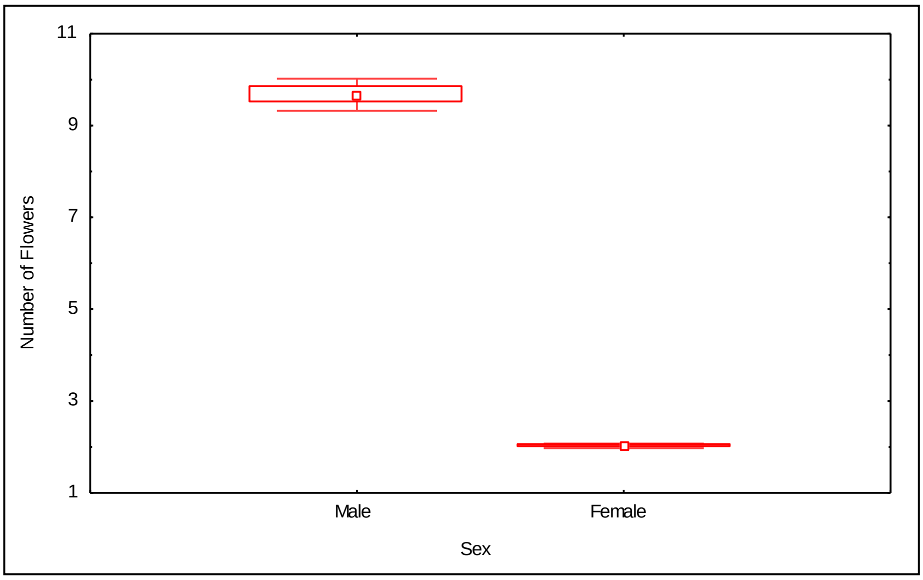
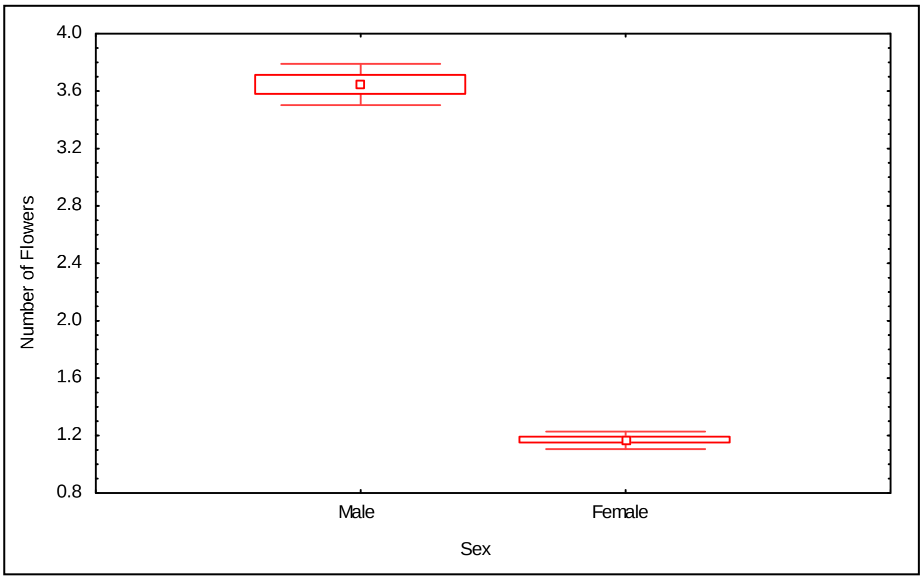


Figure.199: Mean number of male and female flowers produced /plant /day (Late seasonal phase)



4.4.1.5. Size /Dimension of Flower

Mean size of staminate (♂) and pistillate (♀) flowers produced per plant per day increased from initial phase IP (♂=9.22±1.41cm.,

♀=10.22±1.41 cm.) to middle phase MP (♂=11.65±0.78 cm., ♀=12.65±0.78 cm.), where maximum size was observed and then decreased to late phase LP (♂=9.14±0.85 cm., ♀=10.14±0.85 cm.) of the season where minimum size was observed. Size of staminate (♂) and pistillate (♀) flowers within seasonal phases such as IP (p=0.00) (Figure 200); MP (p=0.00) (Figure 201); LP (p=0.00) (Figure 202) and between the seasonal phases were significantly different (P=0.00).

Figure.200: Mean size of male and female flowers produced (Initial seasonal phase)

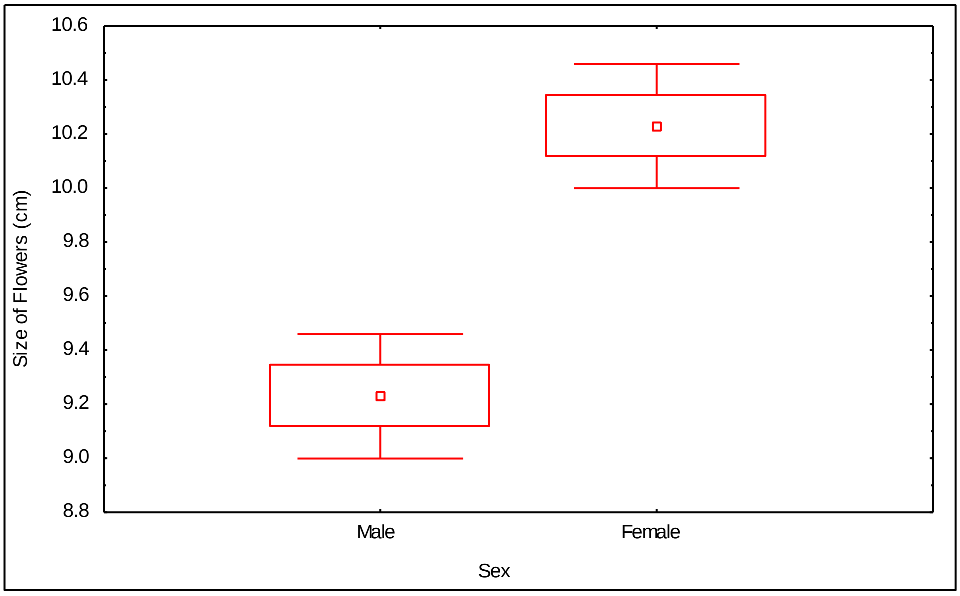


Figure.201. Mean size of male and female flowers produced (Middle seasonal phase)

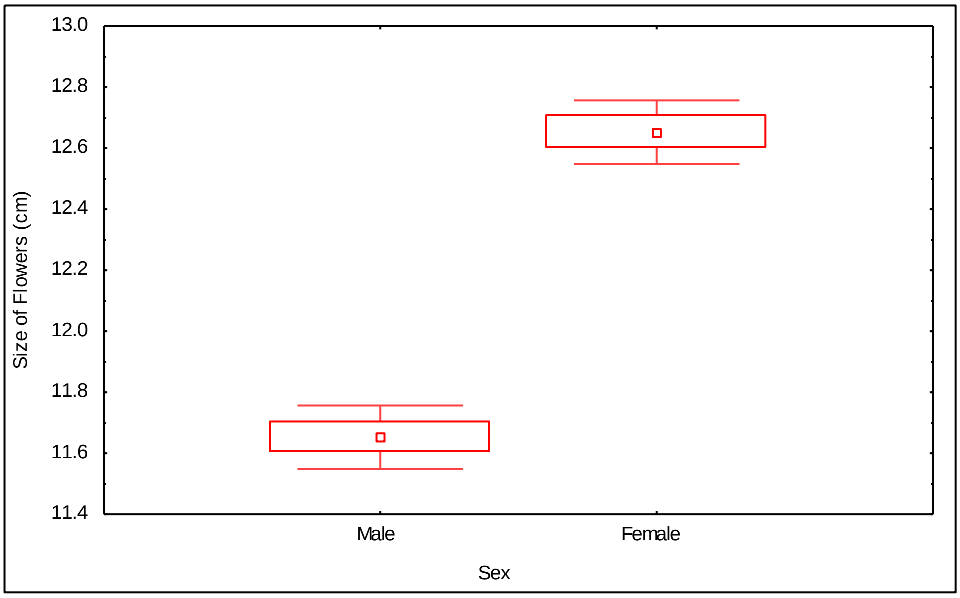
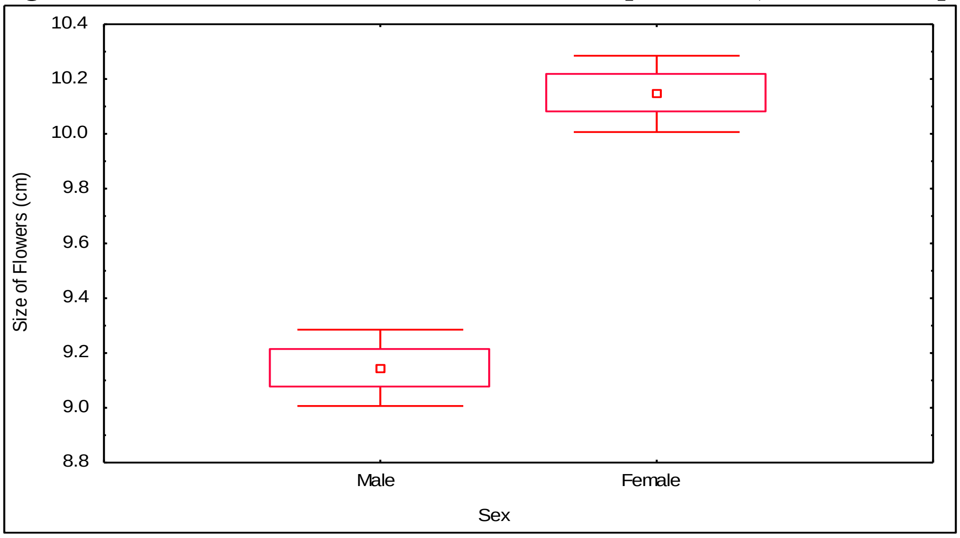


Figure.202: Mean size of male and female flowers produced (Late seasonal phase)



4.4.2. Entomology

4.4.2.1. Identification of Pollinators

A total of 16 insects were recorded mostly from 3 orders during the study (Plate 7 and Plate 8). The most abundant order was the Hymenoptera, including families Apidae, Halictidae, Xylocopidae followed by Coleoptera. Much less abundant was Lepidoptera. The list of pollinators of Ashgourd observed during the study is given in Table 22.

Table.22.List of pollinators

Order	Family	Species
Hymenoptera	Halictidae	*Trigona iridipennis* Smith
		Halictus timidus Smith
		Halictus taprobranae Cameron
	Apidae	*Apis cerana* Fabricius
		Amegilla parhypate Lieftinck
		Apis dorsata Fabricius
		Apis florea Fabricius
		Braunsapis picitarsis Cameron
		Ceratina heiroglyphica Smith
		Ceratina smaragdula Fabricius
	Xylocopidae	*Xylocopa tenuiscapa* Westwood
		Xylocopa aestuans Linnaeus
Coleoptera	Chrysomelidae	*Aulacophora lewisii* Baly
		Aulacophora foveicollis Lucas
Lepidoptera	Sphingidae	*Cephonodes picus* Cramer
		Macroglossum troglodytus Boisduval

4.4.2.2.Floral visitation (Dynamics of Pollinating behaviour)

4.4.2.2.1. Frequency of Pollinator Visit

Mean pollinator visitation rates for all phases and seasonal phases are calculated. The variety of insects encountered and the visits they made were more numerous in the MP, than in IP and LP. Within each season, the visits of different insect groups varied with the flowering phase, the middle phase receiving the larger number of visits. Variation in the case of different diurnal phases in each phase of the season was also observed. Highest frequency of visit was observed in middle diurnal phase of middle phase of season. Lowest frequency of visit was observed in late diurnal phase of late phase of season. It was observed that a mean of 18.66 and 15.25 hymenopterans and 5.25 4.25 and coleopterans visited the male (♂) and female (♀) flowers /day respectively in the initial phase (IP) of the season. In middle phase (MP) a mean of 25.66 and 22.25 hymenopterans, 1.41 and 1.25 coleopterans and 0.5 and 0.41 lepidopterans visited the male (♂) and female (♀) flowers /day respectively. In late phase (LP) of the season a mean of 14.08 and 11.41 hymenopterans and 6.16 and 4.91 coleopterans visited the male (♂) and female (♀) flowers /day respectively. Significant difference was found in visitation frequency shown by different orders of insects [IP (p=0.00) (Figure 203); MP (p=0.01) (Figure 204); LP (p=0.00) (Figure 205)] (Table 23) . The most dominant group was Hymenoptera followed by coleoptera and Lepidoptera. Variation in visitation frequency shown by different species of insects belonging to Hymenoptera, Coleoptera and Lepidoptera was also observed. The visitation frequency shown by different species of insects varied significantly [IP (p=0.00) (Figure 206); MP (p=0.00) (Figure 207); LP (p=0.00) (Figure 208)] (Table 24). *Trigona iridipennis* was the most frequent pollinator. It was followed by *Halictus timidus, Apis cerana Ceratina heiroglyphica and Halictus taprobanae.* They were regular, consistent and made the higher number of visits compared to other insects, at all sites. No significant difference in visitation frequency on staminate (♂) and pistillate (♀) flowers was observed IP (p=0.21); MP (p=0.67); LP (p=0.26). Frequency of visitation during different diurnal phases varied significantly [IP (p=0.00); MP (p=0.00); LP (p=0.01)]. Different seasonal phases also showed significant differences in visitation frequency (p=0.00).

Table.23: Frequency of pollinator (Order) visit /day

Order	Sex of flower	Initial Phase (IP)			Middle Phase (MP)			Late Phase (LP)		
		ip	mp	lp	ip	mp	lp	ip	mp	lp
Hymenoptera	♂	5.91	10.58	2.16	7.58	13.83	4.25	4.41	8.33	1.33
	♀	5.91	9.5	1.58	6.33	12.58	3.33	3.33	7.5	0.58
Coleoptera	♂	0	0	0	0.25	0.16	1	2	1.91	2.25
	♀	0	0	0	0.25	0.16	0.83	1.66	1.58	1.66
Lepidoptera	♂	0	0	0	0.5	0	0	0	0	0
	♀	0	0	0	0.41	0	0	0	0	0

IP - Initial phase of season ip - initial phase of day ♂ -Male flower
MP - Middle phase of season mp - middle phase of day ♀ -Female flower
LP - Late phase of season lp - late phase of day

Figure.203: Frequency of pollinator (Order) visit /day (Initial seasonal phase)

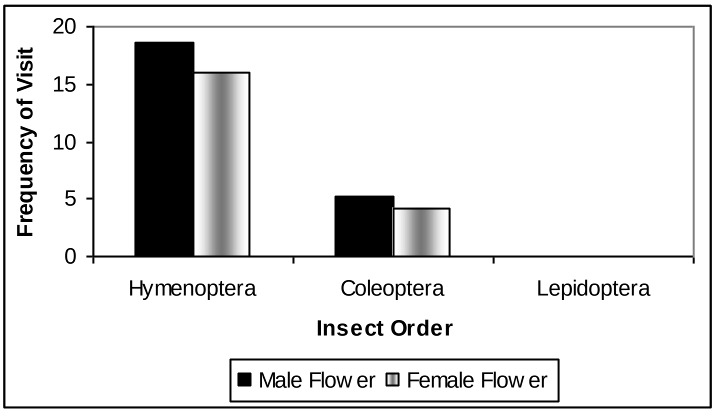


Figure.204: Frequency of pollinator (Order) visit /day (Middle seasonal Phase)

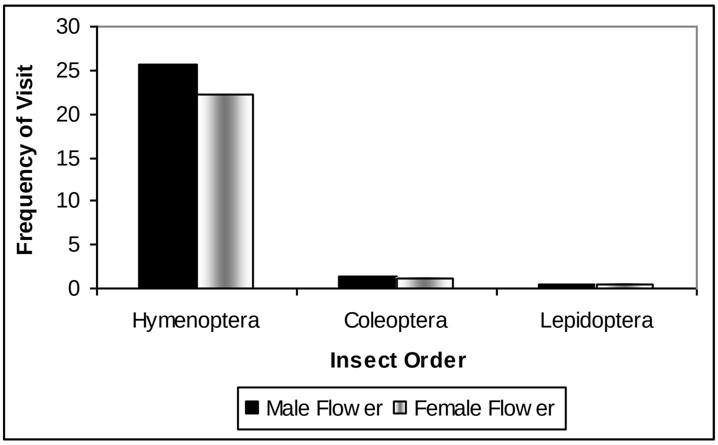


Figure.205: Frequency of pollinator (Order) visit /day (Late seasonal phase)

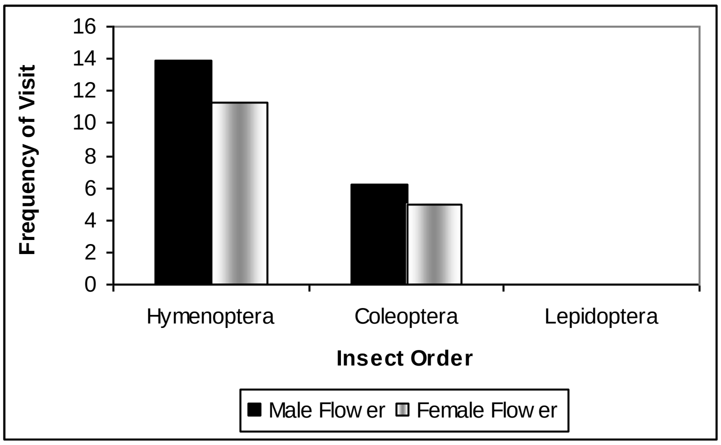


Table.24: Frequency of pollinator (Species) visit /day

Species	Sex of flower	Initial Phase (IP)			Middle Phase (MP)			Late Phase (LP)		
		ip	mp	lp	ip	mp	lp	ip	mp	lp
Trigona	♂	4.25	8.41	0.91	5.33	10.33	2.83	3	6.33	0.5
iridipennis	♀	3.58	7.75	0.58	4.41	9.5	2	2.16	5.91	0.25
Halictus	♂	0.58	0.66	0.41	0.66	0.75	0.58	0.5	0.58	0.25
timidus	♀	0.5	0.58	0.33	0.5	0.75	0.5	0.41	0.5	0.08
Halictus	♂	0.16	0.41	0.16	0.16	0.41	0.16	0.16	0.33	0.16
taprobanae	♀	0.16	0.25	0.08	0.16	0.33	0.16	0.16	0.25	0.08
Ceratina	♂	0.41	0.5	0.25	0.5	0.66	0.25	0.33	0.5	0.16
heiroglyphica	♀	0.33	0.41	0.25	0.41	0.5	0.25	0.25	0.41	0.08
Apis	♂	0.5	0.58	0.41	0.58	0.66	0.41	0.41	0.58	0.25
cerana	♀	0.41	0.5	0.33	0.5	0.58	0.41	0.33	0.41	0.08
Amegilla	♂	0	0	0	0.33	0.41	0	0	0	0
parhypate	♀	0	0	0	0.33	0.33	0	0	0	0
Braunsapis	♂	0	0	0	0	0.16	0	0	0	0
picitarsis	♀	0	0	0	0	0.17	0	0	0	0
Apis	♂	0	0	0	0	0.08	0	0	0	0
florea	♀	0	0	0	0	0.08	0	0	0	0
Ceratina	♂	0	0	0	0	0.08	0	0	0	0
Smaragdula	♀	0	0	0	0	0.08	0	0	0	0
Apis	♂	0	0	0	0	0.08	0	0	0	0
dorsata	♀	0	0	0	0	0.08	0	0	0	0
Xylocopa	♂	0	0	0	0	0.08	0	0	0	0
aestuans	♀	0	0	0	0	0.08	0	0	0	0
Xylocopa	♂	0	0	0	0	0.08	0	0	0	0
tenuiscapa	♀	0	0	0	0	0.08	0	0	0	0
Aulacophora	♂	0.91	0.83	1	0.166	0.08	0.66	1.08	1.08	1.16
foveicollis	♀	0.75	0.66	0.75	0.16	0.08	0.5	0.83	0.83	0.83
Aulacophora	♂	0.83	0.75	0.91	0.08	0.08	0.33	0.91	0.83	1.08
lewisii	♀	0.75	0.58	0.75	0.08	0.08	0.33	0.83	0.75	0.83
Cephonodes	♂	0	0	0	0.25	0	0	0	0	0
picus	♀	0	0	0	0.16	0	0	0	0	0
Macroglossum	♂	0	0	0	0.25	0	0	0	0	0
troglodytus	♀	0	0	0	0.25	0	0	0	0	0

IP - Initial phase of season   ip - initial phase of day   ♂ -Male flower
MP - Middle phase of season   mp - middle phase of day   ♀ -Female flower
LP - Late phase of season   lp - late phase of day

Figure.206: Frequency of pollinator (Species) visit /day (Initial seasonal phase)

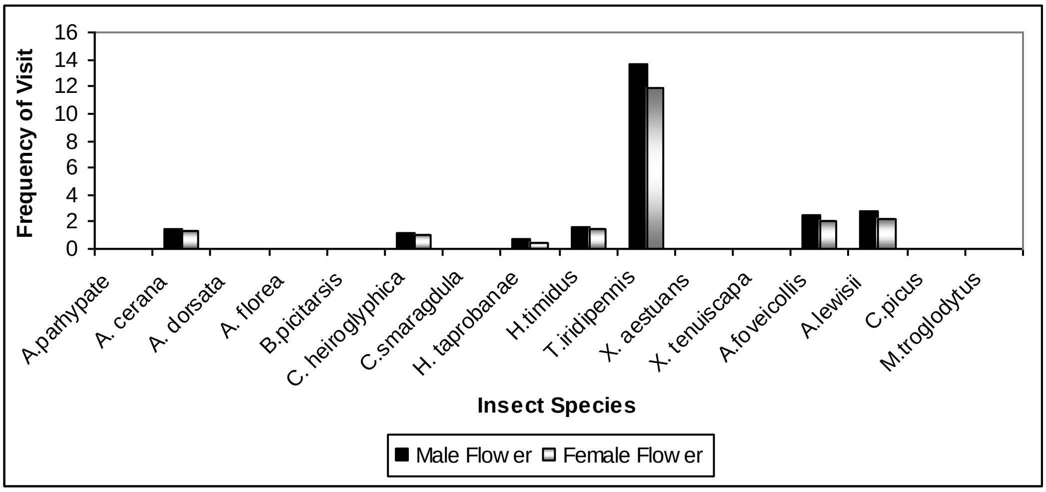


Figure.207: Frequency of pollinator (Species) visit /day (Middle seasonal phase)

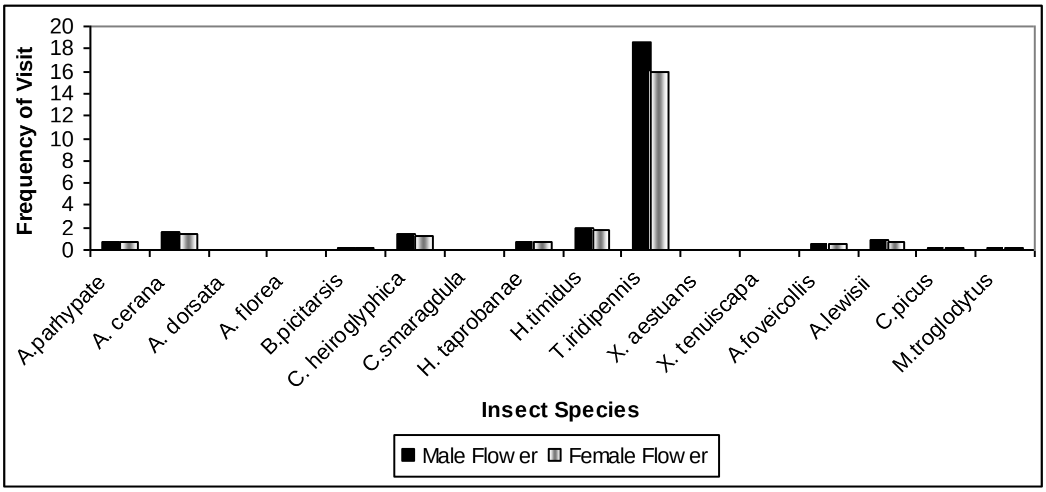
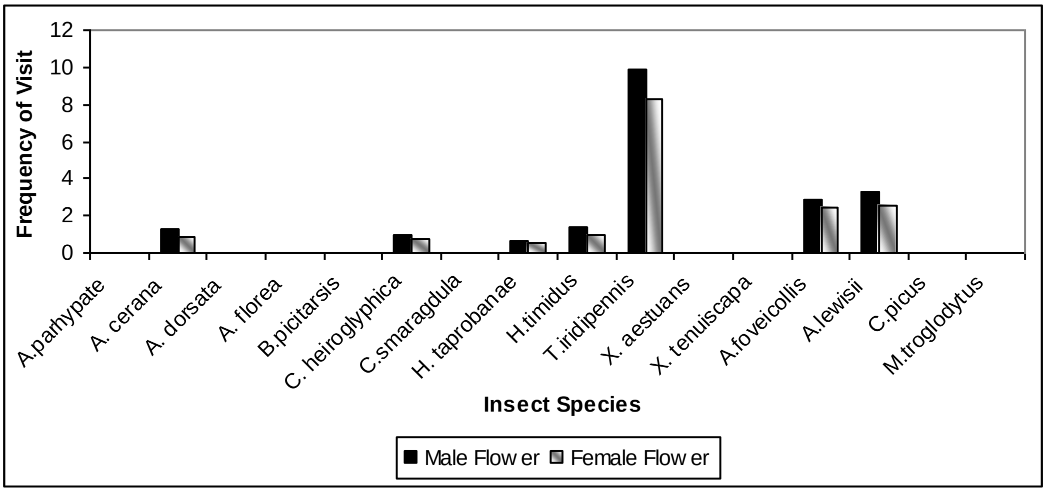


Figure.208: Frequency of pollinator (Species) visit /day (Late seasonal phase)



4.4.2.2.2. Mean Number of Flowers Visited by Pollinators

Mean number of male (♂) and female (♀) flowers visited was recorded during different phases of the day. It increased from initial phase of the season (IP) to middle phase of the season, (MP) and decreased to late of the season (LP). There was significant difference in the way these components changed in number over the day and season. Hymenopterans visited a mean of 32.75 male (♂) flowers and 27.75 female (♀) flowers and coleopterans visited 13.58 male (♂) flowers and 10.16 female (♀) flowers/day in the initial phase (IP) of the season. In middle phase (MP) a mean of 50.16 male (♂) flowers and 43.66 female (♀) flowers were visited by hymenopterans, 3.66 male (♂) flowers and 2.91 female (♀) flowers by coleopterans and 0.58 male (♂) flowers and 0.41 female (♀) flowers by lepidopterans /day. In late phase (LP) of the season it was a mean of 21.58 male (♂) flowers and 17.16 female (♀) flowers by hymenopterans and 12.75 male (♂) flowers and 9.58 female (♀) flowers by coleopterans /day. Variation in number of flowers visited in different diurnal phases in each phase of the season was also observed. Maximum number of flowers were visited in the middle diurnal phase of middle seasonal phase and minimum number of flowers were visited in the late diurnal phase of late seasonal phase. Mean number of flowers visited by different orders varied significantly [IP (p=0.00) (Figure 209); MP (p=0.00) (Figure 210) and LP (p=0.00) (Figure 211)] (Table 25). Hymenopterans visited highest number of flowers. The mean number of flowers visited by different species of pollinators also varied significantly [IP (p= 0.00) (Figure 212); MP (p=0.00) (Figure 213); LP (p=0.00) (Figure 214)] (Table 26) of season. In the mean number of male (♂) and female (♀) flowers visited by different foragers no significant difference was found [IP (p=0.35); MP (p=0.83); LP (p=0.24). There was also significant difference in the mean number of flowers visited by pollinators in different diurnal phases in each seasonal phase, IP (p=0.00); MP (p=0.00); LP (p=0.00) and between different phases of the season (p=0.00).

Table.25: Mean number of flowers visited by pollinators (Order) /day

Order	Sex of flower	Initial Phase (IP)			Middle Phase (MP)			Late Phase (LP)		
		ip	mp	lp	ip	mp	lp	ip	mp	lp
Hymenoptera	♂	11	15.75	6	16.25	23.58	10.33	7.66	11.91	2
	♀	9.91	14	3.83	14.25	21	8.41	6.25	9.83	1.08
Coleoptera	♂	4.41	6.08	3.08	1.08	1.5	1.08	4.25	5.5	3
	♀	3.91	3.91	2.33	0.91	1.08	0.91	3.41	3.83	2.33
Lepidoptera	♂	0	0	0	0.58	0	0	0	0	0
	♀	0	0	0	0.41	0	0	0	0	0

IP - Initial phase of season　　ip - initial phase of day　　♂ -Male flower
MP - Middle phase of season　　mp - middle phase of day　　♀ -Female flower
LP - Late phase of season　　lp - late phase of day

Figure.209: Mean number of flowers visited by pollinators (Order) /day (Initial seasonal phase)

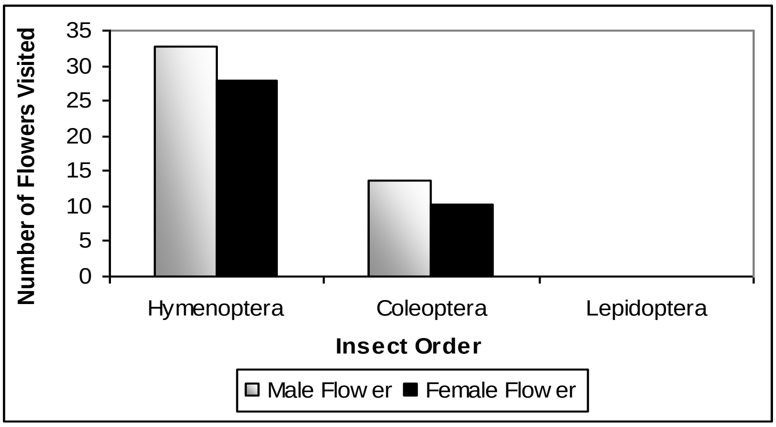


Figure.210: Mean number of flowers visited by pollinators (Order) /day (Middle seasonal phase)

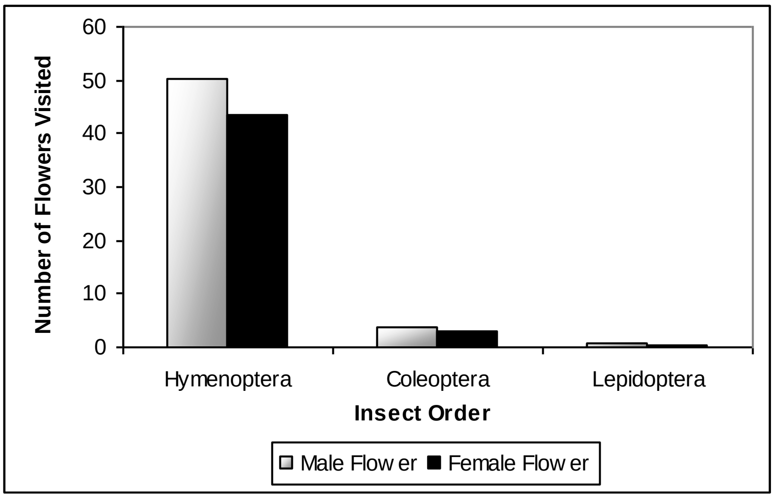


Figure.211: Mean number of flowers visited by pollinators (Order) /day (Late seasonal phase)

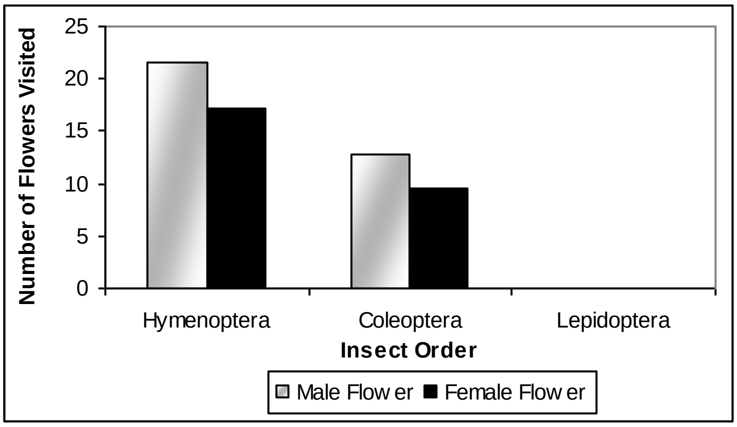


Table.26: Mean number of flowers visited by pollinators (Species) /day

Species	Sex of flower	Initial Phase (IP)			Middle Phase (MP)			Late Phase (LP)		
		ip	mp	lp	ip	mp	lp	ip	mp	Lp
Trigona iridipennis	♂	5.5	7.75	2	0.66	2.66	0.58	4.16	6.16	0.66
	♀	5.08	7.5	1.16	0.58	1.91	0.41	3.75	5.66	0.33
Halictus timidus	♂	2.16	2.75	1.25	2.41	3.33	1.83	1.66	2	0.41
	♀	1.91	2.5	1.08	2.08	3	1.41	1.66	1.5	0.25
Halictus taprobanae	♂	0.33	1.08	0.33	6.91	8.83	5.5	0.33	0.91	0.16
	♀	0.33	0.75	0.16	6.5	8.58	4.83	0.25	0.41	0.16
Ceratina heiroglyphica	♂	1.5	1.66	0.91	2.16	2.83	0.91	0.75	1.08	0.33
	♀	1.08	1.17	0.58	1.75	2.41	0.58	0.5	1.08	0.16
Apis cerana	♂	1.5	2.5	1.5	2.41	3	1.5	0.75	1.75	0.41
	♀	1.5	2.08	0.83	2.08	3	1.16	0.58	1.16	0.16
Amegilla parhypate	♂	0	0	0	1.66	2	0	0	0	0
	♀	0	0	0	1.25	1.25	0	0	0	0
Braunsapis picitarsis	♂	0	0	0	0	0.25	0	0	0	0
	♀	0	0	0	0	0.25	0	0	0	0
Apis florea	♂	0	0	0	0	0.16	0	0	0	0
	♀	0	0	0	0	0.16	0	0	0	0
Ceratina smaragdula	♂	0	0	0	0	0.16	0	0	0	0
	♀	0	0	0	0	0.08	0	0	0	0
Apis dorsata	♂	0	0	0	0	0.16	0	0	0	0
	♀	0	0	0	0	0.16	0	0	0	0
Xylocopa aestuans	♂	0	0	0	0	0.08	0	0	0	0
	♀	0	0	0	0	0.08	0	0	0	0
Xylocopa tenuiscapa	♂	0	0	0	0	0.08	0	0	0	0
	♀	0	0	0	0	0.08	0	0	0	0
Aulacophora foveicollis	♂	2.25	3.41	1.66	0.66	0.75	0.66	2.16	3	1.58
	♀	2.25	2.25	1.16	0.58	0.58	0.58	1.83	2.16	1.16
Aulacophora lewisii	♂	2.16	2.66	1.41	0.41	0.75	0.41	2.08	2.5	1.41
	♀	1.66	1.66	1.16	0.33	0.5	0.33	1.58	1.66	1.16
Cephonodes picus	♂	0	0	0	0.33	0	0	0	0	0
	♀	0	0	0	0.16	0	0	0	0	0
Macroglossum troglodytus	♂	0	0	0	0.25	0	0	0	0	0
	♀	0	0	0	0.25	0	0	0	0	0

IP - Initial phase of season; ip - initial phase of day; ♂ -Male flower
MP - Middle phase of season; mp - middle phase of day; ♀ -Female flower
LP - Late phase of season; lp - late phase of day

Figure.212: Mean number of flowers visited by pollinators (Species) /day (Initial seasonal phase)

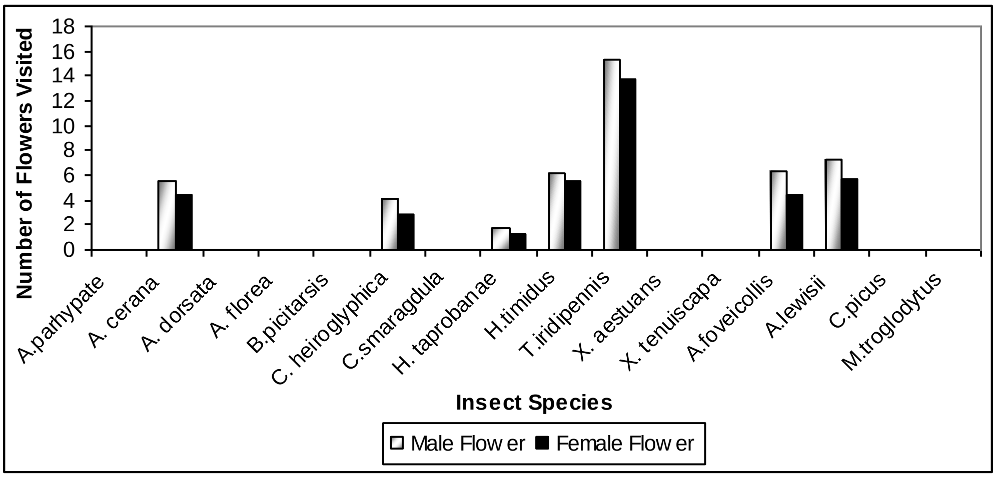


Figure.213: Mean number of flowers visited by pollinators (Species) /day (Middle seasonal phase)

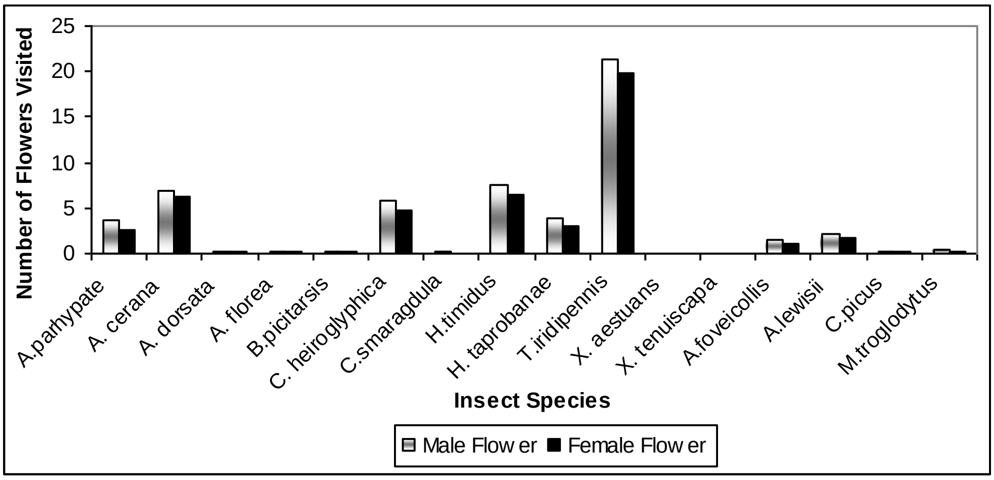
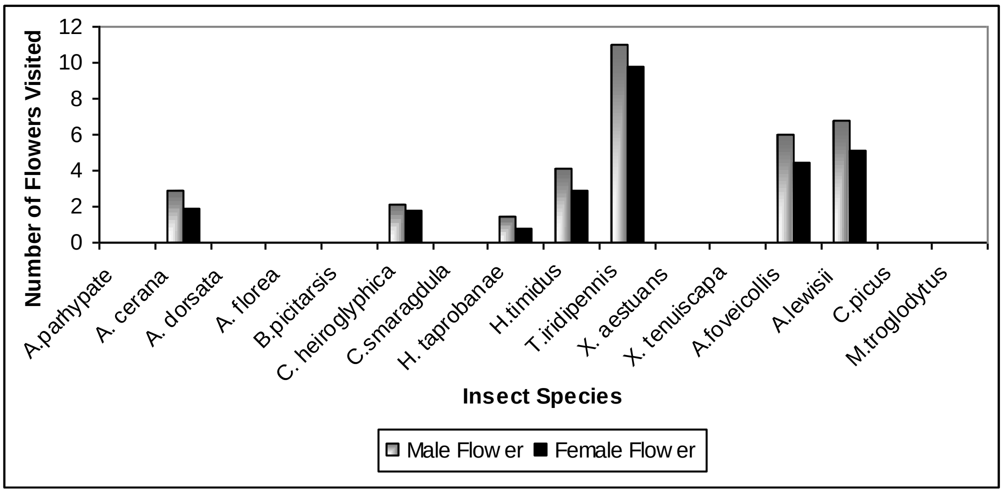


Figure.214: Mean number of flowers visited pollinators (Species) /day (Late seasonal phase)



4.4.2.2.3. Mean Duration of Pollinator Visit

Duration of visit on each flower was also recorded in seconds (sec.) to provide data on the average time spent on male (♂) and female (♀) flowers by different insects. It was observed that mean duration of pollinator visit increased from initial phase, IP to middle phase MP and decreased to late phase LP of the season. But the mean duration of visit decreased from initial to late in diurnal phases of each seasonal phase The pollinators took longest duration in initial diurnal phase of middle seasonal phase and shortest duration in late diurnal phase of late seasonal phase. Mean duration of visit taken by hymenopterans was 36.25 sec. on male (♂) flowers and 29.75 sec. on female (♀) flowers and by coleopterans was 11.08 sec. on male (♂) flowers and 8.25 sec. on female (♀) flowers /day in the initial phase (IP) of the season. In middle phase (MP) 48.91 sec. on male (♂) flowers and 41.16 sec. on female (♀) flowers were taken by hymenopterans, 4.08 sec. on male (♂) flowers and 3.08 sec. on female (♀) flowers by coleopterans and 0.83 sec. on male (♂) flowers and 0.66 sec. on female (♀) flowers by lepidopterans /day. In late phase (LP) of the season it was 25 sec. on male (♂) flowers and 18.08 sec. on female (♀) flowers by hymenopterans and 10.25 sec. on male (♂) flowers and 7.08 sec. on female (♀) flowers by coleopterans /day. Variation in mean duration of visit taken by different orders in different diurnal phases in each phase of the season was also observed. The mean duration taken by different orders [IP (p=0.00) (Figure 215); MP (p=0.00) (Figure 216); LP (p=0.00) (Figure 217)] (Table 27) of pollinators in all phases of season varied significantly. Variation in duration taken by different species of insects belonging to Hymenoptera, Coleoptera and Lepidoptera was observed. The mean duration taken by different species of pollinators in all phases of season also varied significantly [IP (p=0.00) (Figure 218); MP (p=0.00) (Figure 219); LP (p=0.00) (Figure 220)] (Table 28). But there was no significant difference in mean duration of visit to male (♂) and female (♀) flowers IP (p=0.59); MP (p=0.71); LP (p=0.06). The duration of visit during diurnal phases of each season varied significantly [IP (p=0.00); MP (p=0.00); LP (p=0.00)]. Significant difference in mean duration of visit was also found between different seasonal phases (p=0.00).

Table.27: Mean duration of pollinator (Order) visit in seconds

Order	Sex of flower	Initial Phase (IP)			Middle Phase (MP)			Late Phase (LP)		
		ip	mp	lp	ip	mp	lp	ip	mp	lp
Hymenoptera	♂	16.41	13.33	6.5	20.33	17.66	10.91	11.4	9.33	4.25
	♀	14.83	11.33	3.58	18.08	14.41	8.66	9.41	7.08	1.58
Coleoptera	♂	5	3.41	2.66	1.91	1.08	1.08	4.66	3.25	2.33
	♀	4.66	2	1.58	1.25	0.91	0.91	3.58	2	1.5
Lepidoptera	♂	0	0	0	0.83	0	0	0	0	0
	♀	0	0	0	0.66	0	0	0	0	0

IP - Initial phase of season
MP - Middle phase of season
LP - Late phase of season

ip - initial phase of day
mp - middle phase of day
lp - late phase of day

♂ -Male flower
♀ -Female flower

Figure.215: Mean duration of visit on flowers by pollinators (Order) in seconds (Initial seasonal phase)

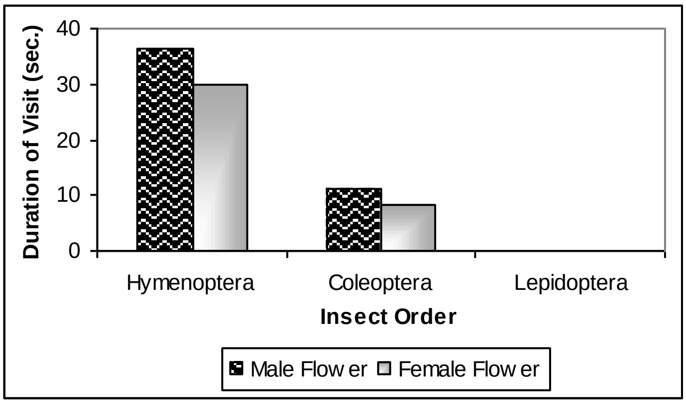


Figure.216: Mean duration of visit on flowers by pollinators (Order) in seconds (Middle seasonal phase)

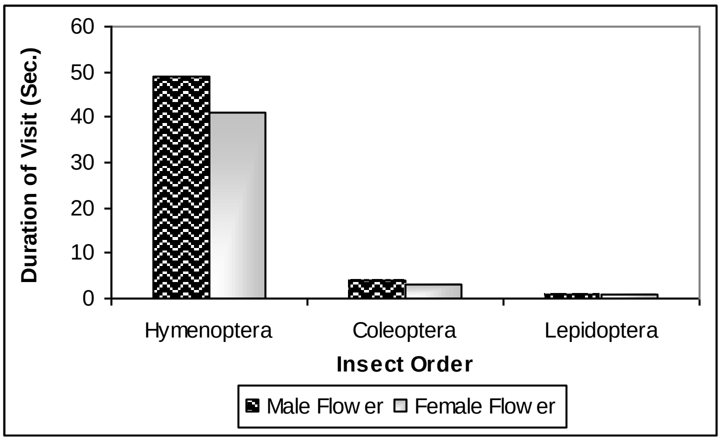


Figure.217: Mean duration of visit on flowers by pollinators (Order) in seconds (Late seasonal phase)

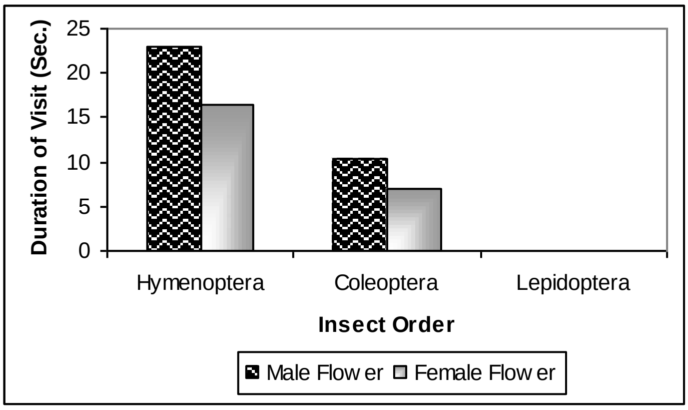


Table.28: Mean duration of pollinator (Species) visit in seconds

Species	Sex of flower	Initial Phase (IP)			Middle Phase (MP)			Late Phase (LP)		
		ip	mp	lp	ip	mp	lp	ip	mp	lp
Trigona iridipennis	♂	8.5	7.33	2.83	3.08	2.25	1.75	6.5	5.25	2.83
	♀	7.66	6.5	1.16	2.91	1.91	1.16	5.5	4.08	1.08
Halictus timidus	♂	2.75	2.16	1.41	3.08	2.25	1.75	2.33	1.58	0.5
	♀	2.58	1.75	1.17	2.91	1.91	1.17	2	1.16	0.16
Halictus taprobanae	♂	0.75	0.75	0.41	0.83	0.75	0.41	0.5	0.5	0.16
	♀	0.58	0.5	0.08	0.58	0.5	0.41	0.33	0.33	0.08
Ceratina heiroglyphica	♂	2.16	1	0.91	2.16	2	0.91	1.08	1	0.25
	♀	1.83	0.75	0.66	2.08	1.25	0.75	0.75	0.75	0.08
Apis cerana	♂	2.25	2.08	0.91	3.08	2.25	0.91	1	1	0.5
	♀	2.16	1.83	0.5	2.91	1.83	0.5	0.83	0.75	0.16
Amegilla parhypate	♂	0	0	0	0.66	0.41	0	0	0	0
	♀	0	0	0	0.41	0.33	0	0	0	0
Braunsapis picitarsis	♂	0	0	0	0	0.41	0	0	0	0
	♀	0	0	0	0	0.25	0	0	0	0
Apis florea	♂	0	0	0	0	0.16	0	0	0	0
	♀	0	0	0	0	0.16	0	0	0	0
Ceratina smaragdula	♂	0	0	0	0	0.33	0	0	0	0
	♀	0	0	0	0	0.25	0	0	0	0
Apis dorsata	♂	0	0	0	0	0.16	0	0	0	0
	♀	0	0	0	0	0.08	0	0	0	0
Xylocopa aestuans	♂	0	0	0	0	0.25	0	0	0	0
	♀	0	0	0	0	0.16	0	0	0	0
Xylocopa tenuiscapa	♂	0	0	0	0	0.16	0	0	0	0
	♀	0	0	0	0	0.16	0	0	0	0
Aulacophora foveicollis	♂	2.08	1.66	1.33	1.25	0.58	0.58	2.08	1.66	1.16
	♀	2.16	1.16	0.75	0.75	0.5	0.5	1.66	1.16	0.75
Aulacophora lewisii	♂	2.91	1.75	1.33	0.66	0.5	0.5	2.58	1.58	1.16
	♀	2.5	0.83	0.83	0.5	0.41	0.41	1.91	0.83	0.75
Cephonodes picus	♂	0	0	0	0.5	0	0	0	0	0
	♀	0	0	0	0.33	0	0	0	0	0
Macroglossum troglodytus	♂	0	0	0	0.33	0	0	0	0	0
	♀	0	0	0	0.33	0	0	0	0	0

IP - Initial phase of season   ip - initial phase of day   ♂ -Male flower
MP - Middle phase of season   mp - middle phase of day   ♀ -Female flower
LP - Late phase of season   lp - late phase of day

Figure.218: Mean duration of visit on flowers by pollinators (Species) in seconds (Initial seasonal phase)

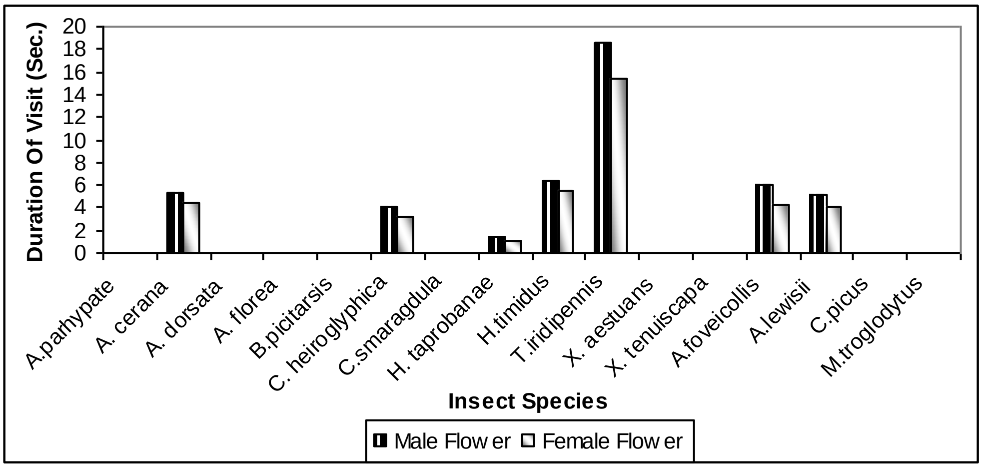


Figure.219: Mean duration of visit on flowers by pollinators (Species) in seconds (Middle seasonal phase)

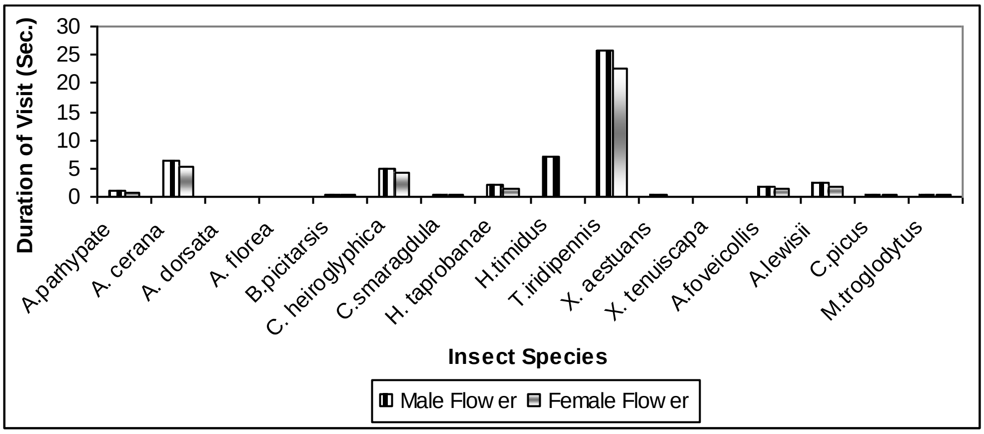
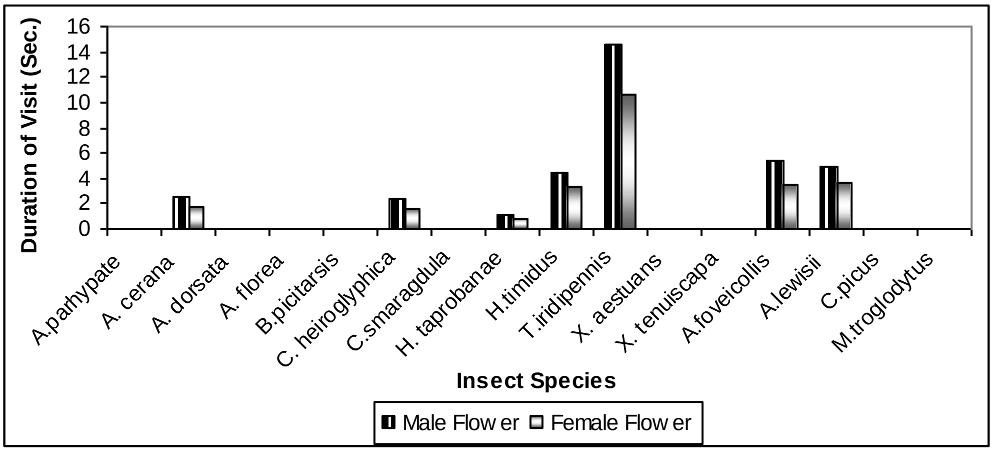


Figure.220: Mean duration of visit on flowers by pollinators (Species) in seconds (Late seasonal phase)



4.4.3. Palynology

4.4.3.1. Pollen Count

The mean number of pollen grains produced by staminate flowers varied by phases of the season. At anthesis staminate flowers contained maximum pollen grains /flower and the number of pollen grains remaining on anthers decreased over time of day IP [ip (13159.75±48.86); mp (10177.5±6.51); lp (4106.5±32.22)]; MP [ip (28511.42±87.31); mp (20614.5±3.61); lp (3655.91±93.85)]; LP [ip (9906.16±16.41); mp (7854.41±5.83); lp (4349.33±24.17)]. The mean number of pollen grains produced was highest in the initial diurnal phase (13159.75±48.86) of middle seasonal phase and lowest in the late diurnal phase (4349.33±24.17) of late seasonal phase. The counts were significantly different in different phases of day such as IP (p=0.00) (Figure 221); MP (p=0.00) (Figure 222); LP (p=0.00) (Figure 223) and between the seasonal phases (p=0.00) (Figure 224).

Figure.221: Mean pollen counts in diurnal phases (Initial seasonal phase)

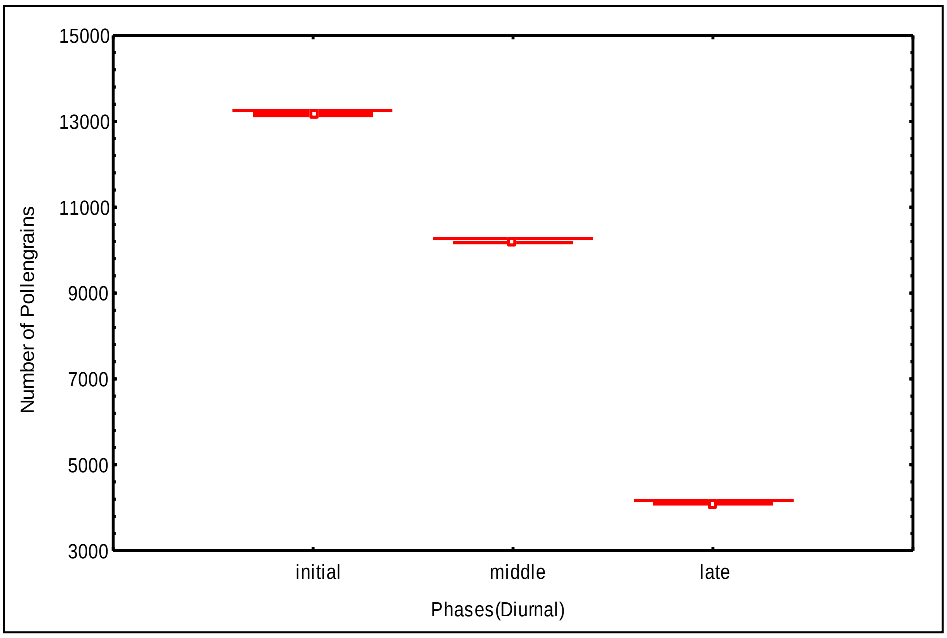


Figure.222: Mean pollen counts in diurnal phases (Middle seasonal phase)

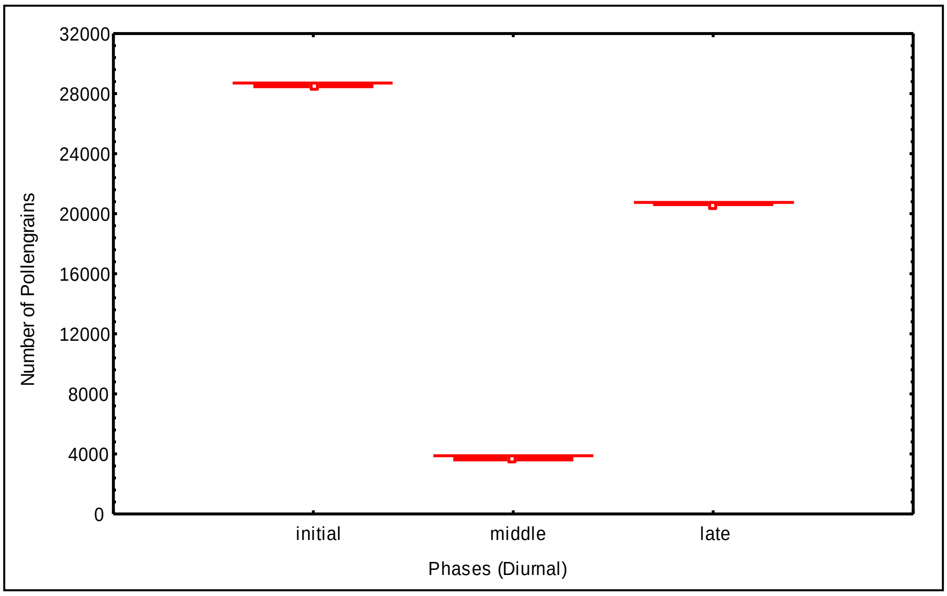


Figure.223: Mean pollen counts in diurnal phases (Late seasonal phase)

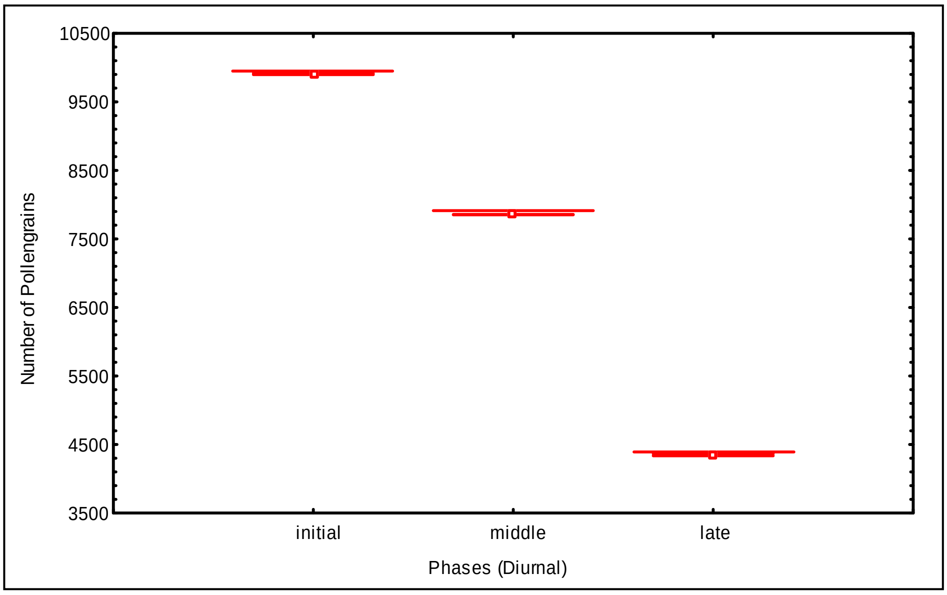
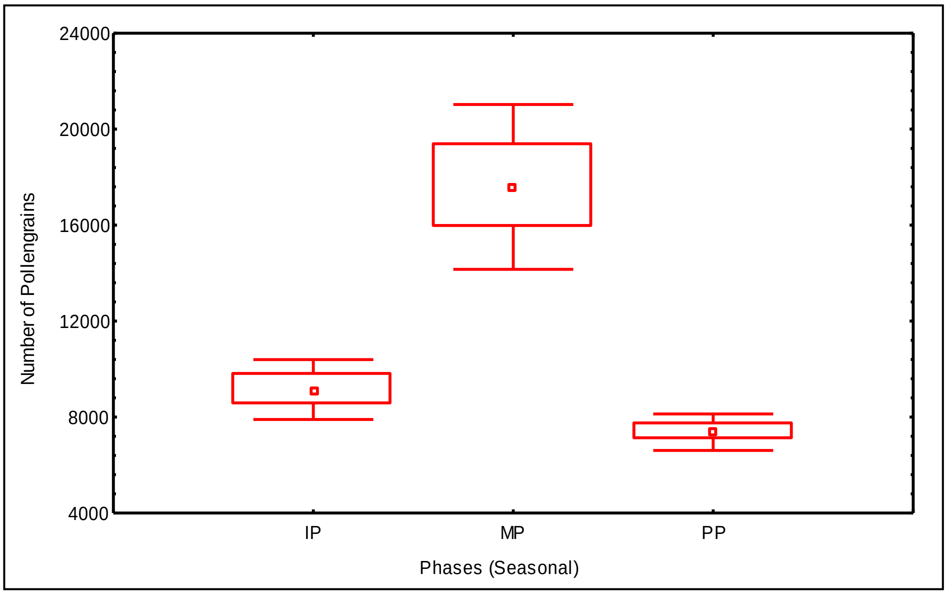


Figure.224: Mean pollen counts in different phases of the season



4.4.3.2. Pollen Removal

The mean number of pollen grains removed from staminate flowers varied by phases of the day and season. Pollen removal increased from IP [ip (2982.25±55.05); mp (6071±25.93); lp (1008.25±7.18)]; to MP [ip (7896.91±90.86); mp (16958.58±90.26); lp (2473.66±24.63)] and then decreased to LP [ip (2051.75±22.14); mp (3505.08±18.37); lp (676.58±10.13)]. In middle diurnal phase of middle seasonal phase maximum number of pollen grains (16958.58±90.26) were removed. In late diurnal phase of late seasonal phase minimum number of pollen grains (676.58±10.13) were removed. The counts were significantly different in different phases of day such as IP (p=0.00) (Figure 225); MP (p=0.00) (Figure 226); LP (p=0.00) (Figure 227) and between the seasonal phases (p=0.00) (Figure 228).

Figure.225: Mean pollen removal in diurnal phases (Initial seasonal phase)

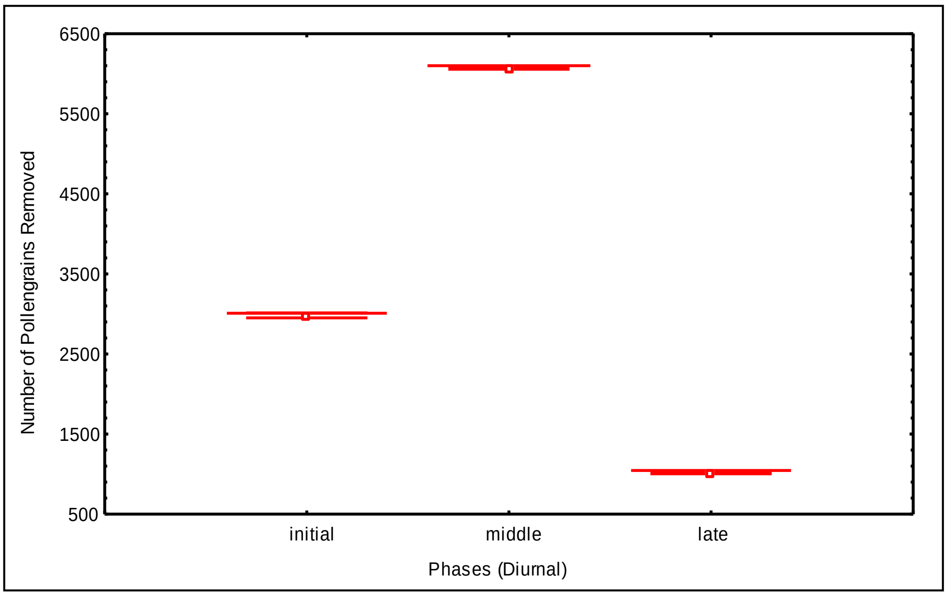


Figure.226: Mean pollen removal in diurnal phases (Middle seasonal phase)

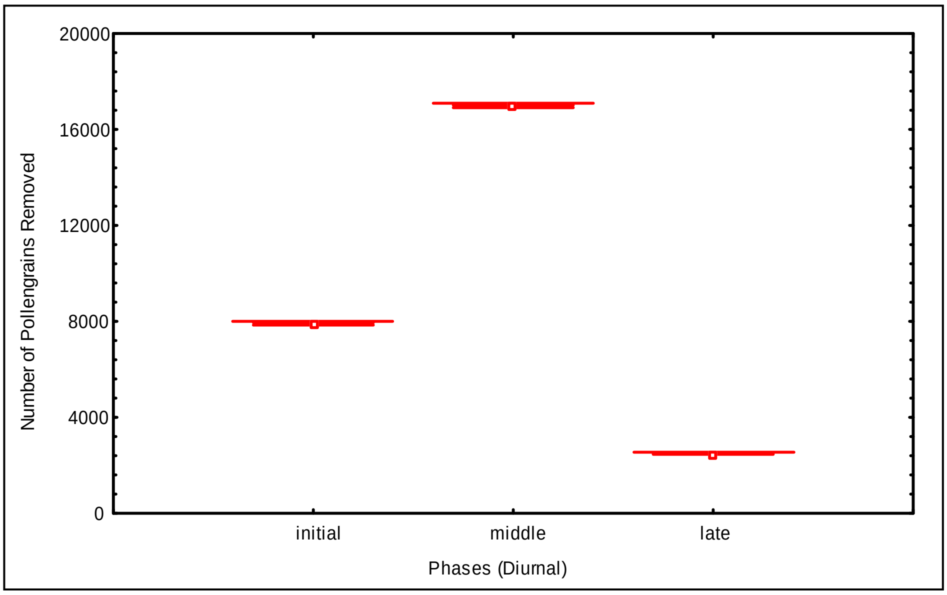


Figure.227: Mean pollen removal in diurnal phases (Late seasonal phase)

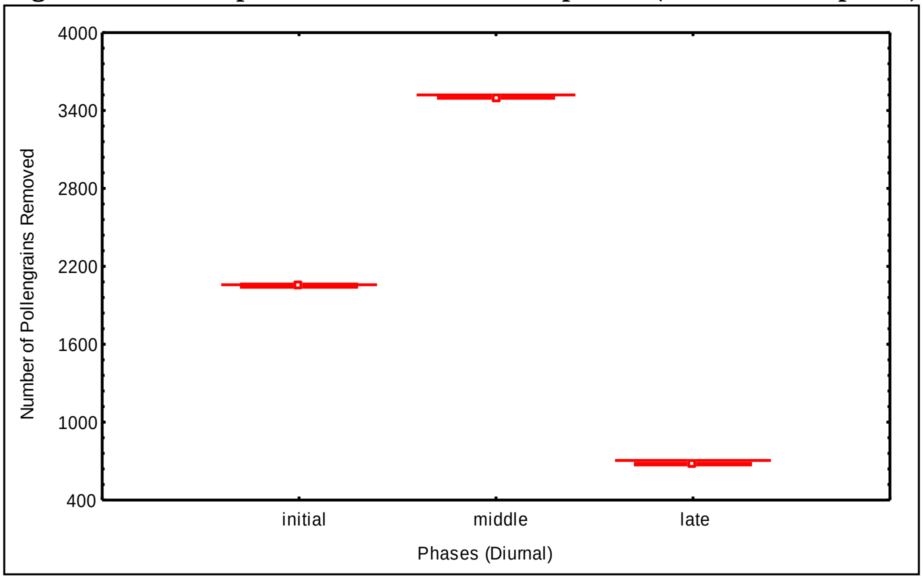
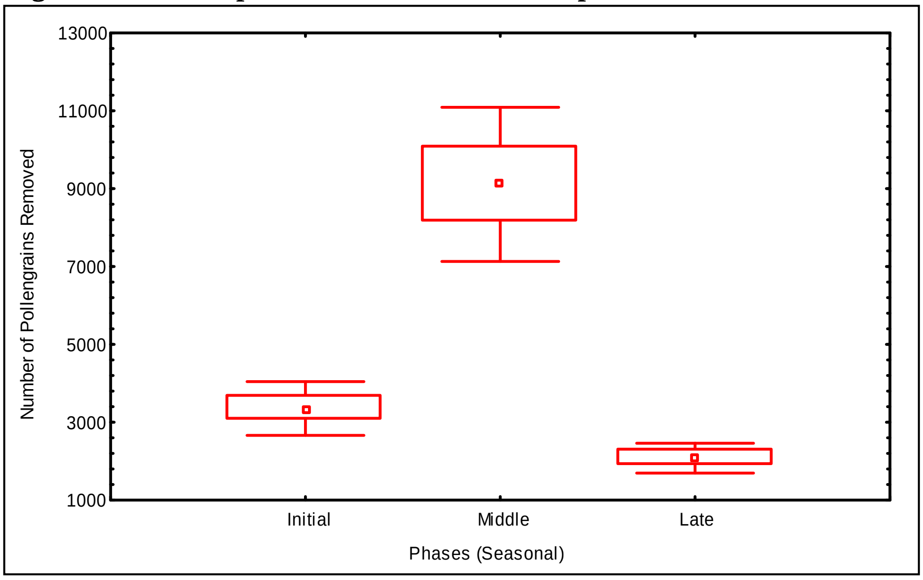


Figure.228: Mean pollen removal in different phases season



4.4.3.3. Pollen Deposition

The mean number of pollen grains deposited on stigma of flowers varied by phases of the day and season. Pollen deposition increased from IP [ip (1350.41±23.61); mp (2922.33±26.91); lp (430.75±13.98)]; to MP [ip (3743.08±26.47); mp (8090.5±37.68); lp (1056.33±31.34)] and then decreased to LP [ip (821.8±11.14); mp (1620.25±7.37); lp (268.75±12.19)].

Maximum pollen grains were deposited in the middle diurnal phase (8090.5±37.68) of middle phase of the season and minimum pollen grains were deposited in the late diurnal phase (268.75±12.19) of late phase of the season. The counts were significantly different in different phases of day such as IP (p=0.00) (Figure 229); MP (p=0.00) (Figure 230); LP (p=0.00) (Figure 231) and between the seasonal phases (p=0.00) (Figure 232).

Figure.229: Mean pollen deposition in diurnal phases (Initial seasonal phase)

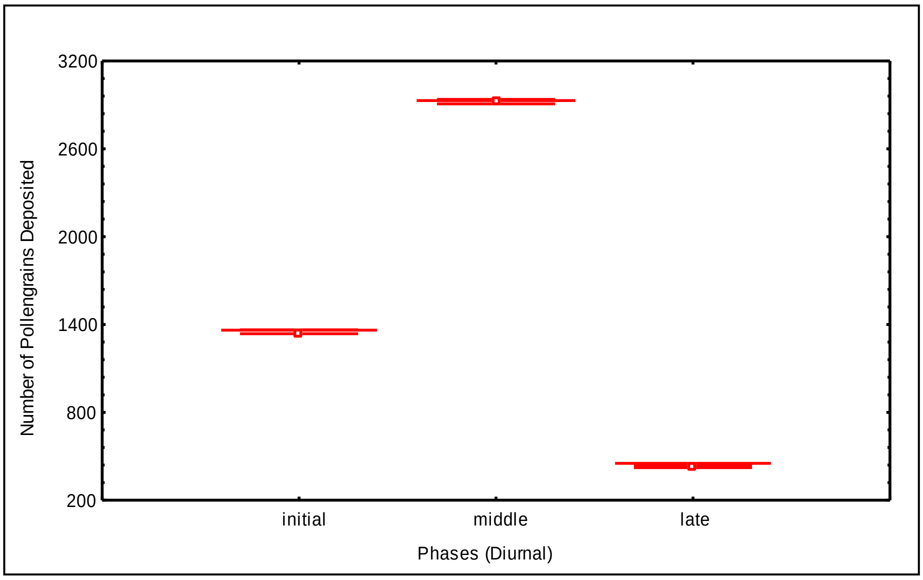


Figure.230: Mean pollen deposition in diurnal phases (Middle seasonal phase)

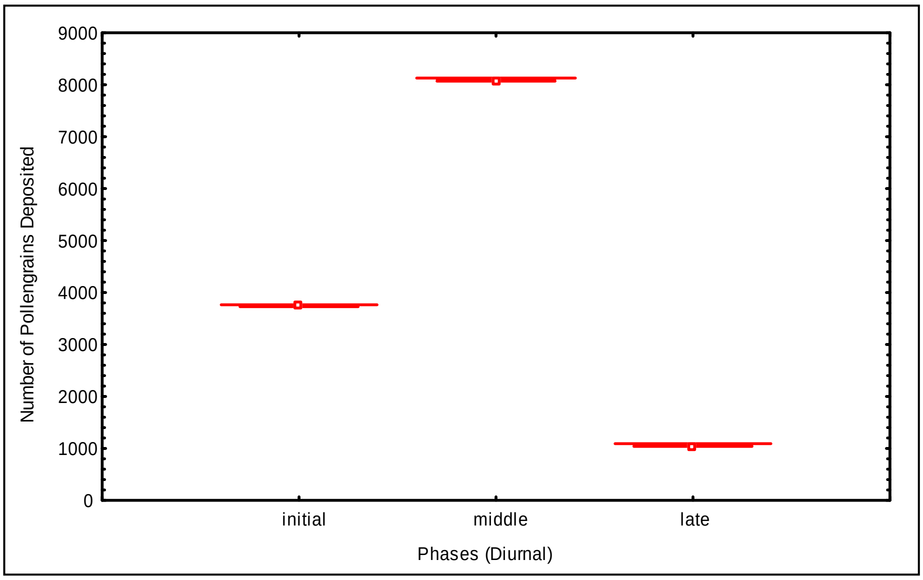


Figure.231: Mean pollen deposition in diurnal phases (Late seasonal phase)

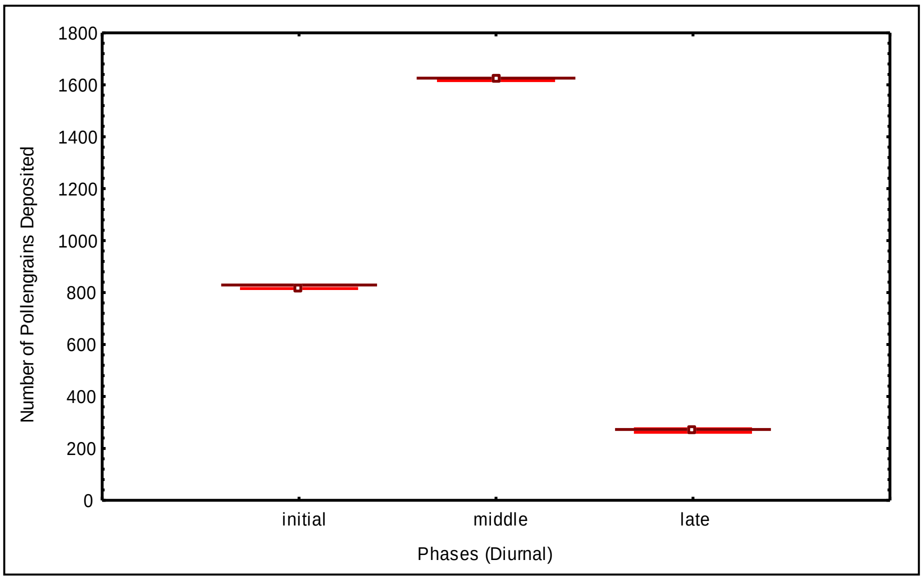
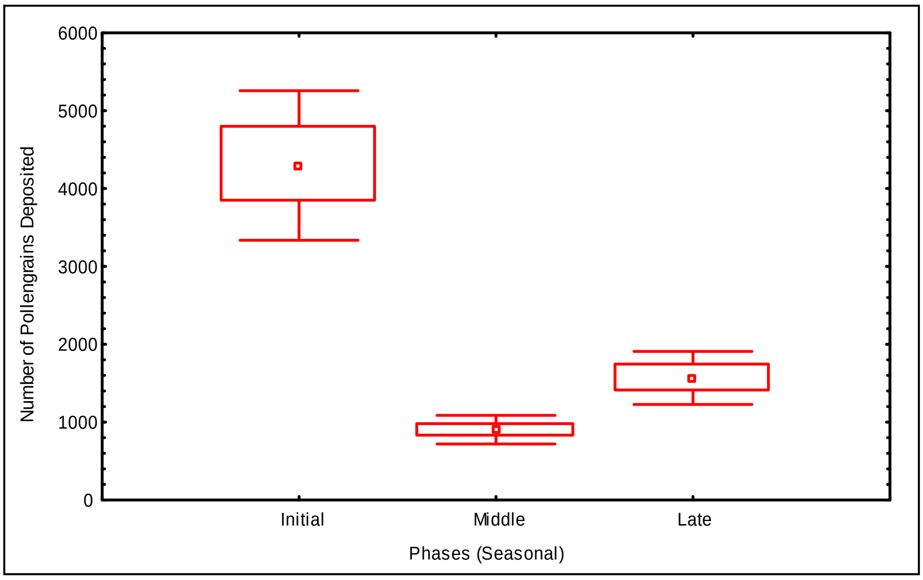


Figure.232: Mean pollen deposition in different phases season



4.4.3.4. Pollen Viability

Viability of pollen grains were also found decreasing through diurnal phases of each season, IP [ip (1736.91±21.55); mp (1587.33±9.93); lp (147±18.50)]; MP [ip (7448.66±33.09); mp (6859.41±29.07); lp (6063.5±29.58)]; LP [ip (1217.75±8.38); mp (1017.08±10.64); lp (924.75±8.90)] and the variations in diurnal phases of each season were significantly different IP (p=0.00) (Figure 233); MP (p=0.00) (Figure 234); LP (p=0.00) (Figure 235). Viability increased from initial phase of the season to middle phase. Most viable pollen grains were found in initial diurnal phase of middle seasonal phase (6859.41±29.07). Least number of viable pollen grains were found in late diurnal phase (924.75±8.90) of late seasonal phase. Significant difference was found in the viability of pollen grains between the seasonal phases also (p=0.00) (Figure 236).

Figure.233: Mean pollen viability in diurnal phases (Initial seasonal phase)

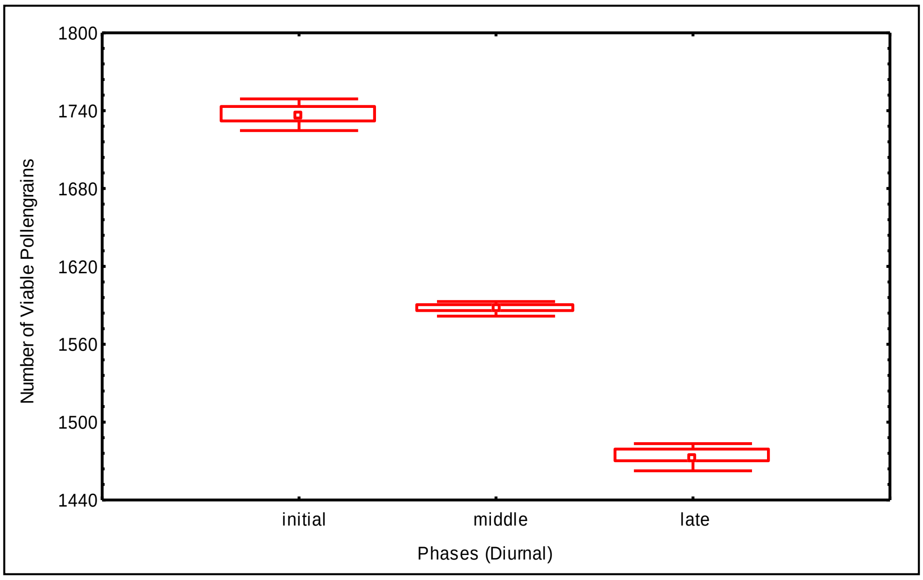


Figure.234: Mean pollen viability in diurnal phases (Middle seasonal phase)

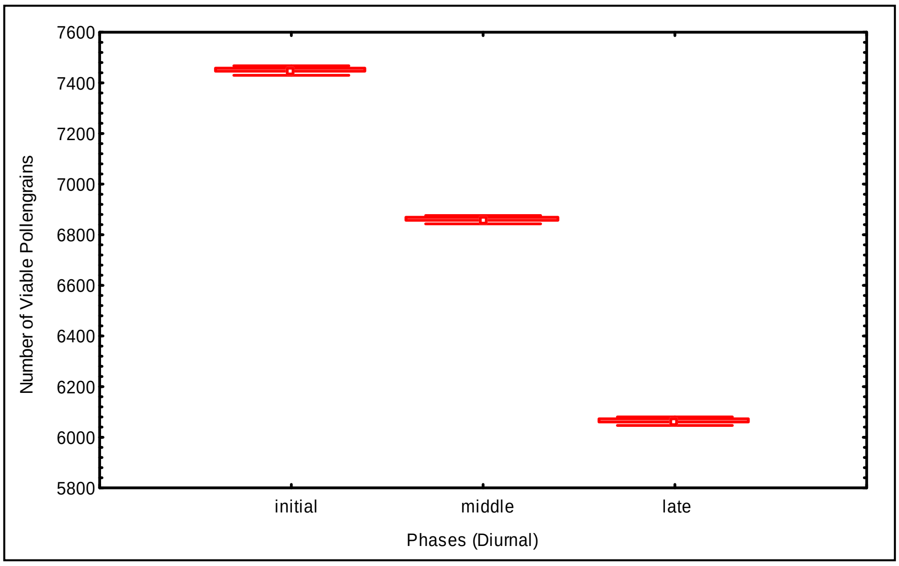


Figure.235: Mean pollen viability in diurnal phases (Late seasonal phase)

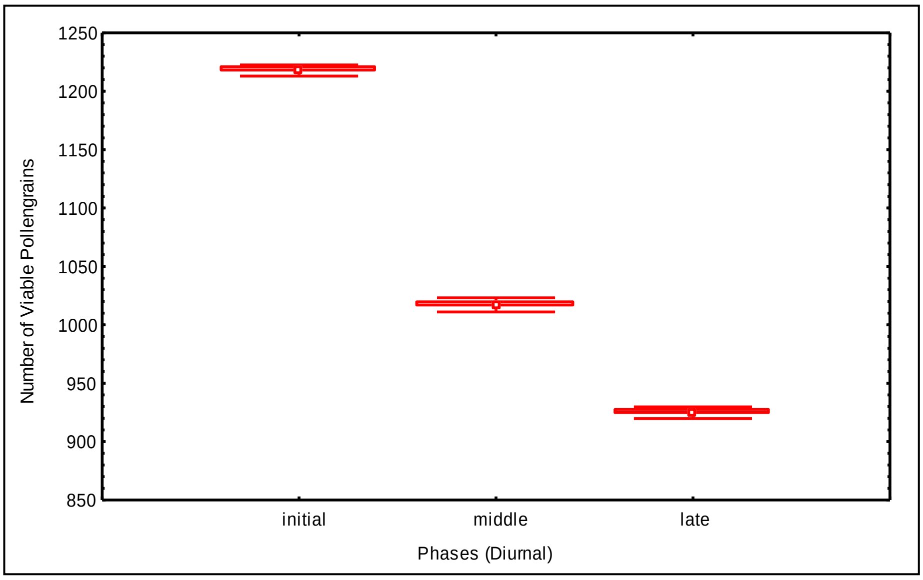
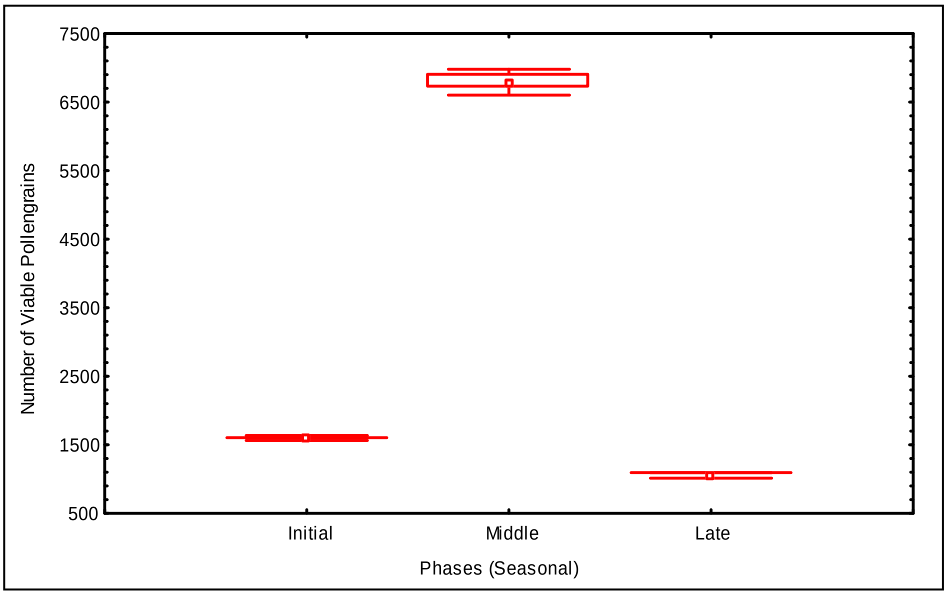


Figure.236: Mean pollen viability in different phases of the season



4.4.4. Pomology

4.4.4.1. Fruit Set

From the bagging experiment it was observed that percentage of fruit set increased from initial phase [IP (34.11%) : (ip)=10.58%; (mp)=16.47%; (lp)=7.05%) to middle phase [MP (40%) : (ip)=12.94%; (mp)=18.82%;

(lp)=8.23%) and then decreased to late phase [LP (25.88%) : (ip)=9.41% (mp)=11.76%; (lp)=4.71%)] of the day and season. All non pollinated flowers were aborted (np=0). Highest fruit set was recorded in middle phase of middle seasonal phase (18.82%). Lowest fruit set was recorded in late seasonal phase (4.71%). Percentage of fruits within each seasonal phase such as IP (Figure 237); MP (Figure 238); LP (Figure 239) and between the seasonal phases were significantly different (Figure 240).

Figure.237: Percentage of fruits in diurnal phases (Initial seasonal phase)

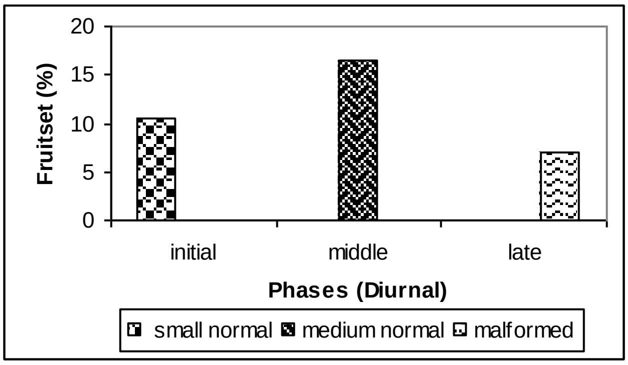


Figure.238: Percentage of fruits in diurnal phases (Middle seasonal phase)

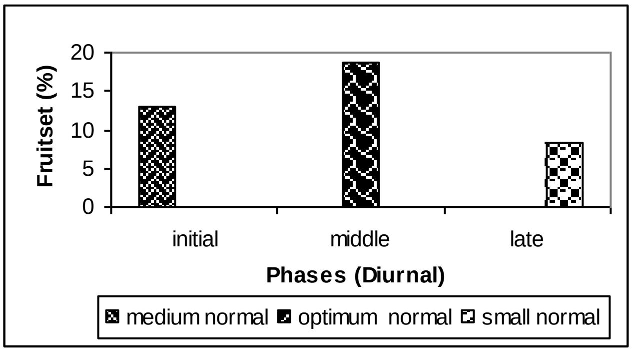


Figure.239: Percentage of fruits in diurnal phases (Late seasonal phase)

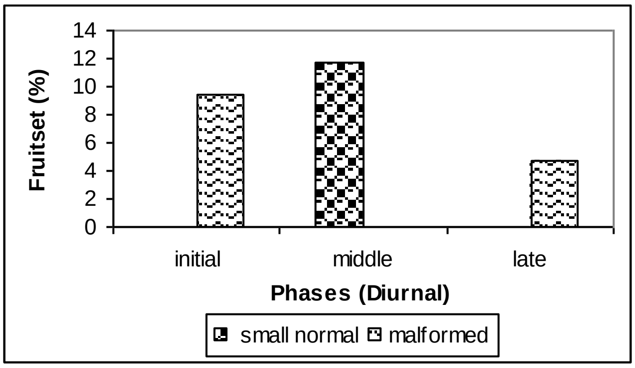
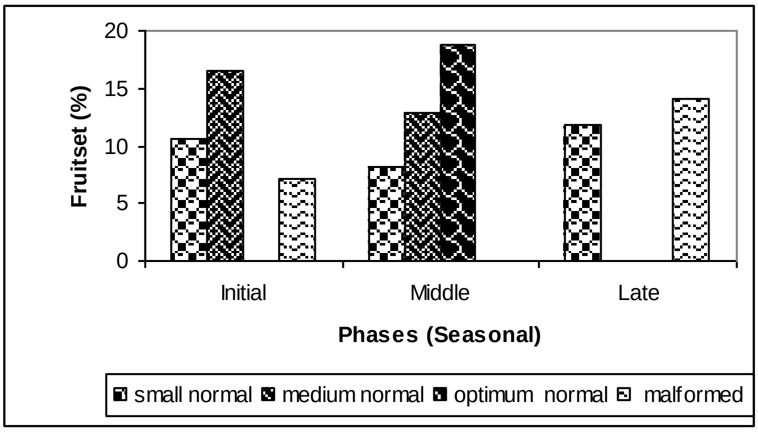


Figure.240: Percentage of fruits in different phases of season



4.4.4.2. Nature of Fruits

Fruits with varied shape and size were produced in the different phases of season. When size was measured in terms of length (l) and breadth (b) it was observed that fruits formed in different diurnal and seasonal phases were differed in the maximum size they attained. By comparing each other fruits with lb ≤ 15 cm. x 12 cm. were included in small sized ones, ≤ 25 cm. x 20 cm. and ≤ 30 cm. x 25 cm. were included in the group of medium and optimum sized ones respectively. Also on the basis of shape the fruits were categorized into normal and malformed ones. So four categories like small normal, medium normal, optimum normal and malformed fruits were found when size and shape were considered together for the assessment of nature of fruits. [IP (ip)=10.58% small normal; (mp)=16.47% medium normal; (lp)=7.05% malformed; MP(ip)=12.94% medium normal; (mp)=18.82% optimum normal; (lp)=8.23% small normal; LP(ip)=9.41% malformed; (mp)=11.76% small normal; (lp)=4.71% malformed] (Plate 10) All non pollinated flowers were aborted in all phases. Majority of fruits formed in the initial and middle phase were normal shaped and in late phase were malformed. Size and shape of the fruits varied significantly within seasonal phases IP (p=0.00) (Figure 237); MP (p=0.00) (Figure 238); LP (p=0.00) (Figure 239) and between the seasonal phases (p=0.00) (Figure 240).

4.4.4.3. Weight of Fruits

Mean weight of fruits increased from initial phase IP [(ip)=301.58±182.15gm; (mp)=951.75±33.44 gm; (lp)=135.33±261.72 gm.] to middle phase MP [(ip)=1171.58±370.77 gm.; (mp)=2905.41±76.31 gm.; (lp)=156.91±138.64 gm.] and then decreased to late phase LP [(ip)=264.91±83.92 gm.; (mp)=550±24.02 gm.; (lp)=49.91±39.66 gm.] of the day and season. As non pollinated flowers were aborted no weights were recorded. In middle diurnal phase of middle seasonal phase the average weight of fruit was highest (2905.41±76.31 gm.). In late diurnal phase of late seasonal phase the average weight of fruit was lowest (49.91±39.66 gm). Weight of fruits within seasonal phases such as IP (p=0.00) (Figure 241); MP (p=0.00) (Figure 242); LP (p=0.00) (Figure 243) and between the seasonal phases were significantly different (p=0.00) (Figure 244).

Figure.241: Mean weight of fruits in diurnal phases (Initial seasonal phase)

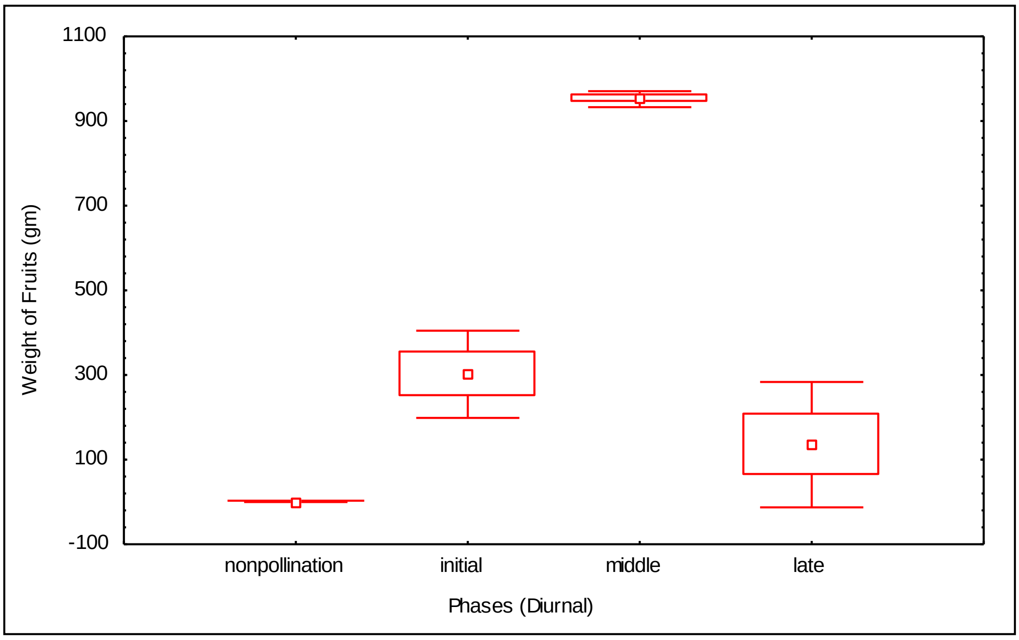


Figure.242: Mean weight of fruits in diurnal phases (Middle seasonal phase)

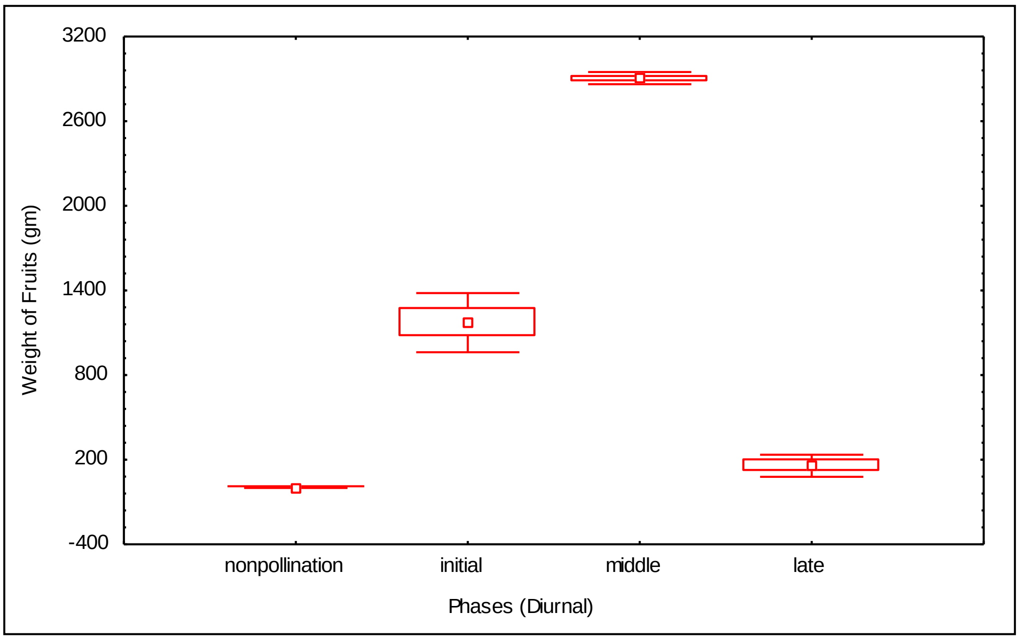


Figure.243: Mean weight of fruits in diurnal phases (Late seasonal phase)

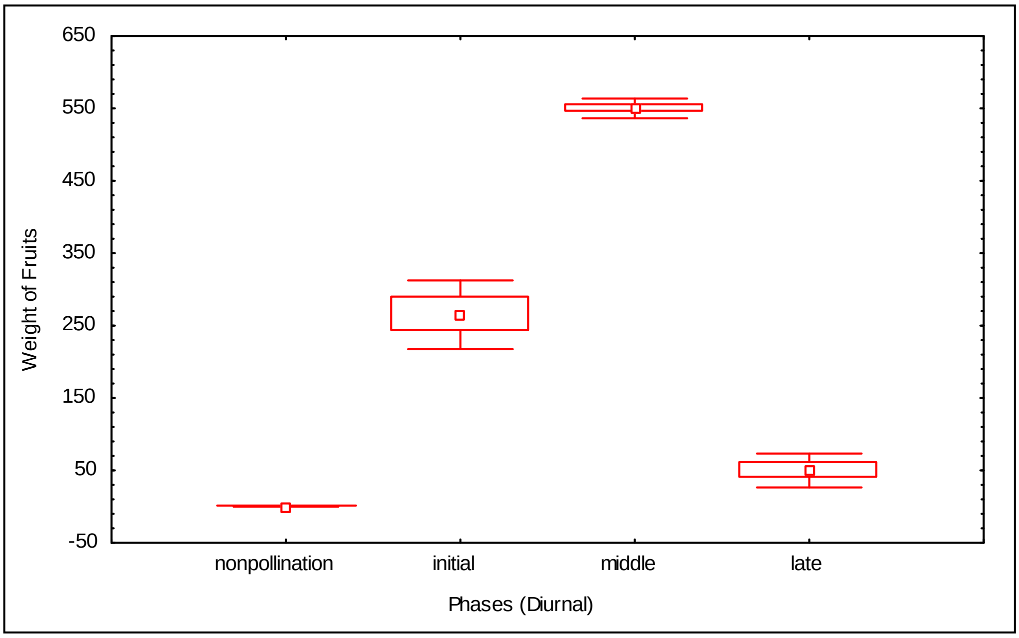
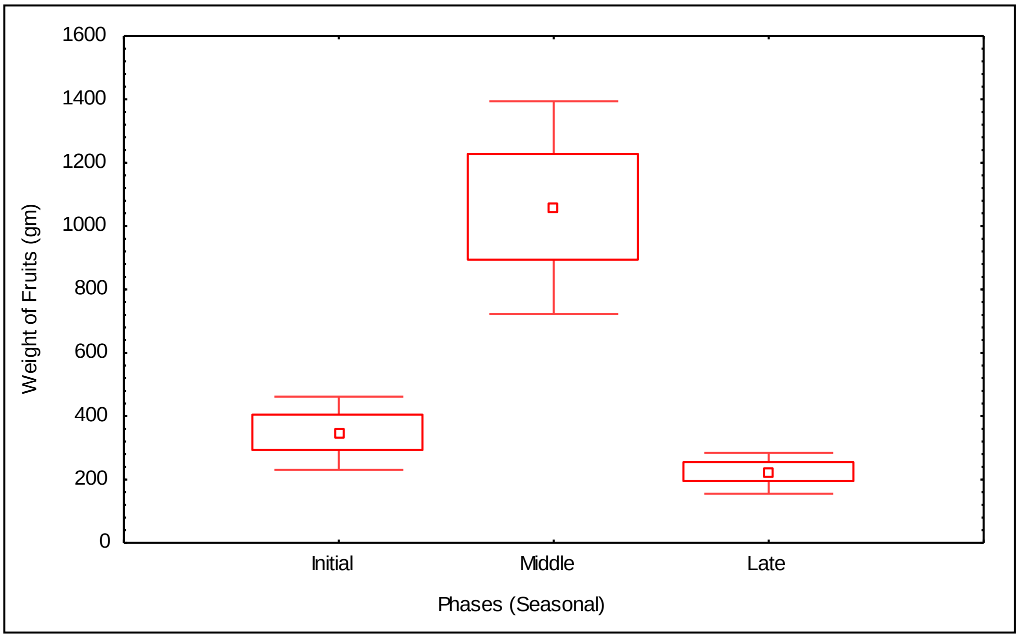


Figure.244: Mean weight of fruits in different phases of season



4.4.4.4. Number of Seeds

Mean number of seeds increased from initial phase [IP (ip=39.83±24.05; mp=127.25±3.74; lp=7.25±7.59)] to middle phase [MP (ip=158.91±50.23; mp=419.25±9.66; lp=21.91±19.47)] and then decreased to late phase [LP (ip=24.5±18.11; mp=59.33±27.84; lp=3.41±5.05)] of the day and season. As non pollinated flowers were aborted no seeds were found. Maximum number of seeds were recorded in middle diurnal phase (419.25±9.66) of middle seasonal phase. In late diurnal phase of late seasonal phase minimum number of seeds (3.41±5.05) were recorded. Mean number of seeds within each seasonal phase such as IP (p=0.00) (Figure.245); MP (p=0.00) (Figure 246); LP (p=0.00) (Figure 247) and between the seasonal phases were significantly different (p=0.00) (Figure 248).

Figure.245: Mean number of seeds in diurnal phases (Initial seasonal phase)

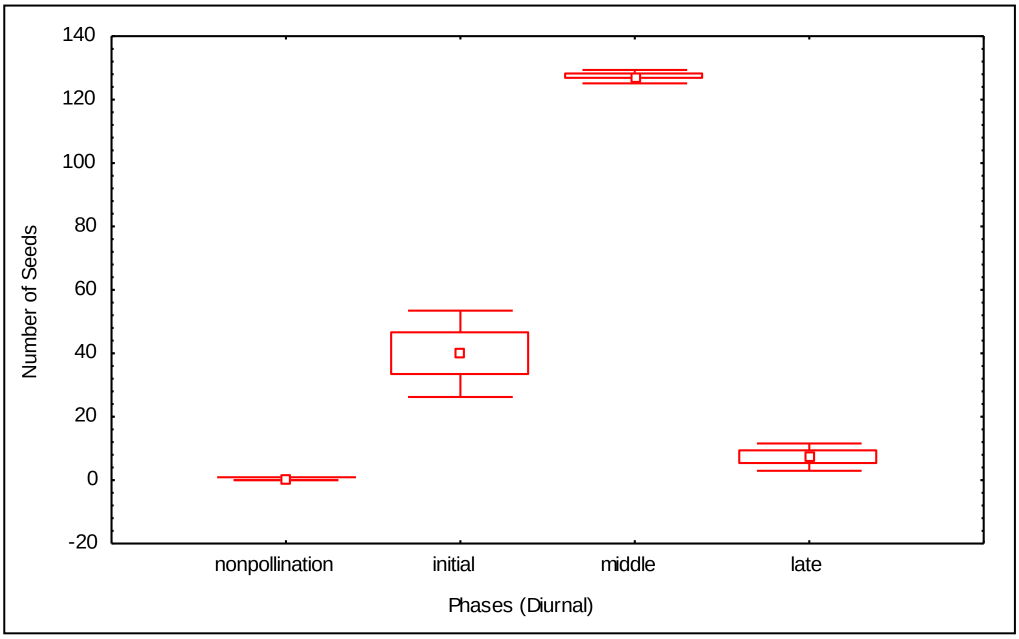


Figure.246: Mean number of seeds in diurnal phases (Middle seasonal phase)

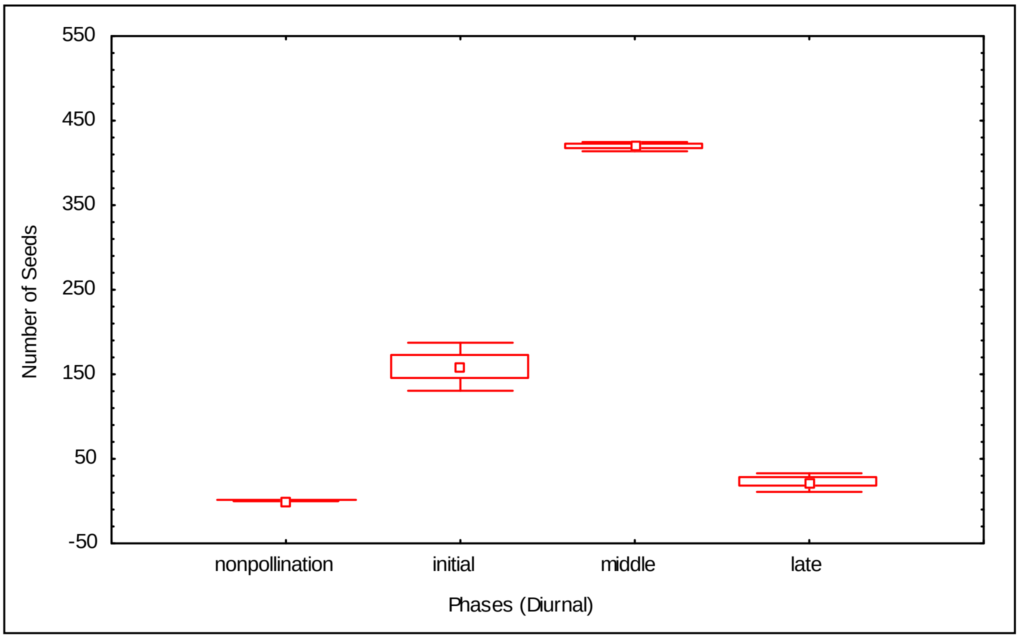


Figure.247: Mean number of seeds in diurnal phases (Late seasonal phase)

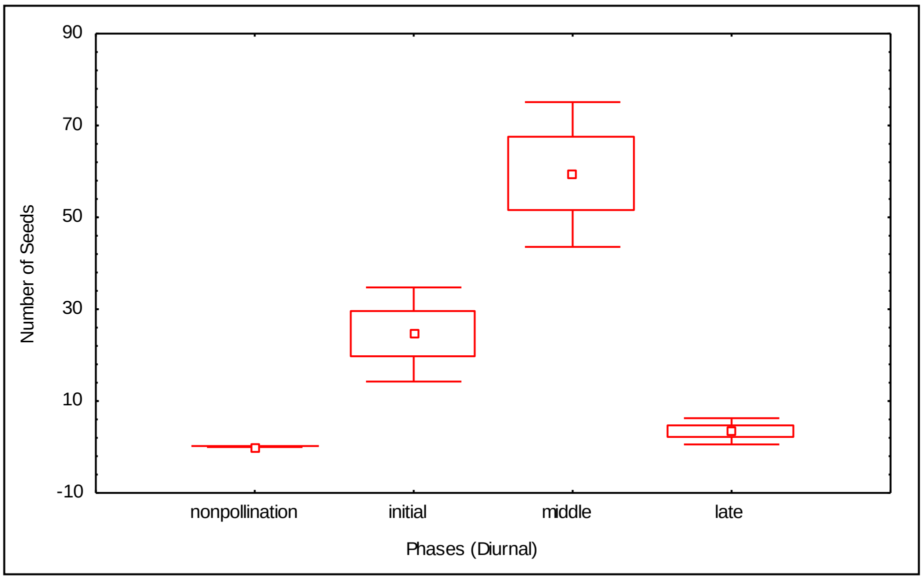
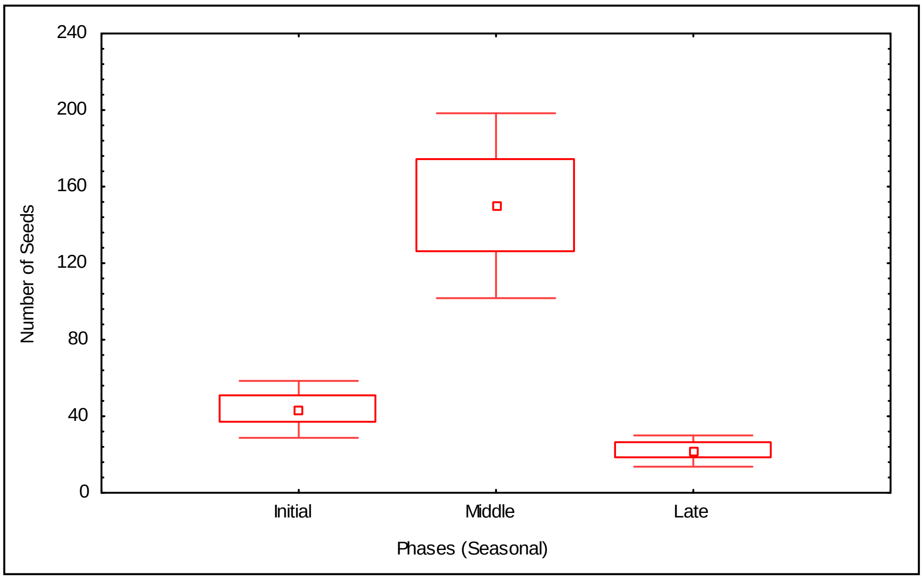


Figure.248: Mean number of seeds in different phases of season



4.4.4.5. Viability of Seeds

Mean number of viable seeds increased from initial phase of the season IP [ip=30.58±18.48; mp=104.91±3.14; lp=5.5±5.77] to middle phase of the season MP [ip=140.41±44.41; mp=403.83±14.25; lp=17.58±15.86] and then decreased to late phase LP [ip=12.66±9.37; mp=33.5±15.71; lp=1.66±2.46] of the season. As non pollinated flowers were aborted no seeds were found. Maximum viable seeds were recorded in middle diurnal phase (403.83±14.25) of middle seasonal phase. In late diurnal phase of late seasonal phase minimum number of viable seeds (1.66±2.46) were found. Mean number of seeds within each seasonal phase such as IP (p=0.00) (Figure 249); MP (p=0.00) (Figure 250); LP (p=0.00) (Figure 251) and between the seasonal phases were significantly different (p=0.00) (Figure 252).

Figure.249: Mean number of viable seeds in diurnal phases (Initial seasonal phase)

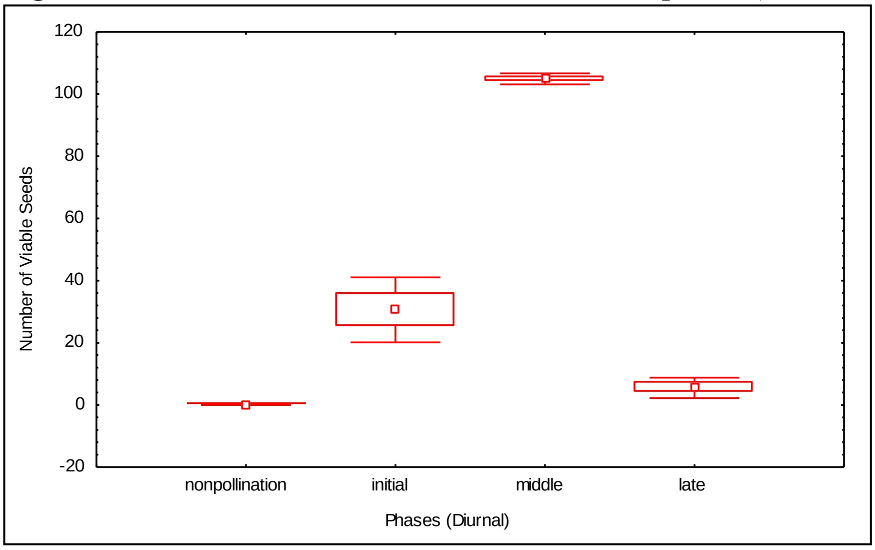


Figure.250: Mean number of viable seeds in diurnal phases (Middle seasonal phase)

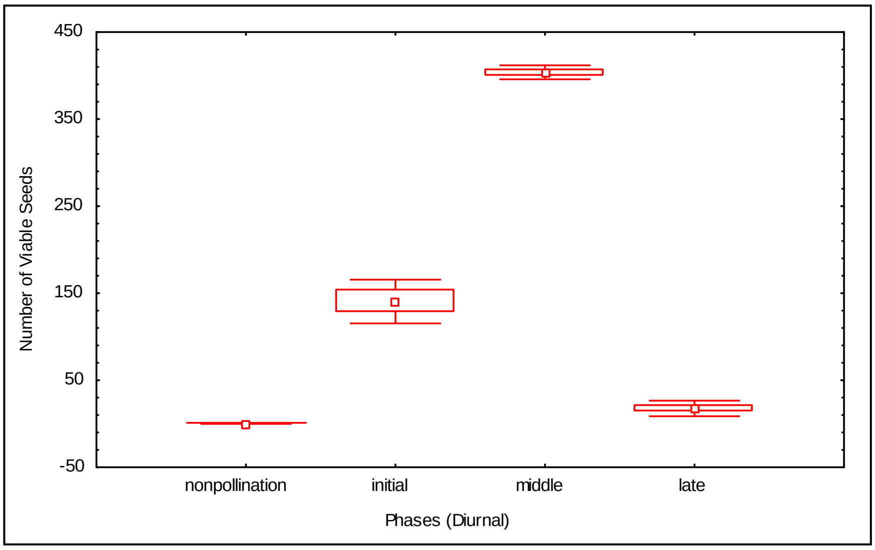


Figure.251: Mean number of viable seeds in diurnal phases (Late seasonal phase)

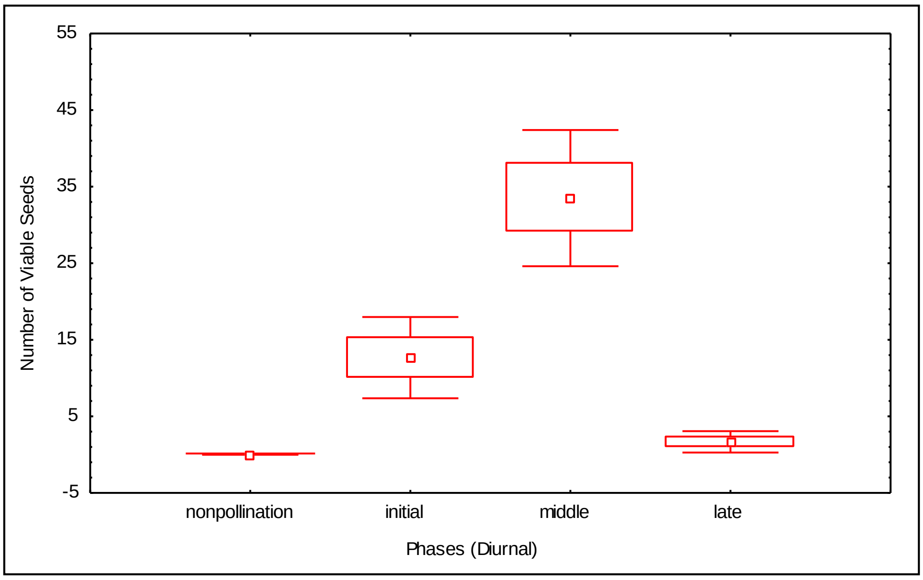
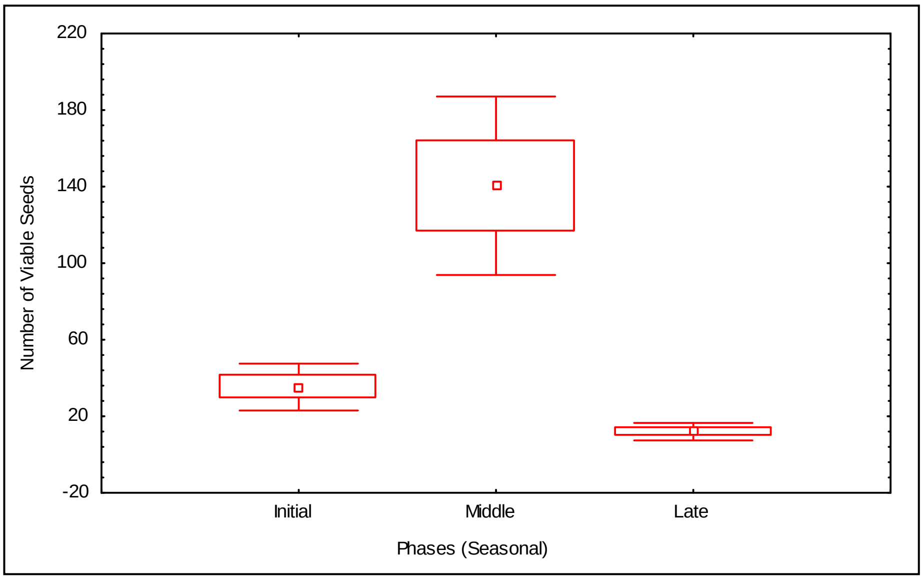


Figure.252: Mean number of viable seeds in different phases of season



4.4.5. Correlation

Positive correlation was observed between number of flowers and number of insects visited (r=0.99) (Figure 253), size of flowers and number of insects visited (r=0.99) (Figure 254), number of insects visited and number of pollen grains deposited (r=0.89) (Figure 255), duration of insect visit and number of pollen grains deposited (r=0.88) (Figure 256), number of pollen grains deposited and percentage of fruit set (r=0.95) (Figure 257), number of pollen grains deposited and weight of fruit (r=0.98) (Figure 258), number of pollen grains deposited and number of seeds (r=0.89) (Figure 259), and number of pollen grains deposited and number of viable seeds (r=0.92) (Figure 260).

Figure.253: Correlation between number of flowers /plant and number of insects visited

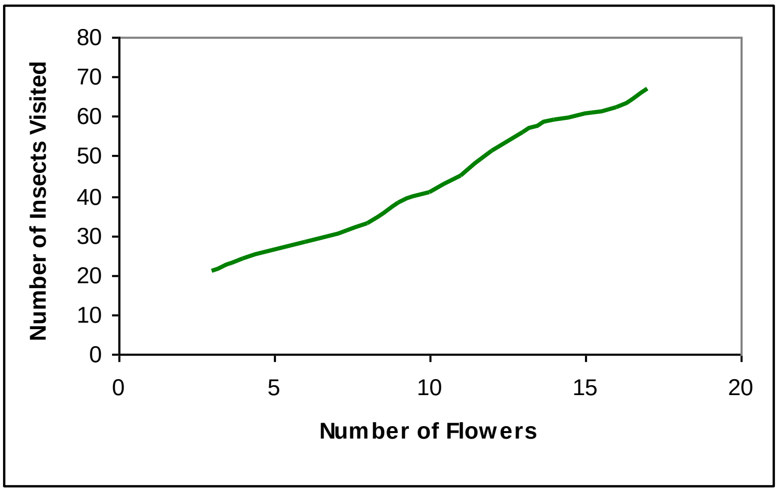


Figure.254: Correlation between size of flowers and number of insects visited

Figure.255: Correlation between number of insects visited and number of pollen grains deposited

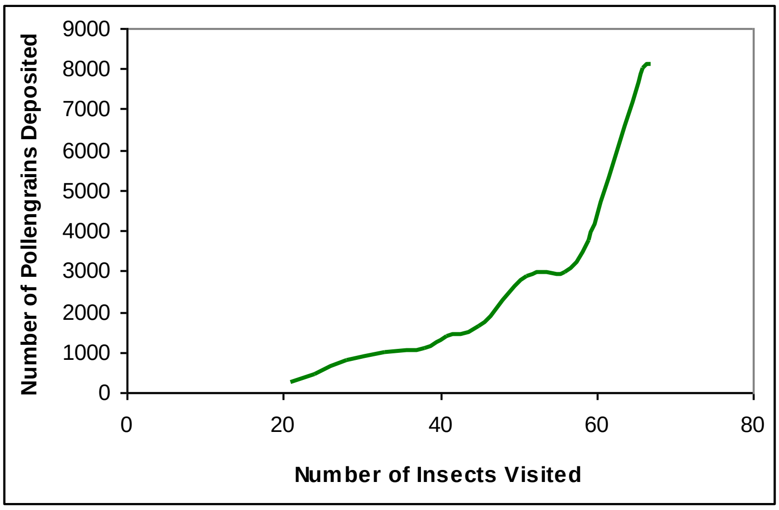


Figure.256: Correlation between duration of visit and number of pollen grains deposited

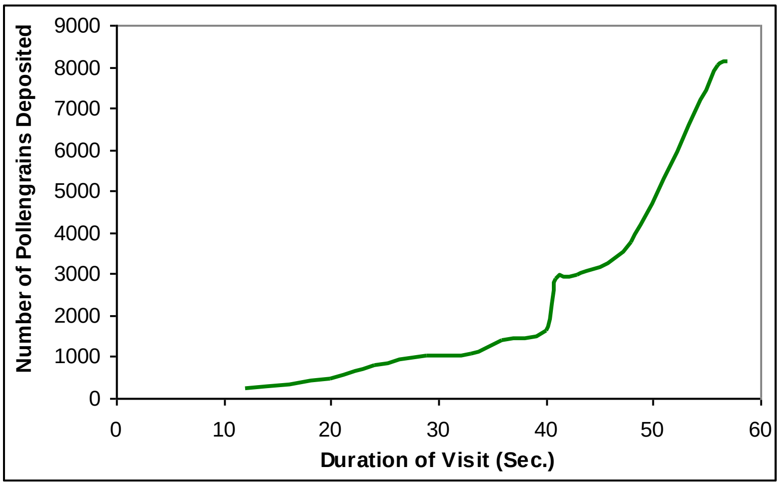


Figure.257: Correlation between number of pollen grains deposited and fruit set.

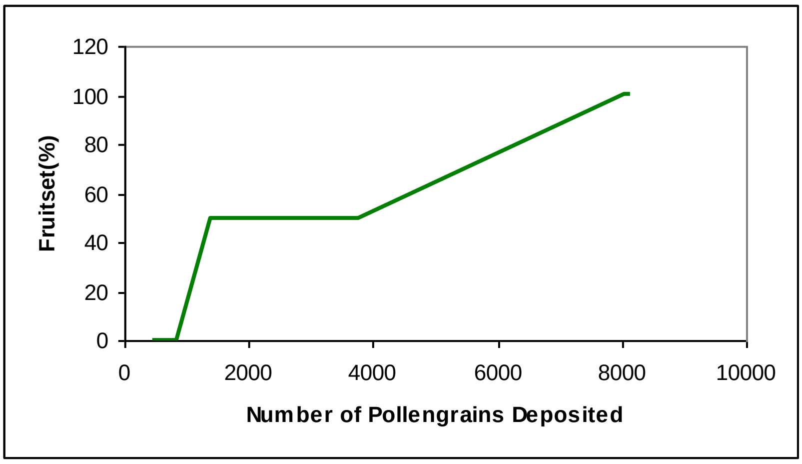


Figure.258: Correlation between number of pollen grains deposited and weight of fruit.

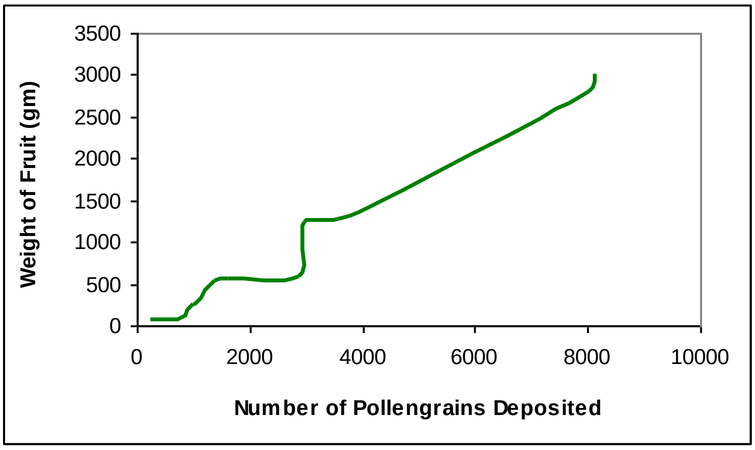


Figure.259: Correlation between number of pollen grains deposited and number seeds.

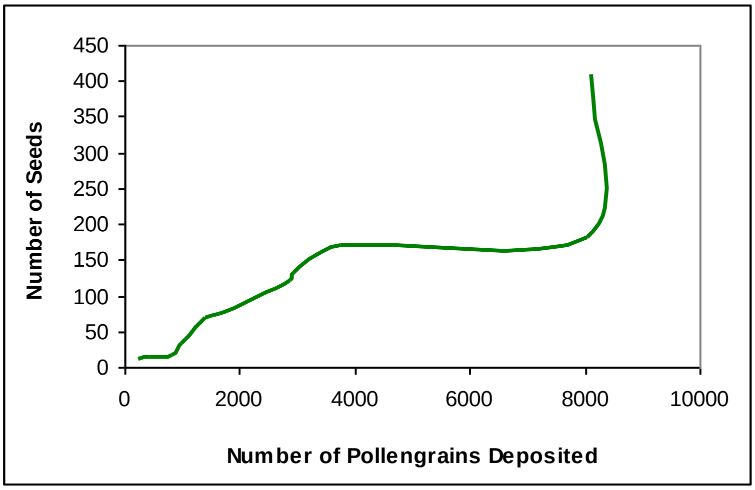
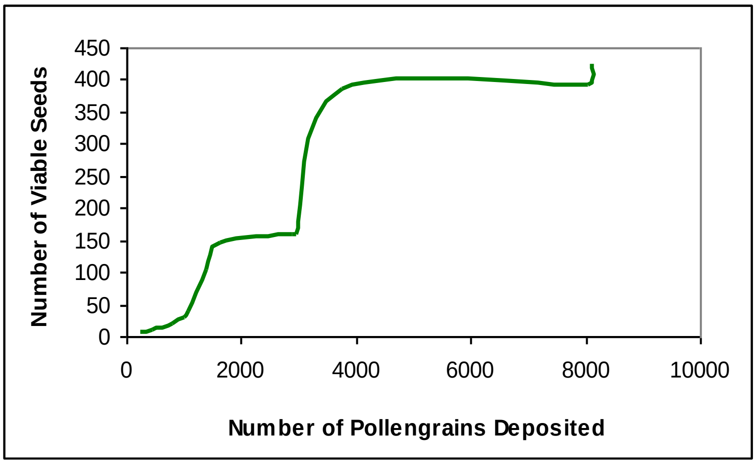


Figure.260: Correlation between number of pollen grains deposited and number of viable seeds.



Number of Viable Seeds
450
400
350
300
250
200
150
100
50
0
0
2000
4000
6000
8000
10000
Number of Pollengrains Deposited

4.5. Pumpkin

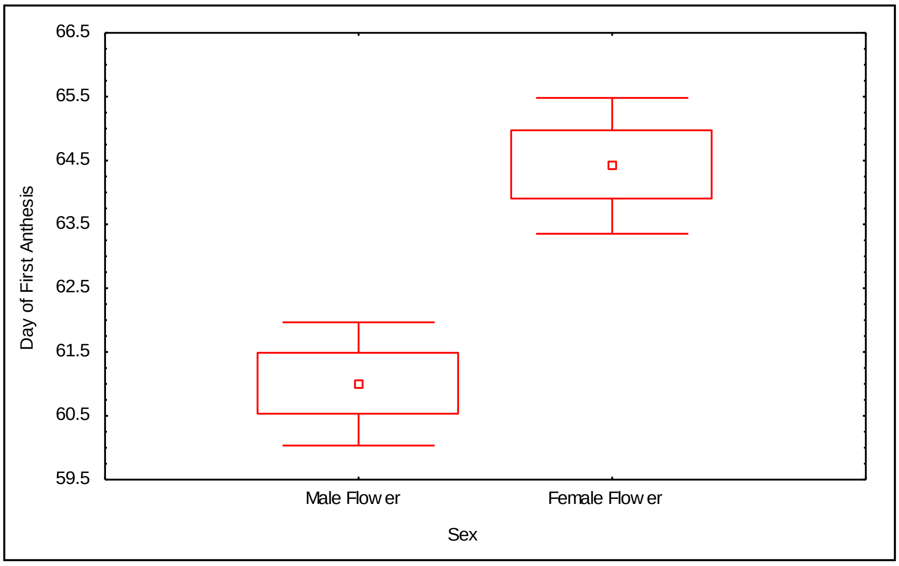
[*Cucurbita moschata* L.]

4.5.1. Phenology

4.5.1.1. Day of First Anthesis

It was found that first male (♂) and female (♀) flower opened on 61± 1.71th and 64.41±1.88th day respectively from the day of germination. Both male and female anthesis were significantly different (p=0.00) (Figure 261).

Figure.261: Day of first anthesis of male and female flowers after germination



4.5.1.2. Flower Opening Time

Male (♂) flower anthesis commenced between 0332 h. and 0610 h. and female (♀) flower between 0316 h. and 0554 h. There was significant difference between initiation of opening time of male (♂) and female (♀) flowers (p=0.00). Mean durations taken for full corolla expansion were 1.11±0.08 h., 1.32±0.03 h. by male (♂) and female (♀) respectively and they showed significant difference (p=0.01).

4.5.1.3. Flower Closing Time

Male (♂) flower closing commenced between 0930 h. and 1035 h. and female (♀) flower between 0945 h. and 1049 h. The times at which male (♂) and female (♀) flowers closed were significantly different (p=0.00). Mean durations taken for full petal constriction were 1.01± 0.02 h. and 1.12±0.03 h. by male (♂) and female (♀) respectively and they showed significant difference (p=0.00).

4.5.1.4. Number of Flowers

Mean number of staminate or male (♂) and pistillate or female (♀) flowers produced per plant per day increased from initial phase (IP) (♂=5.39±1.65, ♀=1.43±0.49) of the season to middle phase (MP) (♂=8.00±1.98, ♀=2.01±0.62) where maximum number of flowers were found and then decreased to late phase (LP) (♂=3.21±0.718, ♀=1.18±0.38) of the season where minimum number of flowers were found. Mean number of staminate (♂) and pistillate (♀) flowers within seasonal phases such as IP (p=0.00) (Figure 262.); MP (p=0.00) (Figure 263); LP (p=0.00) (Figure 264) and the mean number of flowers between seasonal phases were significantly different (p=0.00).

Figure.262: Mean number of male and female flowers produced /plant /day (Initial seasonal phase)

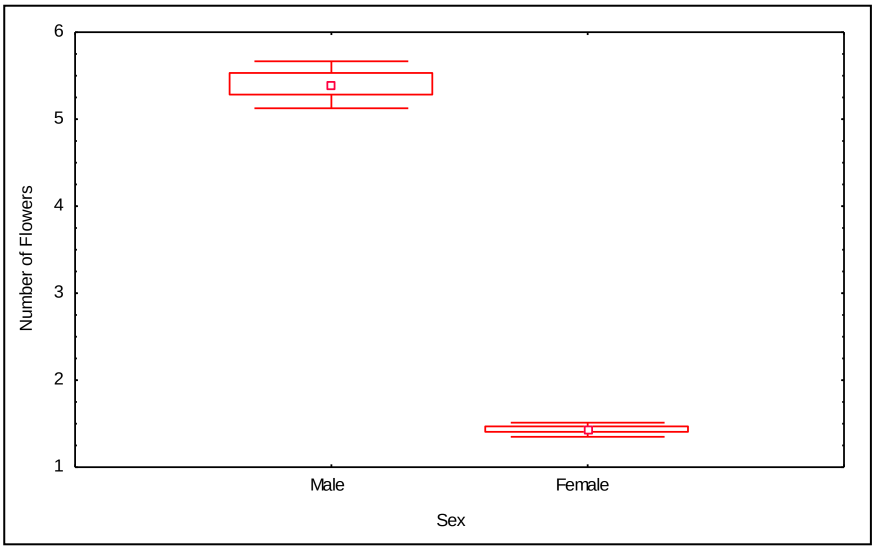


Figure.263: Mean number of male and female flowers Produced /plant /day (Middle seasonal phase)

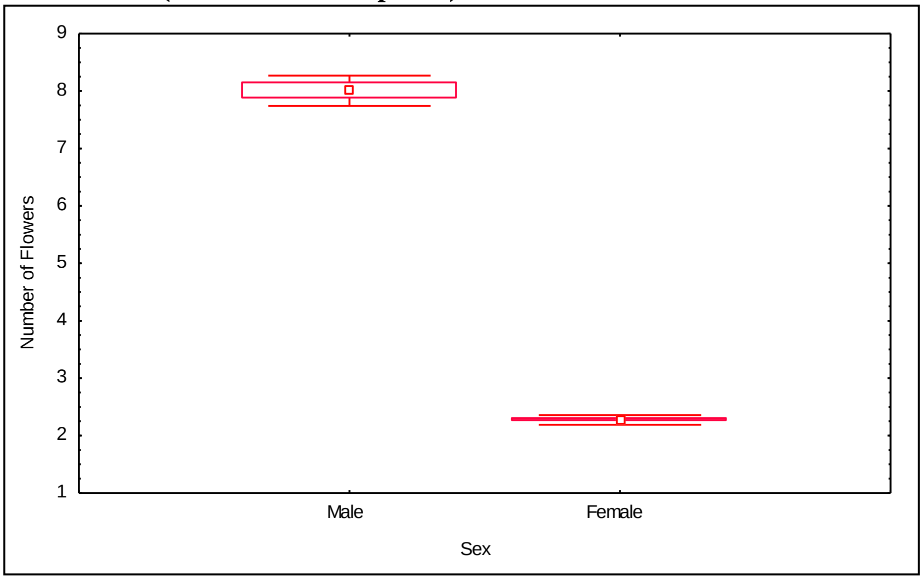
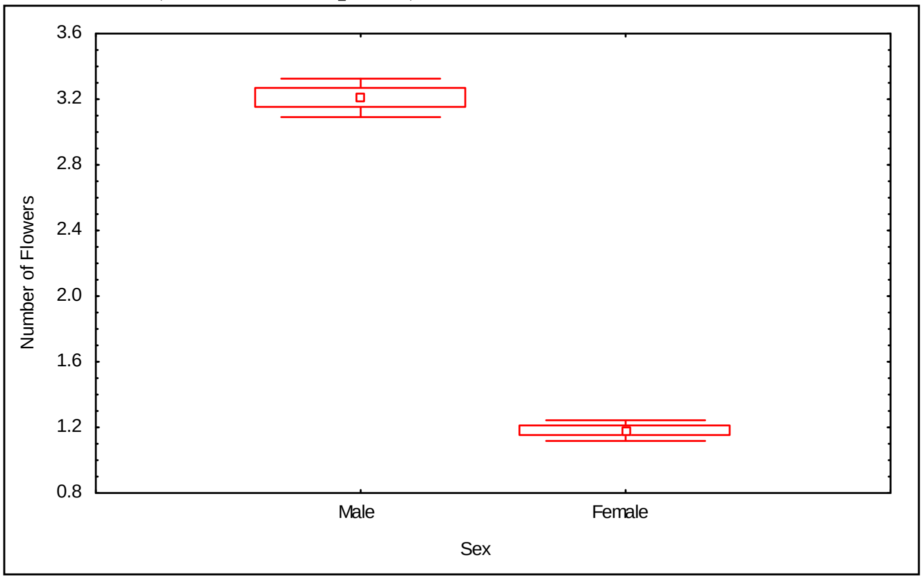


Figure.264: Mean number of male and female flowers produced /plant /day (Late seasonal phase)



4.5.1.5. Size /Dimension of Flower

Mean size of staminate (♂) and pistillate (♀) flowers produced per plant per day increased from initial phase [IP (♂=17.71±0.6 cm., ♀=19.62±0.74 cm.)] to middle phase [MP (♂=19.88±0.87 cm.,

♀=21.91±0.86 cm.)], where maximum size was observed and then decreased to late phase [LP (♂=17.01±1.16 cm., ♀=19.01±1.16 cm.)] of the season where minimum size was observed. Size of staminate (♂) and pistillate (♀) flowers within seasonal phases such as IP (p=0.00) (Figure 265); MP (p=0.00) (Figure 266); LP (p=0.00) (Figure 267) and mean size of flowers between seasonal phases were significantly different (p=0.00).

Figure.265: Mean size of male and female flowers produced (Initial seasonal phase)

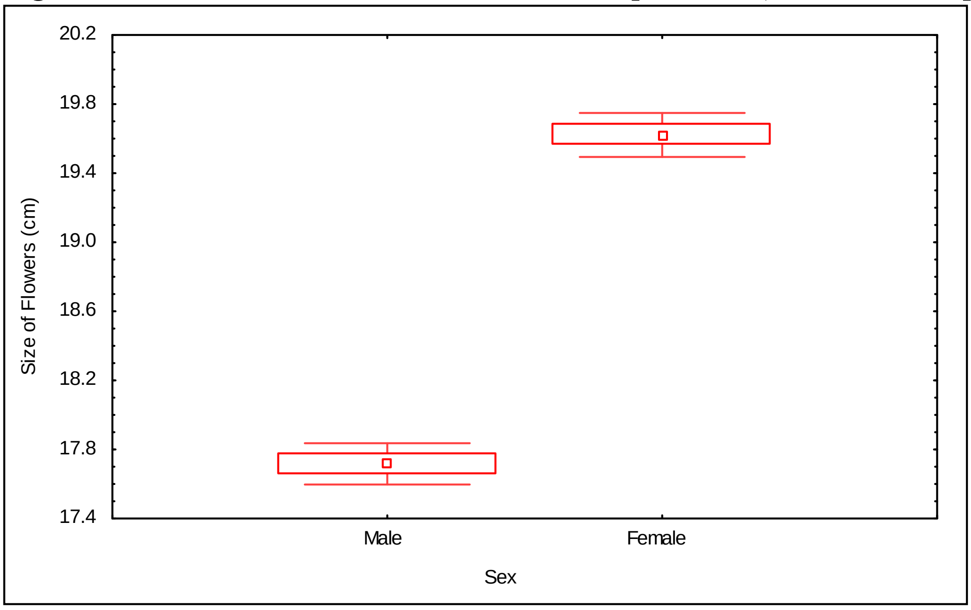


Figure.266: Mean size of male and female flowers produced (Middle seasonal phase)

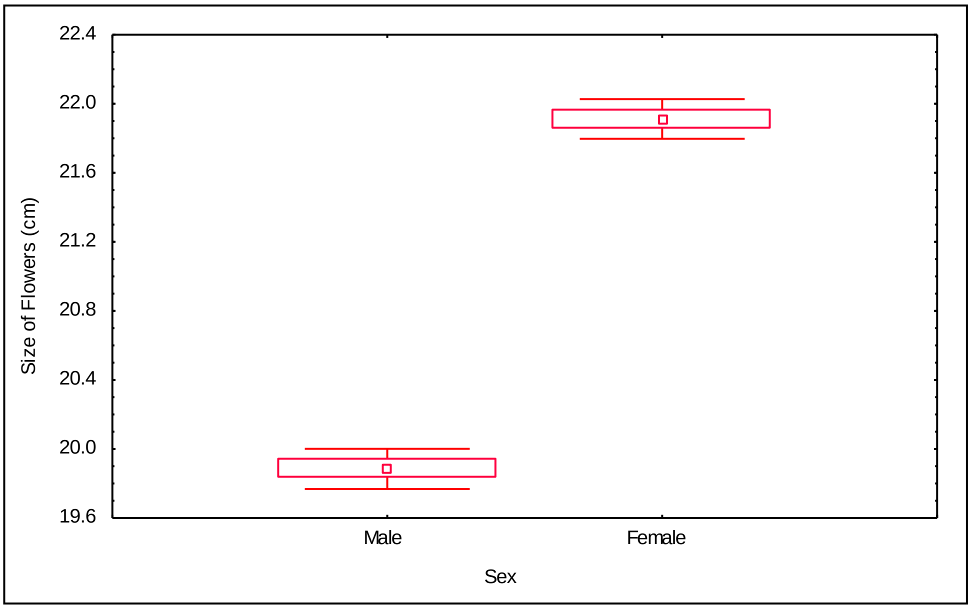
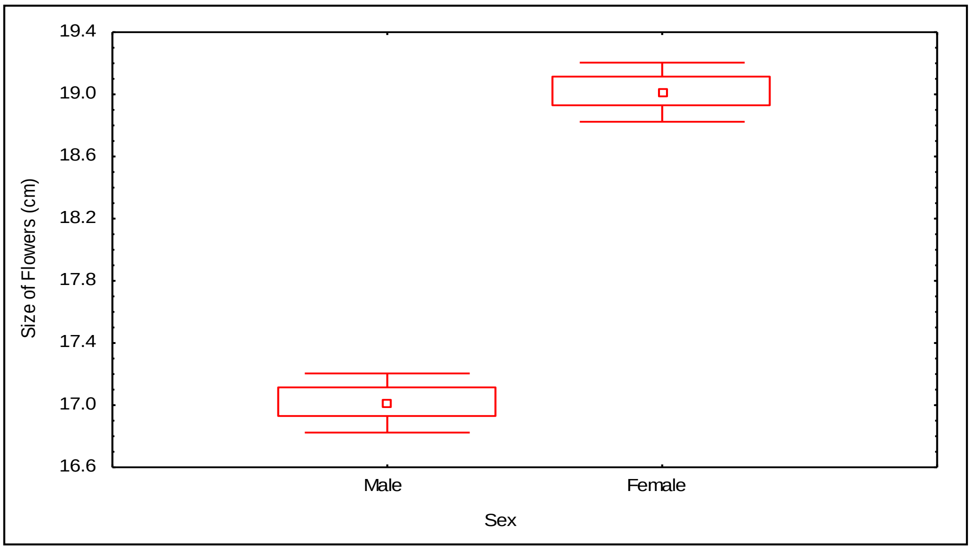


Figure.267: Mean size of male and female flowers produced (Late seasonal phase)



4.5.2. Entomology

4.5.2.1. Identification of Pollinators

A total of 16 insects were recorded mostly from 3 orders during the study (Plate 7 and Plate 8). The most abundant order was the hymenoptera, including families Apidae, Halictidae, Xylocopidae followed by coleoptera. Much less abundant was Lepidoptera. The list of pollinators of Pumpkin observed during the study is given in Table 29.

Table.29: List of pollinators

Order	Family	Species
Hymenoptera	Apidae	*Apis cerana* Fabricius
		Ceratina heiroglyphica Smith
		Amegilla parhypate Lieftinck
		Apis dorsata Fabricius
		Apis florea Fabricius
		Braunsapis picitarsis Cameron
		Ceratina smaragdula Fabricius
	Halictidae	*Halictus timidus* Smith
		Halictus taprobanae Cameron
		Trigona iridipennis Smith
	Xylocopidae	*Xylocopa tenuiscapa* Westwood
		Xylocopa aestuans Linnaeus
Coleoptera	Chrysomelidae	*Aulacophora foveicollis* Lucas
		Aulacophora lewisii Baly
Lepidoptera	Sphingidae	*Cephonodes picus* Cramer
		Macroglossum troglodytus Boisduval

4.5.2.2. Floral Visitation (Dynamics of Pollinating behaviour)

4.5.2.2.1. Frequency of Pollinator Visit

Mean pollinator visitation rates for all phases and seasonal phases are calculated. The variety of insects encountered and the visits they made were more numerous in the MP, than in IP and LP. The most dominant group was hymenoptera followed by coleoptera and Lepidoptera. Within each season, the visits of different insect groups varied with the flowering phase, the middle phase receiving the larger number of visits. It was observed that a mean of 21.16 and 17.75 hymenopterans and a mean of 3.16 and 2.91 coleopterans visited the male (♂) and female (♀) flowers /day respectively in the initial phase (IP) of the season. In middle phase (MP) a mean of 27.25 and 23.91 hymenopterans, 1.25 and 1.08 coleopterans and 0.33 and 0.33 lepidopterans visited the male (♂) and female (♀) flowers/day respectively. In late phase (LP) of the season a mean of 16.08 and 13.25 hymenopterans and 3.91 and 3.08 coleopterans visited the (♂) and female (♀) flowers/day respectively. Variation in the case of different diurnal phases in each phase of the season was also observed. Highest frequency of visit was observed in middle diurnal phase of middle phase of season. Lowest frequency of visit was observed in late diurnal phase of late phase of season. Hymenopterans were the most frequent visitors. Significant difference was found in visitation frequency shown by different orders of insects [IP (p=0.00) (Figure 268); MP (p=0.00) (Figure 269); LP (p=0.00) (Figure 270)] (Table 30). Also visitation frequency shown by different species changed significantly over the day [IP (p=0.00) (Figure 271); MP (p=0.00) (Figure 272); LP (p=0.00) (Figure 273)] (Table 31). *Apis cerana* was the most frequent pollinator. It was followed by *Halictus timidus, Ceratina heiroglyphica Halictus taprobanae and Trigona iridipennis.* They were regular, consistent and made the higher number of visits compared to other insects, at all sites. But no significant difference was found in visitation frequency on staminate (♂) and pistillate (♀) flowers [IP (p=0.96); MP (p=0.61); LP (p=0.61)]. Diurnal phases of each seasonal phase also showed significant difference in the visitation frequency IP (p=0.00); MP (p=0.00) and LP (p=0.00). Different seasonal phases also showed significant difference in visitation frequency (p=0.00).

Table.30: Frequency of pollinator visit (Order) /day

Order	Sex of flower	Initial Phase (IP)			Middle Phase (MP)			Late Phase (LP)		
		ip	mp	lp	ip	mp	lp	ip	mp	lp
Hymenoptera	♂	6.66	11.58	2.91	8.25	14.5	4.5	4.83	9.25	2
	♀	5.5	10.16	2.08	7.25	13	3.66	4	8.08	1.16
Coleoptera	♂	1.08	0.91	1.166	0.16	0.16	0.91	1.66	1.33	1.91
	♀	1.08	0.75	1.08	0.16	0.16	0.75	1.25	1.25	1.25
Lepidoptera	♂	0	0	0	0.33	0	0	0	0	0
	♀	0	0	0	0.33	0	0	0	0	0

IP - Initial phase of season
MP - Middle phase of season
LP - Late phase of season

ip - initial phase of day
mp - middle phase of day
lp - late phase of day

♂ -Male flower
♀ -Female flower

Figure.268: Frequency of pollinator (Order) visit /day (Initial seasonal phase)

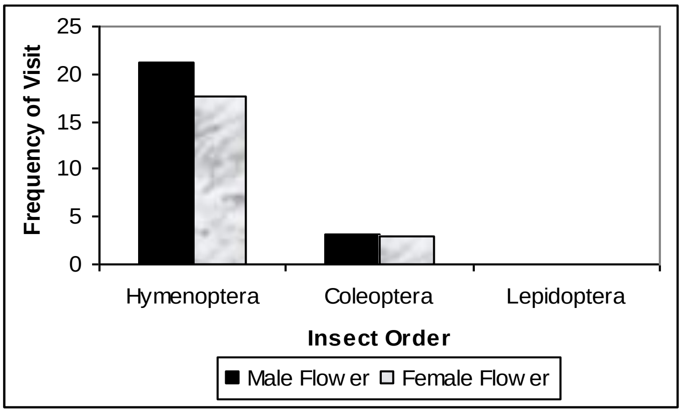


Figure.269: Frequency of pollinator (Order) visit /day (Middle seasonal phase)

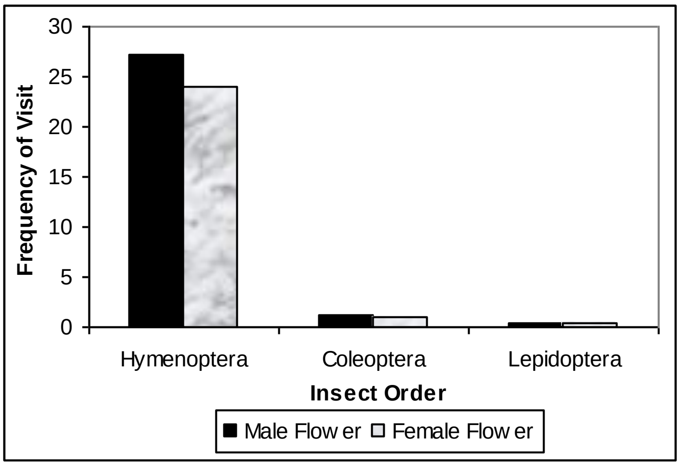


Figure.270: Frequency of pollinator (Order) visit /day (Late seasonal phase)

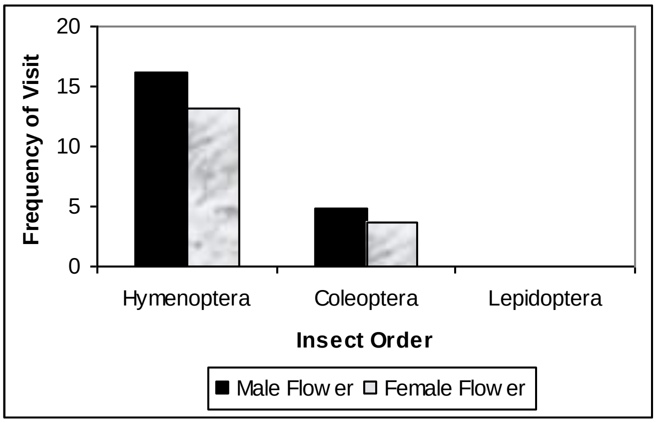


Table.31: Frequency of pollinator (Species) visit /day

Species	Sex of flower	Initial Phase (IP)			Middle Phase (MP)			Late Phase (LP)		
		ip	mp	lp	ip	mp	lp	ip	mp	lp
Apis cerana	♂	5.16	9.33	2	6.41	11.33	3.41	3.5	7.08	1.41
	♀	4.16	8.25	1.33	5.58	10.25	2.75	2.75	6.16	0.83
Ceratina heiroglyphica	♂	0.5	0.66	0.33	0.58	0.75	0.33	0.41	0.66	0.16
	♀	0.41	0.58	0.25	0.5	0.66	0.25	0.33	0.58	0.08
Amegilla parhypate	♂	0	0	0	0.16	0	0	0	0	0
	♀	0	0	0	0.16	0	0	0	0	0
Braunsapis picitarsis	♂	0	0	0	0	0.16	0	0	0	0
	♀	0	0	0	0	0.16	0	0	0	0
Apis florea	♂	0	0	0	0	0.08	0	0	0	0
	♀	0	0	0	0	0.08	0	0	0	0
Ceratina smaragdula	♂	0	0	0	0	0.08	0	0	0	0
	♀	0	0	0	0	0.08	0	0	0	0
Apis dorsata	♂	0	0	0	0	0.08	0	0	0	0
	♀	0	0	0	0	0.08	0	0	0	0
Halictus timidus	♂	0.66	0.83	0.41	0.66	1	0.41	0.58	0.75	0.25
	♀	0.58	0.67	0.33	0.66	0.83	0.33	0.58	0.66	0.08
Halictus taprobanae	♂	0.16	0.41	0.08	0.17	0.41	0.16	0.16	0.41	0.08
	♀	0.16	0.33	0.08	0.16	0.33	0.16	0.16	0.33	0.08
Trigona iridipennis	♂	0.16	0.33	0.08	0.25	0.41	0.16	0.16	0.33	0.08
	♀	0.16	0.33	0.08	0.17	0.33	0.16	0.16	0.33	0.08
Xylocopa aestuans	♂	0	0	0	0	0.08	0	0	0	0
	♀	0	0	0	0	0.08	0	0	0	0
Xylocopa tenuiscapa	♂	0	0	0	0	0.08	0	0	0	0
	♀	0	0	0	0	0.08	0	0	0	0
Aulacophora foveicollis	♂	0.58	0.5	0.58	0.08	0.08	0.5	0.91	0.75	1
	♀	0.58	0.41	0.58	0.08	0.08	0.41	0.66	0.66	0.66
Aulacophora lewisii	♂	0.5	0.41	0.58	0.08	0.08	0.41	0.75	0.58	0.91
	♀	0.5	0.33	0.5	0.08	0.08	0.33	0.58	0.58	0.58
Cephonodes picus	♂	0	0	0	0.16	0	0	0	0	0
	♀	0	0	0	0.16	0	0	0	0	0
Macroglossum troglodytus	♂	0	0	0	0.16	0	0	0	0	0
	♀	0	0	0	0.16	0	0	0	0	0

IP - Initial phase of season   ip - initial phase of day   ♂ -Male flower
MP - Middle phase of season   mp - middle phase of day   ♀ -Female flower
LP - Late phase of season   lp - late phase of day

Figure.271: Frequency of pollinator (Species) visit /day (Initial seasonal phase)

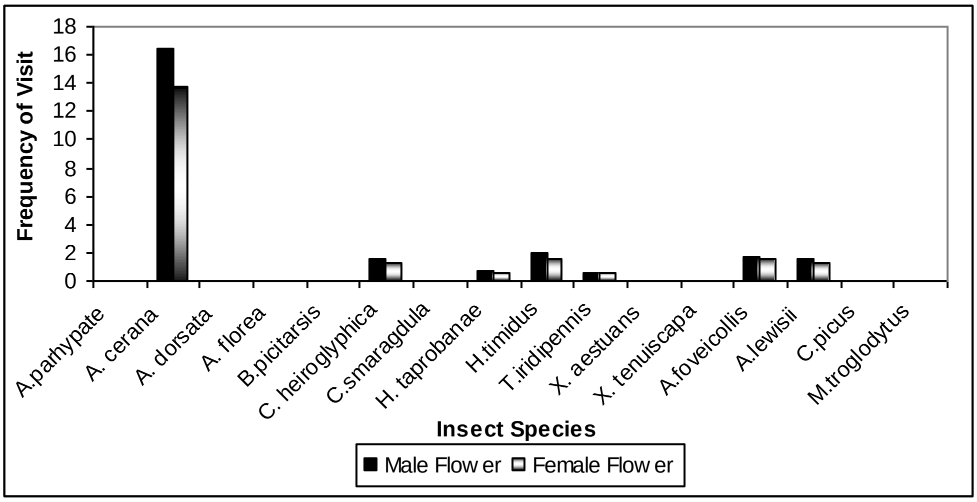


Figure.272: Frequency of pollinator (Species) visit /day (Middle seasonal phase)

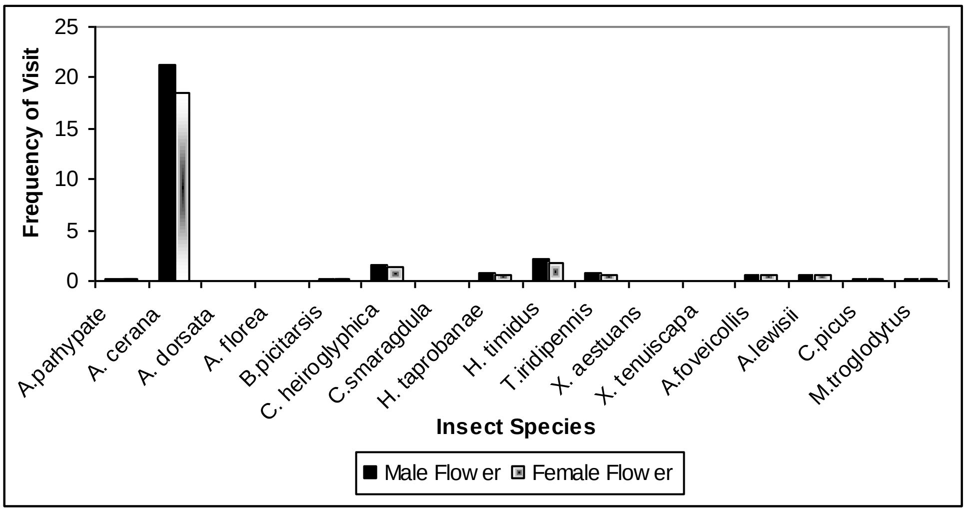
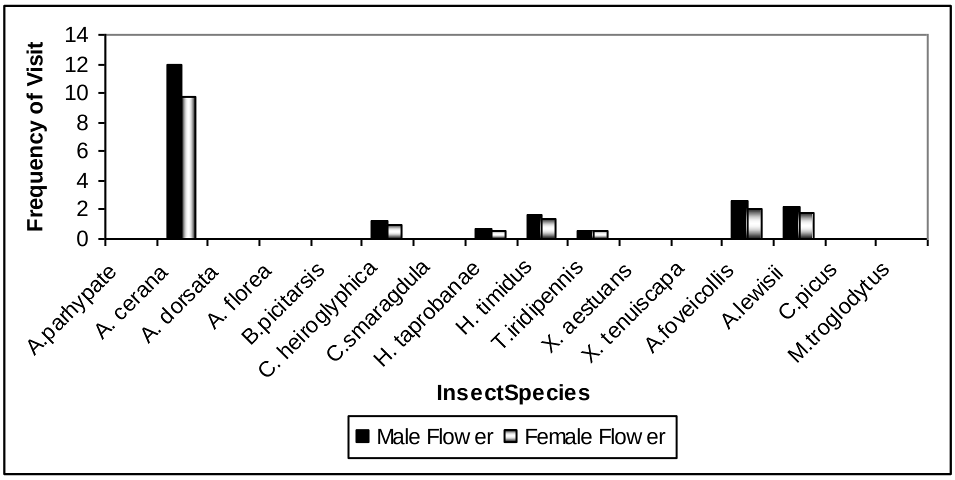


Figure.273: Frequency of pollinator (Species) visit /day (Late seasonal phase)



4.5.2.2.2. Mean Number of Flowers Visited by Pollinators

Mean number of male (♂) and female (♀) flowers visited increased from initial phase of the season (IP) to middle phase of the season, (MP) and decreased to late of the season (LP). There was significant difference in the way these components changed in number over the day and season. Hymenopterans visited a mean of 31.08 male (♂) flowers and 23.41 female (♀) flowers and coleopterans visited 8.5 male (♂) flowers and 6.58 female (♀) flowers /day in the initial phase (IP) of the season. In middle phase (MP) a mean of 42.5 male (♂) flowers and 31.83 female (♀) flowers were visited by hymenopterans, 2.58 male (♂) flowers and 2.41 female (♀) flowers by coleopterans and 0.41 male (♂) flowers and 0.41 female (♀) flowers by lepidopterans /day. In late phase (LP) of the season it was a mean of 21.25 male (♂) flowers and 18 female (♀) flowers by hymenopterans and 8.25 male (♂) flowers and 6.41 female (♀) flowers by coleopterans /day. Variation in number of flowers visited in different diurnal phases in each phase of the season was also observed. Maximum number of flowers were visited in the middle diurnal phase of middle seasonal phase and minimum number of flowers were visited in the late diurnal phase of late seasonal phase. Significant difference was found in number of flowers visited by different orders of insects [IP (p=0.00) (Figure.274); MP (p=0.00) (Figure.275) and LP (p=0.00) (Figure.276)] (Table 32). Hymenopterans visited highest number of flowers. Number of flowers visited by different species of pollinators also varied significantly [IP (p=0.00) (Figure 277); MP (p=0.00) (Figure 278); LP (p=0.00) (Figure 279)] (Table 33). But there was no significant difference in the number of male (♂) and female (♀) flowers visited by different pollinators [IP (p=0.06)]; MP (p=0.07)]; LP (p=0.48)]. Significant difference was found in the number of flowers visited by pollinators in different diurnal phases of the season [IP (p=0.00)]; MP (p=0.00)]; LP (p=0.00)]. Number of flowers visited by pollinators varied significantly in different seasonal phases also ($p=0.00$).

Table.32: Mean number of flowers visited by pollinators (Order) /day

Order	Sex of flower	Initial Phase (IP)			Middle Phase (MP)			Late Phase (LP)		
		ip	mp	lp	ip	mp	lp	ip	mp	lp
Hymenoptera	♂	10.5	14	6.58	13.41	20.75	8.33	6.83	10.5	3.91
	♀	8.33	10.91	4.16	11	15.33	5.5	6	8.75	3.25
Coleoptera	♂	3	3.16	2.33	0.83	1	0.75	2.91	3.16	2.16
	♀	2.33	2.5	1.75	0.83	0.83	0.75	2.25	2.5	1.6
Lepidoptera	♂	0	0	0	0.16	0	0	0	0	0
	♀	0	0	0	0.16	0	0	0	0	0

IP - Initial phase of season
MP - Middle phase of season
LP - Late phase of season

ip - initial phase of day
mp - middle phase of day
lp - late phase of day

♂ -Male flower
♀ -Female flower

Figure.274: Mean number of flowers visited by pollinators (Order) /day (Initial seasonal phase)

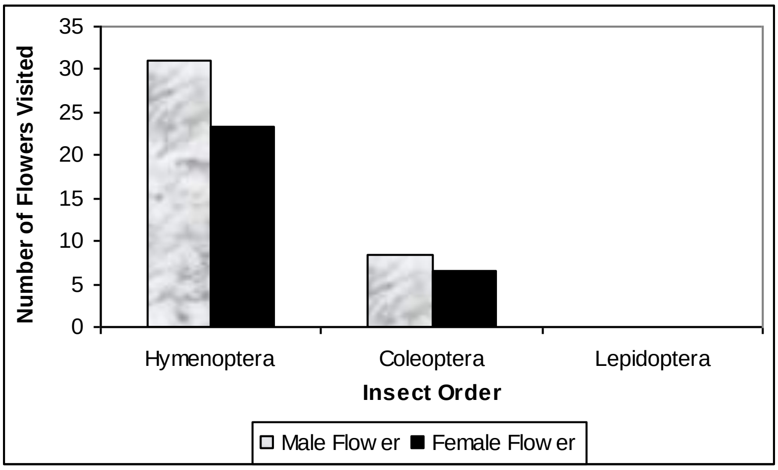


Figure.275: Mean number of flowers visited by pollinators (Order) /day (Middle seasonal phase)

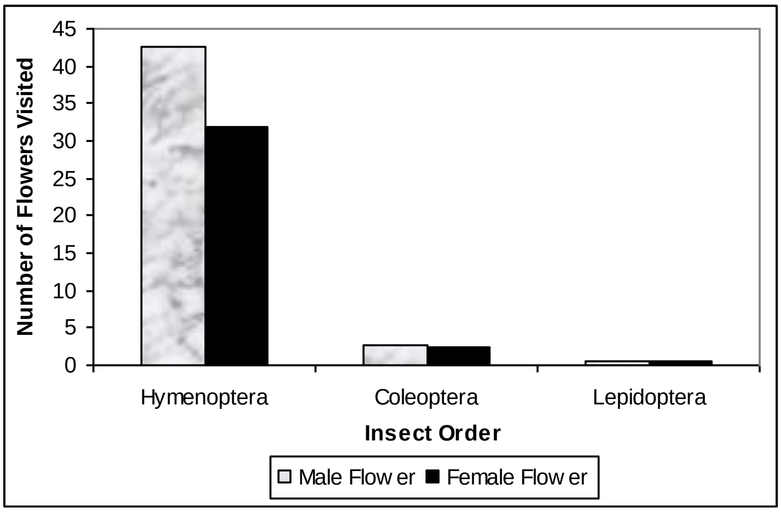


Figure.276: Mean number of flowers visited by pollinators (Order) /day (Late seasonal phase)

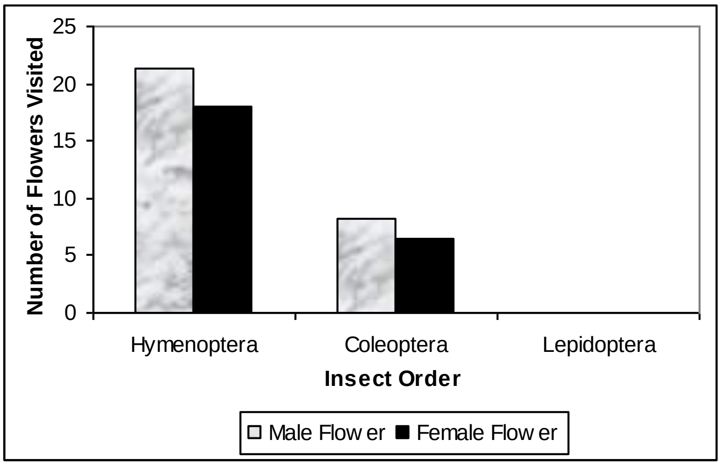


Table.33: Mean number of flowers visited by pollinators (Species) /day

Species	Sex of flower	Initial Phase (IP)			Middle Phase (MP)			Late Phase (LP)		
		ip	mp	lp	ip	mp	lp	ip	mp	lp
Apis	♂	4.75	5.83	3.83	5.91	6.83	4.75	3.75	4.91	2.83
cerana	♀	4.25	4.91	3.16	5.16	6.41	3.5	3.5	4.66	2.75
Ceratina	♂	2	2.25	1.08	2.75	4.33	1.08	0.41	0.66	0.16
heiroglyphica	♀	1	1.75	0.25	1.75	2.41	0.58	0.33	0.58	0.08
Amegilla	♂	0	0	0	0.58	0	0	0	0	0
parhypate	♀	0	0	0	0.25	0	0	0	0	0
Braunsapis	♂	0	0	0	0	0.33	0	0	0	0
picitarsis	♀	0	0	0	0	0.33	0	0	0	0
Apis	♂	0	0	0	0	0.25	0	0	0	0
florea	♀	0	0	0	0	0.16	0	0	0	0
Ceratina	♂	0	0	0	0	0.08	0	0	0	0
smaragdula	♀	0	0	0	0	0.08	0	0	0	0
Apis	♂	0	0	0	0	0.16	0	0	0	0
dorsata	♀	0	0	0	0	0.16	0	0	0	0
Halictus	♂	2.5	2.75	1.25	2.83	4.83	1.5	1.41	2	0.58
timidus	♀	2.08	2.41	0.41	2.66	3.58	0.75	1.33	1.66	0.16
Halictus	♂	0.66	1.75	0.25	0.66	2.16	0.58	0.66	1.75	0.16
taprobanae	♀	0.5	1	0.16	0.66	1.16	0.41	0.5	1	0.16
Trigona	♂	0.58	1.41	0.16	0.66	1.58	0.41	0.58	1.166	0.16
iridipennis	♀	0.5	0.83	0.16	0.5	0.91	0.25	0.33	0.83	0.08
Xylocopa	♂	0	0	0	0	0.08	0	0	0	0
aestuans	♀	0	0	0	0	0.08	0	0	0	0
Xylocopa	♂	0	0	0	0	0.08	0	0	0	0
tenuiscapa	♀	0	0	0	0	0.08	0	0	0	0
Aulacophora	♂	1.5	1.58	1.16	0.41	0.5	0.41	1.5	1.58	1.08
foveicollis	♀	1.41	1.5	0.91	0.41	0.41	0.41	1.33	1.5	0.91
Aulacophora	♂	1.5	1.58	1.16	0.41	0.5	0.33	1.41	1.58	1.08
lewisii	♀	0.91	1	0.83	0.41	0.41	0.33	0.91	1	0.75
Cephonodes	♂	0	0	0	0.16	0	0	0	0	0
picus	♀	0	0	0	0.16	0	0	0	0	0
Macroglossum	♂	0	0	0	0.25	0	0	0	0	0
troglodytus	♀	0	0	0	0.25	0	0	0	0	0

IP - Initial phase of season
MP - Middle phase of season
LP - Late phase of season

ip - initial phase of day
mp - middle phase of day
lp - late phase of day

♂ -Male flower
♀ -Female flower

Figure.277: Mean number of flowers visited by pollinators (Species) /day (Initial seasonal phase)

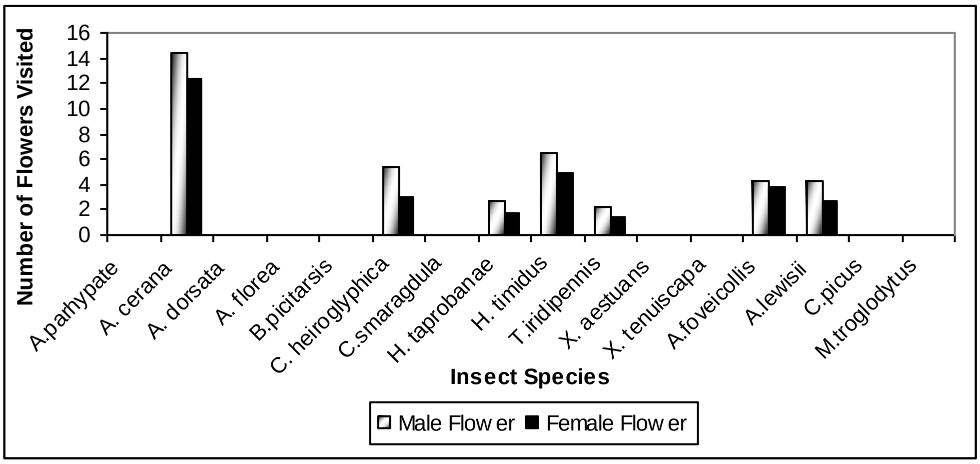


Figure.278: Mean number of flowers visited by pollinators (Species) /day (Middle seasonal phase)

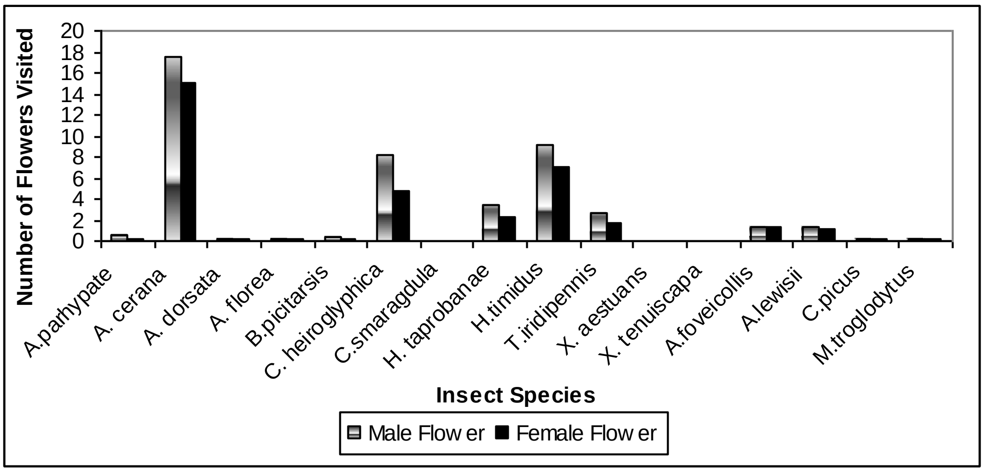
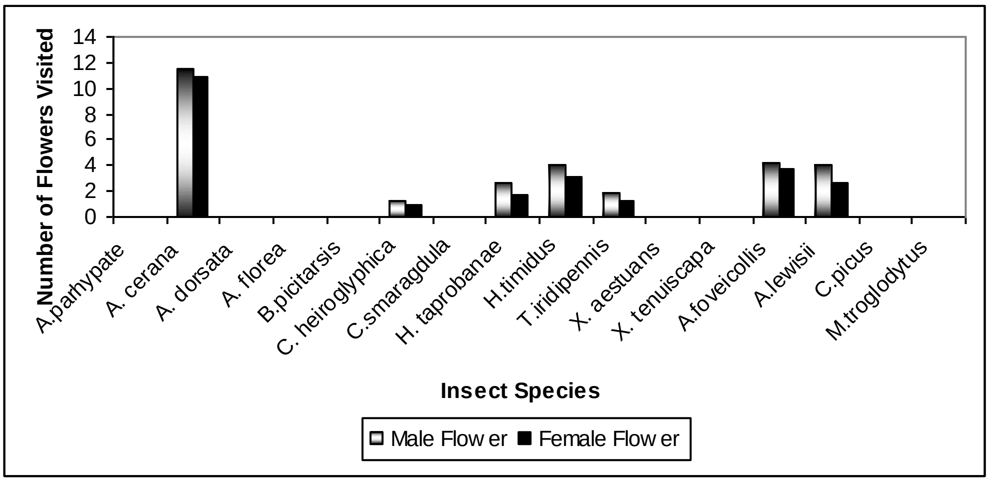


Figure.279: Mean number of flowers visited by pollinators (Species) /day (Late seasonal phase)



4.5.2.2.3. Mean Duration of Pollinator Visit

Duration of visit on each flower was also recorded in seconds (sec.) to provide data on the average time spent on male (♂) and female (♀) flowers by different insects. It was observed that mean duration of pollinator visit increased from initial phase, IP to middle phase MP and decreased to late phase LP of the season. But the mean duration of visit decreased from initial to late in diurnal phases of each seasonal phase The pollinators took longest duration in initial diurnal phase of middle seasonal phase and shortest duration in late diurnal phase of late seasonal phase. Mean duration of visit taken by hymenopterans was 44.25 sec. on male (♂) flowers and 35.91 sec. on female (♀) flowers and by coleopterans was 13.91 on male (♂) flowers and 10.5 sec. on female (♀) flowers /day in the initial phase (IP) of the season. In middle phase (MP) 58.58 sec. on male (♂) flowers and 44.58 sec. on female (♀) flowers were taken by hymenopterans, 4.25 sec. on male (♂) flowers and 4 sec. on female (♀) flowers by coleopterans and 0.66 sec. on male (♂) flowers and 0.58 sec. on female (♀) flowers by lepidopterans /day. In late phase (LP) of the season it was 29.75 sec. on male (♂) flowers and 22.75 sec. on female (♀) flowers by hymenopterans and 12.25 sec. on male (♂) flowers and 9.58 sec. on female (♀) flowers by coleopterans /day. Variation in mean duration of visit taken by different orders in different diurnal phases in each phase of the season was also observed. The mean duration taken by different orders of pollinators in all phases of season varied significantly [IP (p=0.00) (Figure 280); MP (p=0.00) (Figure 281); LP (p=0.00) (Figure 282)] (Table 34). The mean duration taken by different species of pollinators in all phases of season also varied significantly [IP (p=0.00) (Figure 283); MP (p=0.00) (Figure 284); LP (p=0.00) (Figure 285)] (Table 35). But there was no significant difference in mean duration of visit to male (♂) and female (♀) flowers

IP (p=0.16); MP (p=0.14); LP (p=0.21). But the duration of visit during diurnal phases of each season [IP (p=0.00); MP (p=0.00); LP (p=0.00)] varied significantly. Seasonal phases also showed significant difference in mean duration of visit (p=0.00).

Table.34: Mean duration of pollinator (Order) visit in seconds

Order	Sex of flower	Initial Phase (IP)			Middle Phase (MP)			Late Phase (LP)		
		ip	mp	lp	ip	mp	lp	ip	mp	lp
Hymenoptera	♂	19.25	15.41	9.58	24.5	21.91	12.16	12.8	10.3	6.58
	♀	15.83	12.5	7.58	20.08	15.66	8.83	10.4	7.75	4.58
Coleoptera	♂	5.91	4.75	3.25	1.58	1.41	1.25	5.5	3.83	2.91
	♀	4.83	3.33	2.33	1.41	1.33	1.25	3.91	3.16	2.5
Lepidoptera	♂	0	0	0	0.66	0	0	0	0	0
	♀	0	0	0	0.58	0	0	0	0	0

IP - Initial phase of season ip - initial phase of day ♂ -Male flower
MP - Middle phase of season mp - middle phase of day ♀ -Female flower
LP - Late phase of season lp - late phase of day

Figure.280: Mean duration of visit on flowers by pollinators (Order) in seconds (Initial seasonal phase)

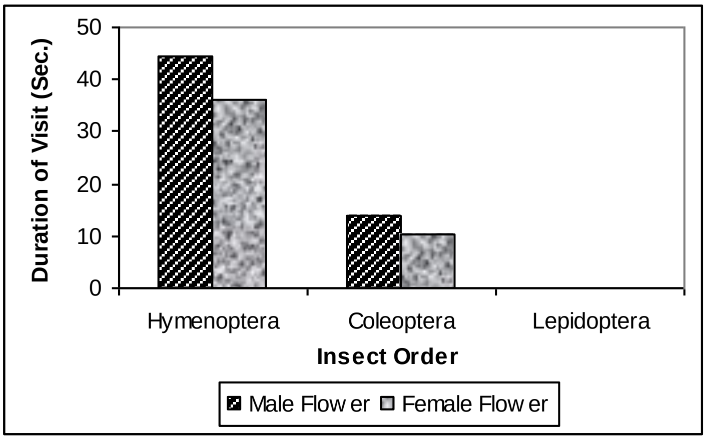


Figure.281: Mean duration of visit on flowers by pollinators (Order) in seconds (Middle seasonal phase)

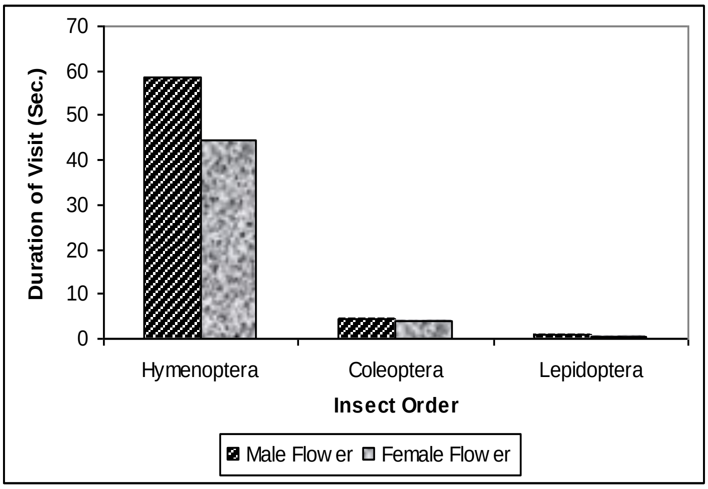


Figure.282: Mean duration of visit on flowers by pollinators (Order) in seconds (Late seasonal phase)

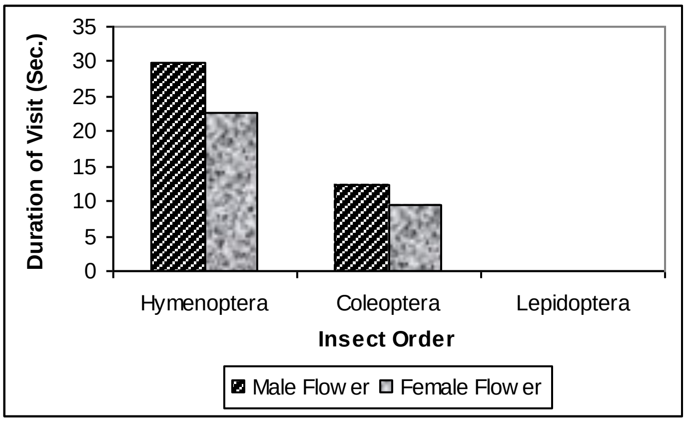


Table.35: Mean duration of pollinator (Order) visit in seconds

Species	Sex of flower	Initial Phase (IP)			Middle Phase (MP)			Late Phase (LP)		
		ip	mp	lp	ip	mp	lp	ip	mp	lp
Apis cerana	♂	10.1	7.5	6	12.66	9.83	7.83	8	6.5	5.5
	♀	9	6.75	5.5	11.25	8.5	6.08	7	5	4.16
Ceratina heiroglyphica	♂	3.16	2.5	1.25	4.16	3.75	1.25	1.41	1.16	0.33
	♀	1.91	1.66	0.66	3	1.83	0.66	1	0.75	0.08
Amegilla parhypate	♂	0	0	0	0.41	0	0	0	0	0
	♀	0	0	0	0.25	0	0	0	0	0
Braunsapis picitarsis	♂	0	0	0	0	0.41	0	0	0	0
	♀	0	0	0	0	0.25	0	0	0	0
Apis florea	♂	0	0	0	0	0.25	0	0	0	0
	♀	0	0	0	0	0.08	0	0	0	0
Ceratina smaragdula	♂	0	0	0	0	0.08	0	0	0	0
	♀	0	0	0	0	0.08	0	0	0	0
Apis dorsata	♂	0	0	0	0	0.16	0	0	0	0
	♀	0	0	0	0	0.08	0	0	0	0
Halictus timidus	♂	4.08	3.58	1.91	4.75	4.58	2.08	2.16	1.5	0.41
	♀	3.66	2.91	1	3.91	3.08	1.41	1.5	1.08	0.16
Halictus taprobanae	♂	0.91	0.83	0.16	1	1	0.5	0.66	0.66	0.16
	♀	0.66	0.58	0.16	1	1	0.41	0.5	0.5	0.08
Trigona iridipennis	♂	1	1	0.25	1.5	1.5	0.5	0.58	0.5	0.16
	♀	0.58	0.58	0.25	0.66	0.58	0.25	0.41	0.41	0.08
Xylocopa aestuans	♂	0	0	0	0	0.16	0	0	0	0
	♀	0	0	0	0	0.08	0	0	0	0
Xylocopa tenuiscapa	♂	0	0	0	0	0.16	0	0	0	0
	♀	0	0	0	0	0.08	0	0	0	0
Aulacophora foveicollis	♂	3.25	3	1.83	0.75	0.66	0.66	3.25	2.33	1.67
	♀	2.41	2.08	1.16	0.66	0.58	0.5	2.25	2.08	1.58
Aulacophora lewisii	♂	2.66	1.75	1.41	0.83	0.75	0.58	2.25	1.5	1.25
	♀	2.41	1.25	1.16	0.75	0.75	0.75	1.66	1.08	0.91
Cephonodes picus	♂	0	0	0	0.41	0	0	0	0	0
	♀	0	0	0	0.33	0	0	0	0	0
Macroglossum troglodytus	♂	0	0	0	0.25	0	0	0	0	0
	♀	0	0	0	0.25	0	0	0	0	0

IP - Initial phase of season　ip - initial phase of day　♂ -Male flower
MP - Middle phase of season　mp - middle phase of day　♀ -Female flower
LP - Late phase of season　lp - late phase of day

Figure.283: Mean duration of visit on flowers by pollinators (Species) in seconds (Initial seasonal phase)

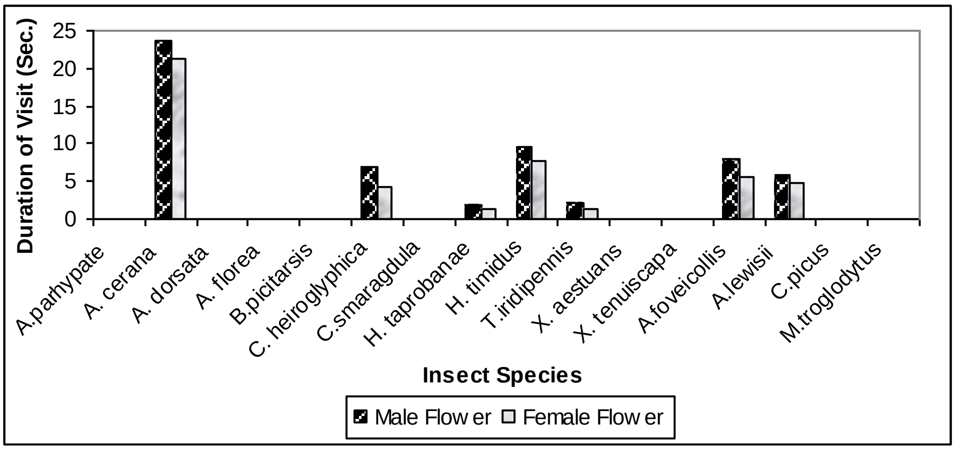


Figure.284: Mean duration of visit on flowers by pollinators (Species) in seconds (Middle seasonal phase)

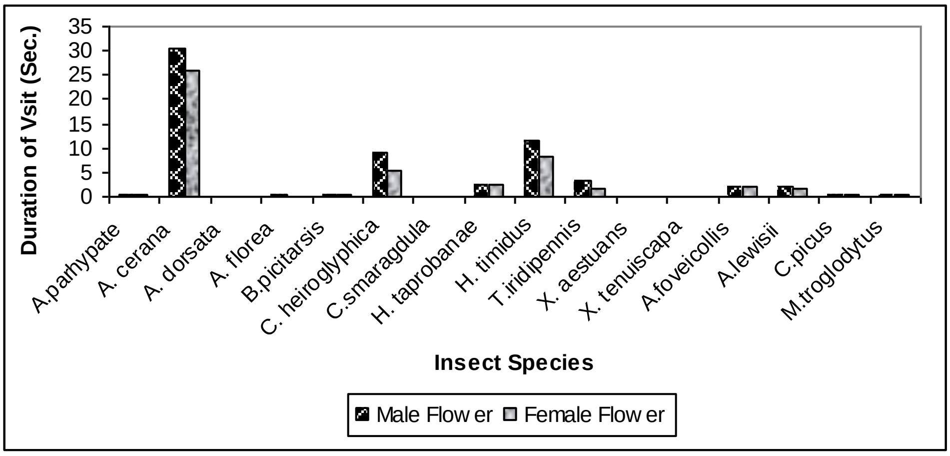
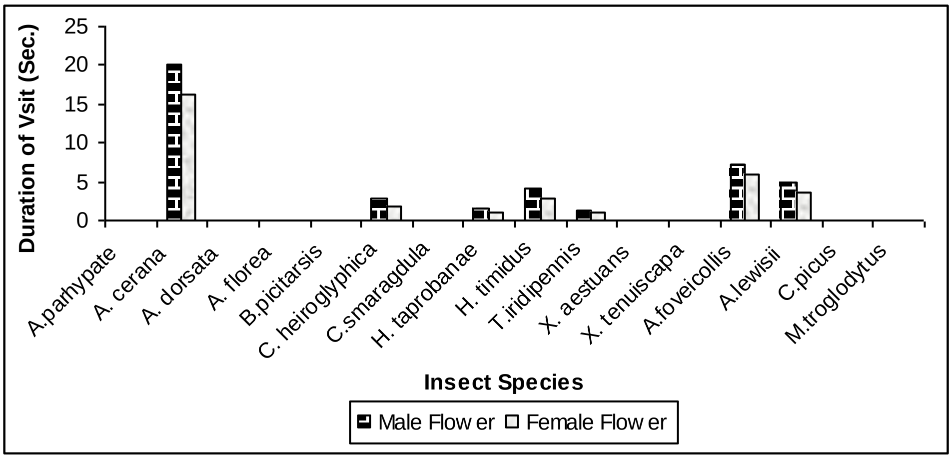


Figure.285: Mean duration of visit on flowers by pollinators (Species) in seconds (Late seasonal phase)



4.5.3. Palynology

4.5.3.1. Pollen Count

The mean pollen grains produced by staminate flowers varied by phases of the season. It was highest in middle phase than in initial and late phase of the season. At anthesis, staminate flowers contained maximum pollen grains /flower and the number of pollen grains remaining on anthers decreased over time of day IP [ip (17150.75±53.53); mp (13093±10.08); lp (4379.83±53.05)]; MP [ip (35800.67±91.86); mp (25166.17±7.39); lp (3635±88.37)]; LP [ip (12787.08±32.21) mp (10011.33±5.71) lp (4851.83±36.85)]. The mean number of pollen grains produced was highest in the initial diurnal phase (17150.75±53.53) of middle seasonal phase and lowest in the late diurnal phase (4851.83±36.85) of late seasonal phase. The counts were significantly different in different phases of day such as IP (p=0.00) (Figure 286); MP (p=0.00) (Figure 287); LP (p=0.00) (Figure 288) and between the seasonal phases (p=0.00) (Figure 289).

Figure.286: Mean pollen counts in diurnal phases (Initial seasonal phase)

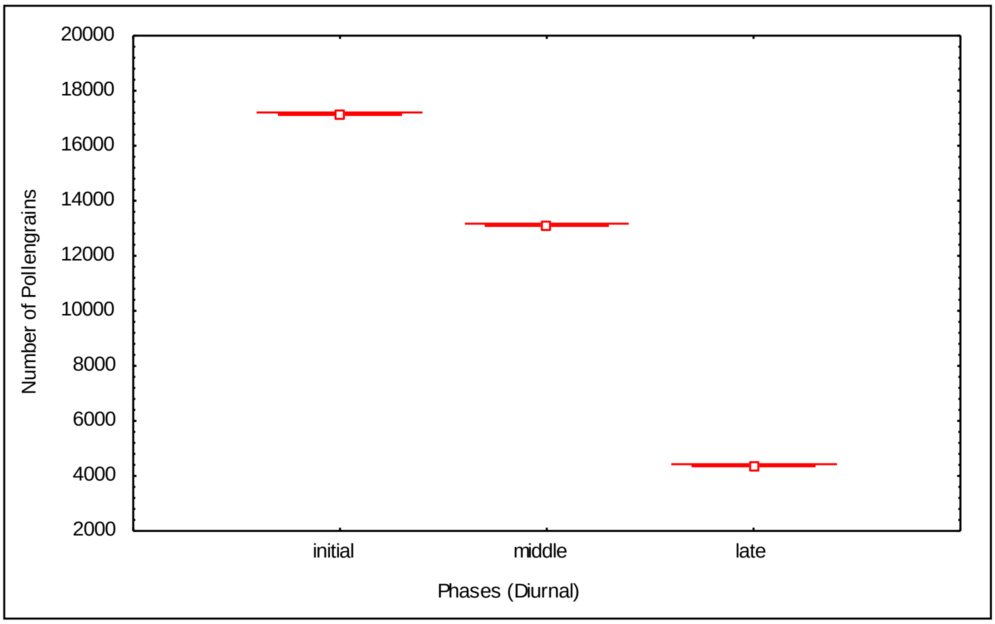


Figure.287: Mean pollen counts in diurnal phases (Middle seasonal phase)

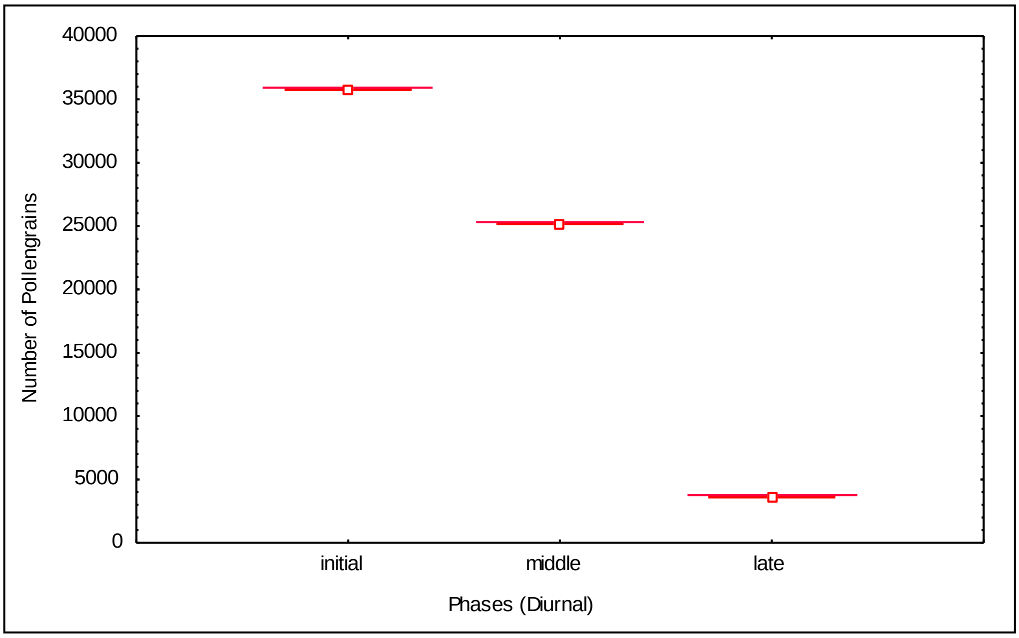


Figure.288: Mean pollen counts in diurnal phases (Late seasonal phase)

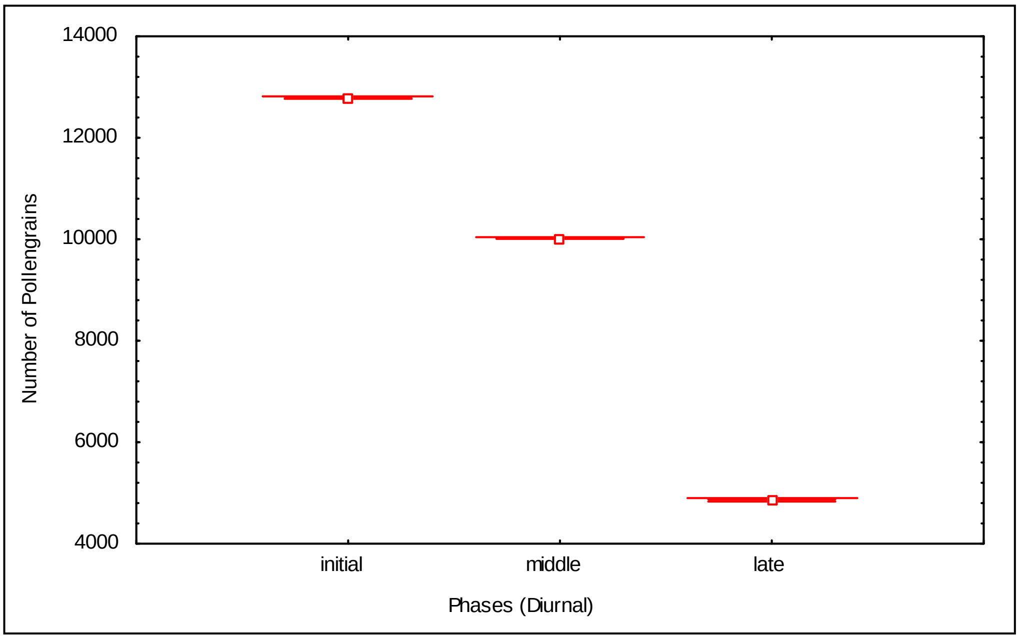
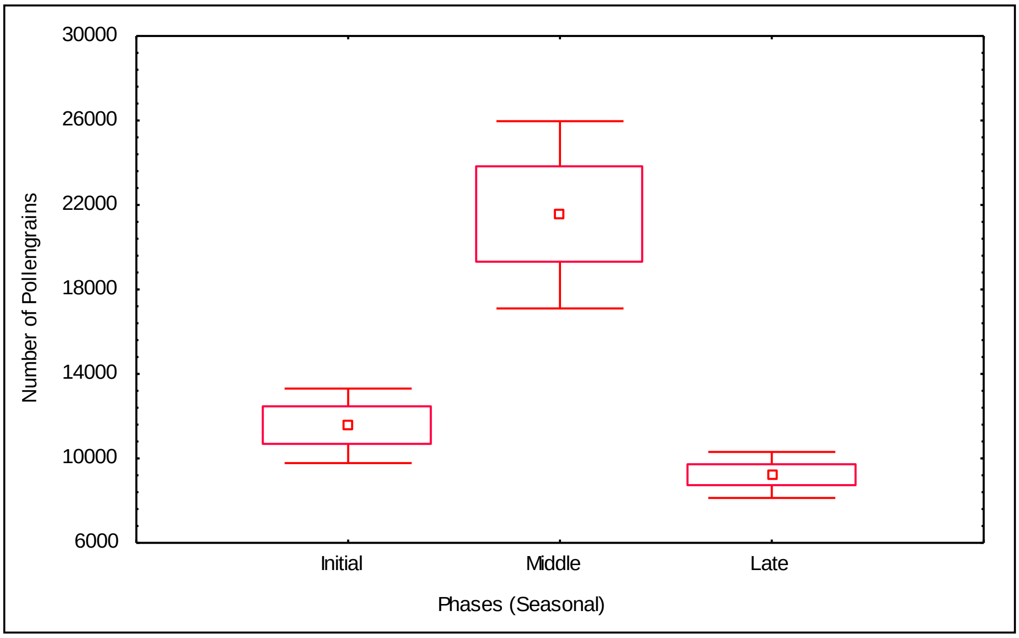


Figure.289: Mean pollen counts in different phases of the season



4.5.3.2. Pollen Removal

The mean number of pollen grains removed from staminate flowers varied by phases of the day and season. Pollen removal increased from IP [ip (4057.75±63.53); mp (8713.16±43.02); lp (1406.25±14.66)]; to MP [ip (10634.5±99.09); mp (21531.16±81.06); lp (3244.75±21.20)] and then decreased to LP [ip (2775.75±37.83); mp (5159.5±31.16); lp (934±14.12)] of the day and season. In middle diurnal phase of middle seasonal phase maximum number of pollen grains (21531.16±81.06) were removed. In late diurnal phase of late seasonal phase minimum number of pollen grains (934±14.12) were removed. The counts were significantly different in different phases of day such as IP (p=0.00) (Figure.290); MP (p=0.00) (Figure 291); LP (p=0.00) (Figure 292) and between the seasonal phases (p=0.00) (Figure 293).

Figure.290: Mean pollen removal in diurnal phases (Initial seasonal phase)

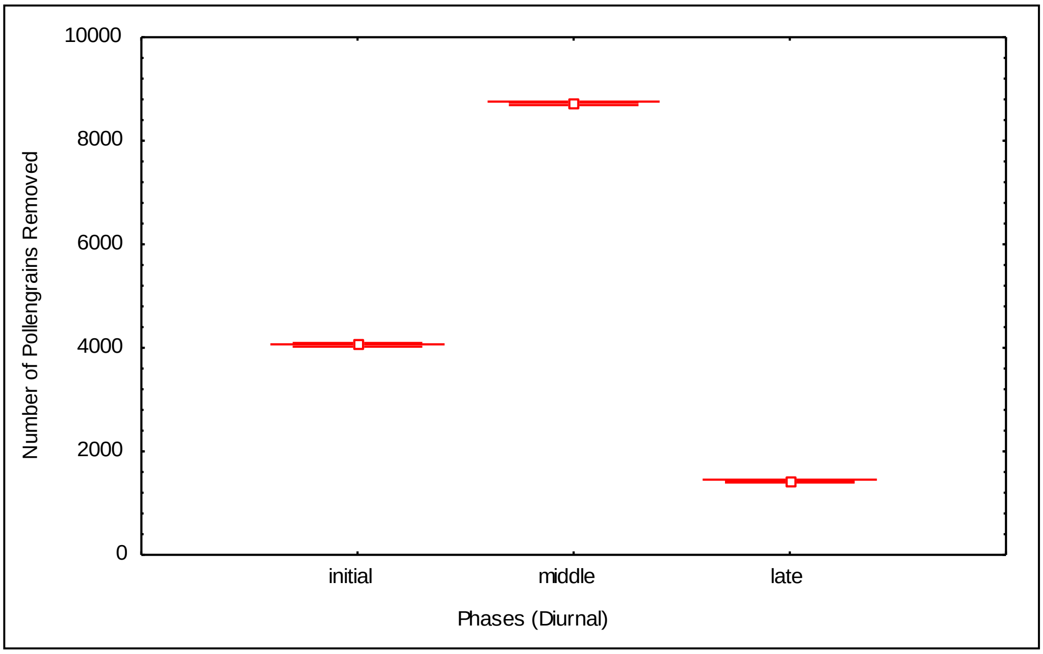


Figure.291: Mean pollen removal in diurnal phases (Middle seasonal phase)

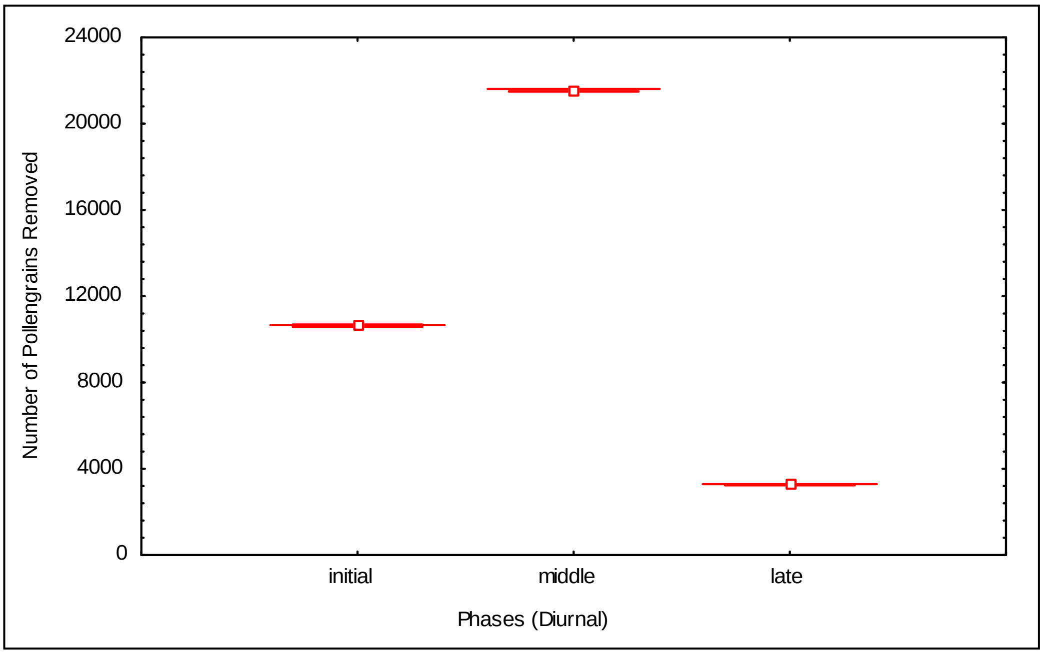


Figure.292: Mean pollen removal in diurnal phases (Late seasonal phase)

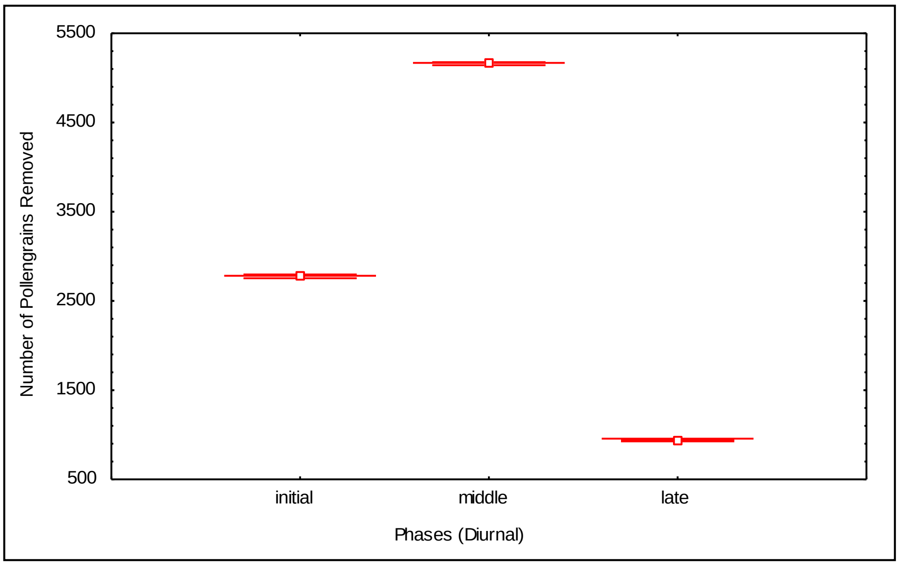
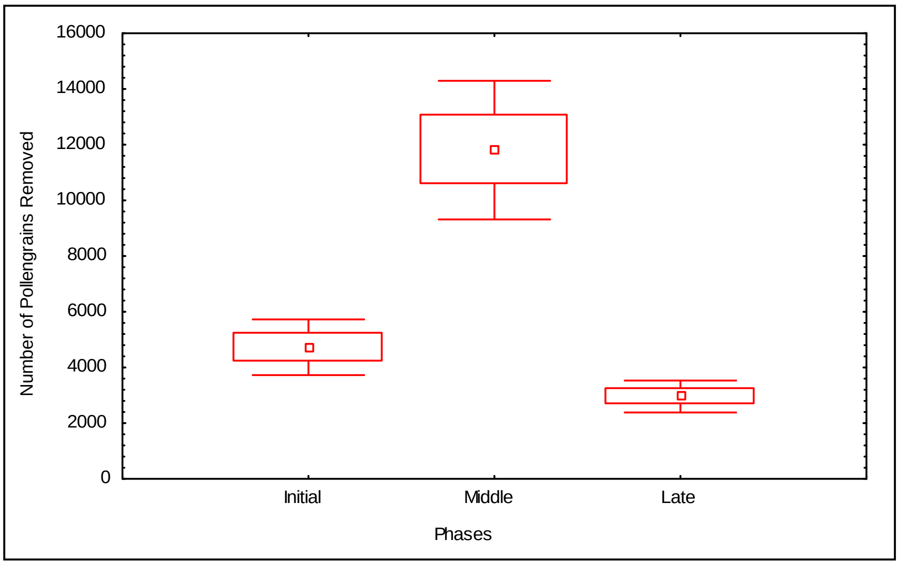


Figure.293: Mean pollen removal in different phases of the season



4.5.3.3. Pollen Deposition

Pollen deposition rate varied by time of day and season. The mean number of pollen grains deposited on stigma of pistillate flowers increased from IP [ip (1932.25±22.88); mp (4136.41±23.03); lp (651.58±13.24)]; to MP [ip (5056.91±31.22); mp (10456.83±72.18); lp (1503.91±46.94)] and then decreased to LP [ip (1287.58±7.36); mp (2451.08±16.60); lp (402.91±14.43)]. Maximum pollen grains were deposited in the middle diurnal phase (10456.83±72.18) of middle phase of the season and minimum pollen grains were deposited in the late diurnal phase (402.91±14.43) of late phase of the season. The counts were significantly different in different phases of day such as IP (p=0.00) (Figure 294); MP (p=0.00) (Figure 295); LP (p=0.00) (Figure 296) and between the seasonal phases (p=0.00) (Figure 297).

Figure.294: Mean pollen deposition in diurnal phases (Initial seasonal phase)

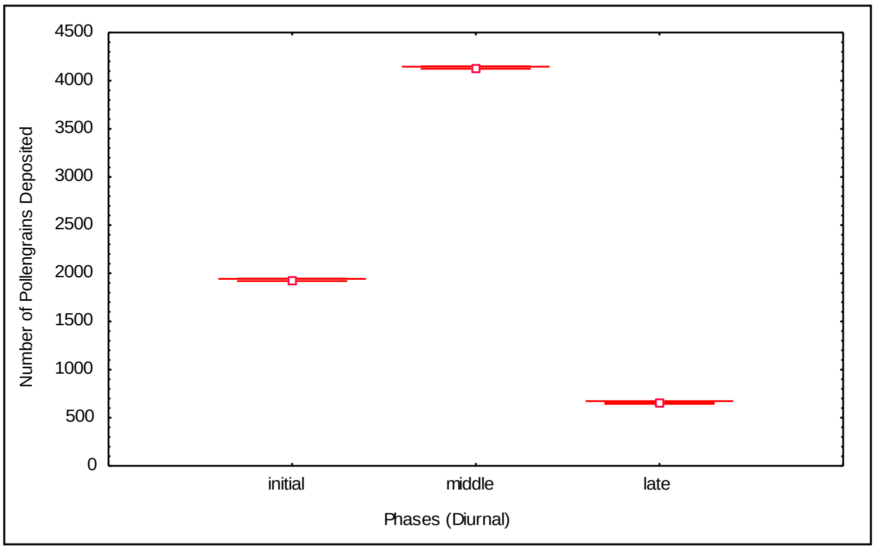


Figure.295: Mean pollen deposition in diurnal phases (Middle seasonal phase)

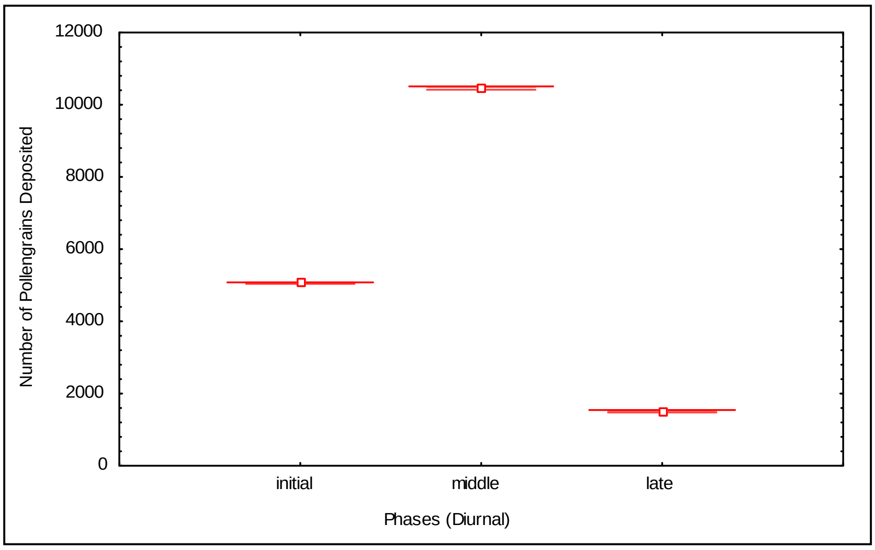


Figure.296: Mean pollen deposition in diurnal phases (Late seasonal phase)

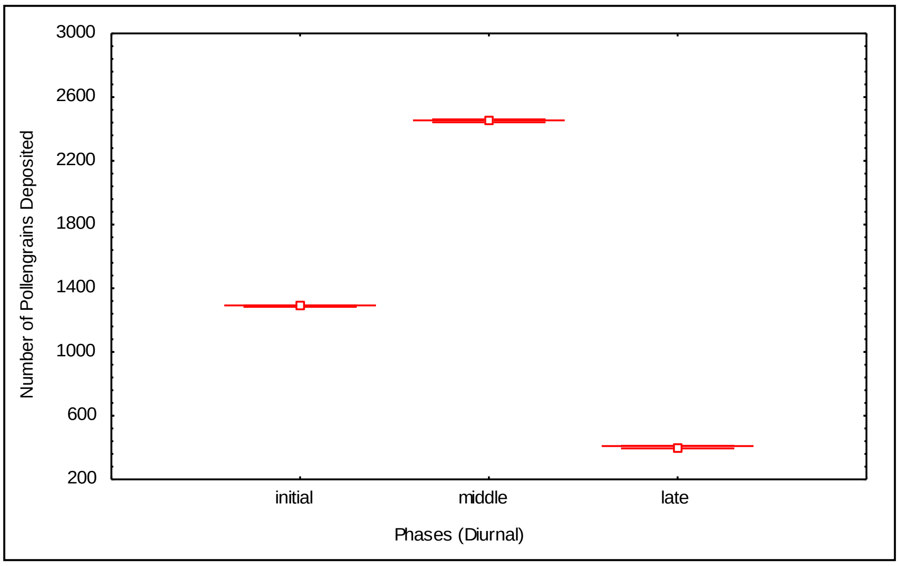
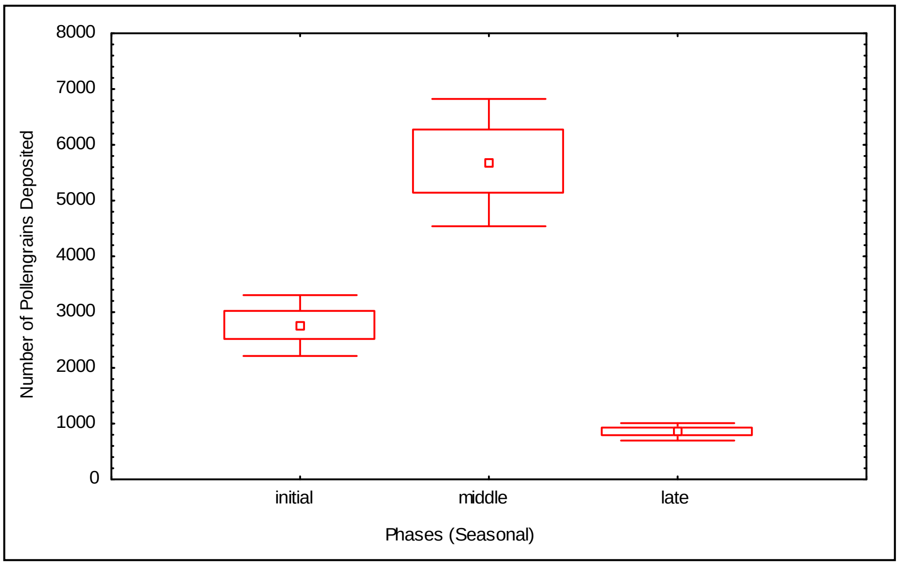


Figure.297: Mean pollen deposition in different phases season



4.5.3.4. Pollen Viability

Viability of pollen grains were also found decreasing through diurnal phases of each season, IP [ip (2442.41±26.21); mp (2265±25.69); lp (2075.5±16.21)]; MP [ip (10051.08±35.19) mp (8993.75±34.35) lp (8290.5±32.82)]; LP [ip (1674.5±11.8) mp (1555.33±16.35) lp

(1287.33±8.11)] and the variations in diurnal phases of each season were significantly different. IP (p=0.00) (Figure 298) MP (p=0.00) (Figure 299), LP (p=0.00) (Figure 300). Viability increased from initial phase of the season to middle phase. Maximum viable pollen grains were observed in initial diurnal phase of middle seasonal phase (10051.08±35.19). Minimum number of viable pollen grains were observed in late diurnal phase (1287.33±8.11) of late seasonal phase. Significant difference was found in the viability of pollen grains between the seasonal phases also (p=0.00) (Figure 301).

Figure.298: Mean pollen viability in diurnal phases (Initial seasonal phase)

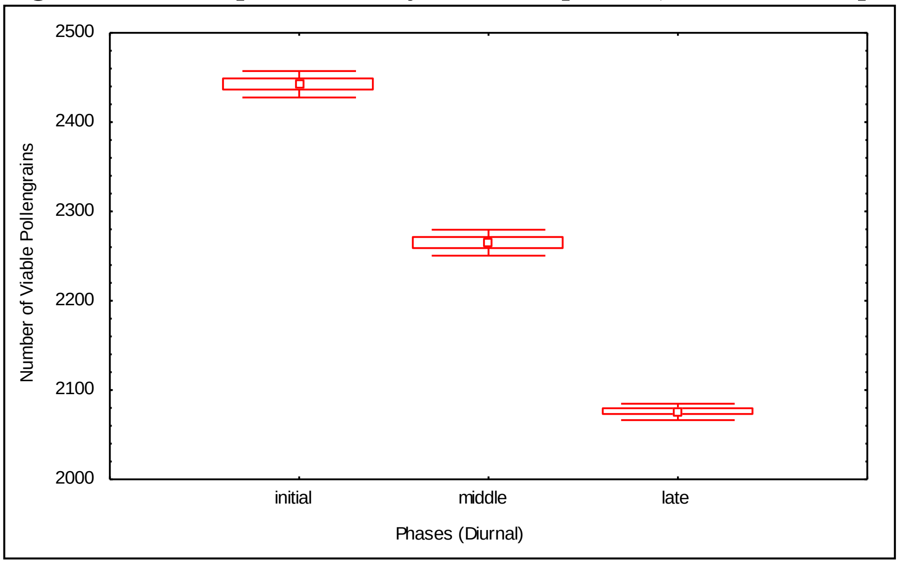


Figure.299: Mean pollen viability in diurnal phases (Middle seasonal phase)

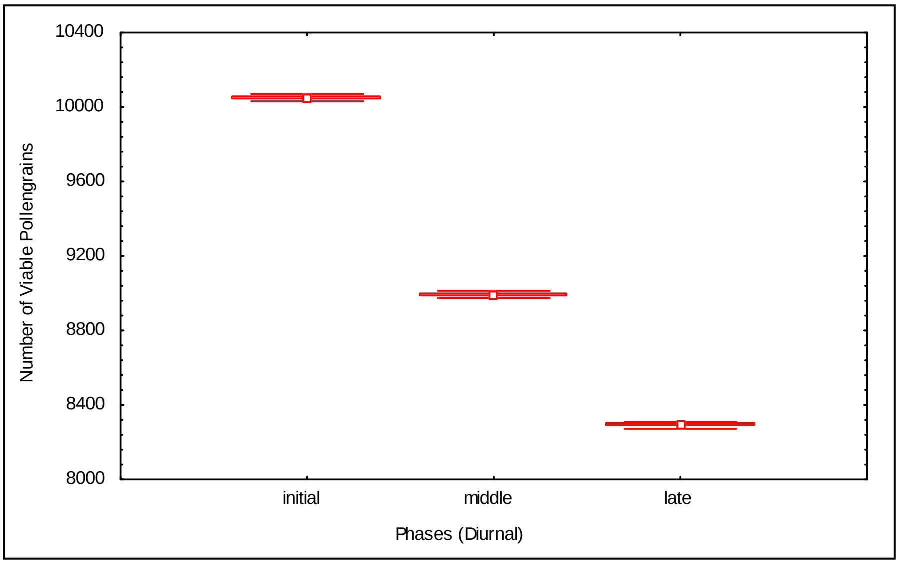


Figure.300: Mean pollen viability in diurnal phases (Late seasonal phase)

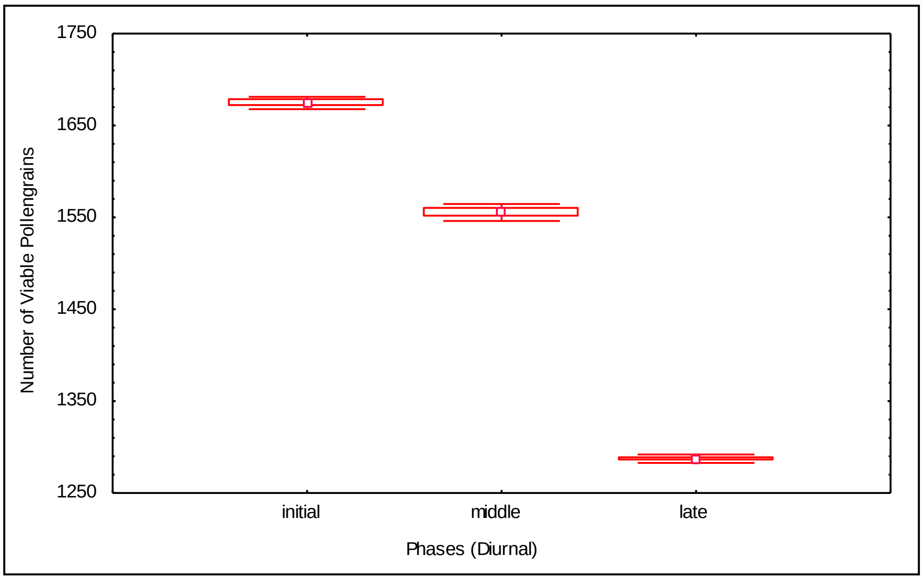
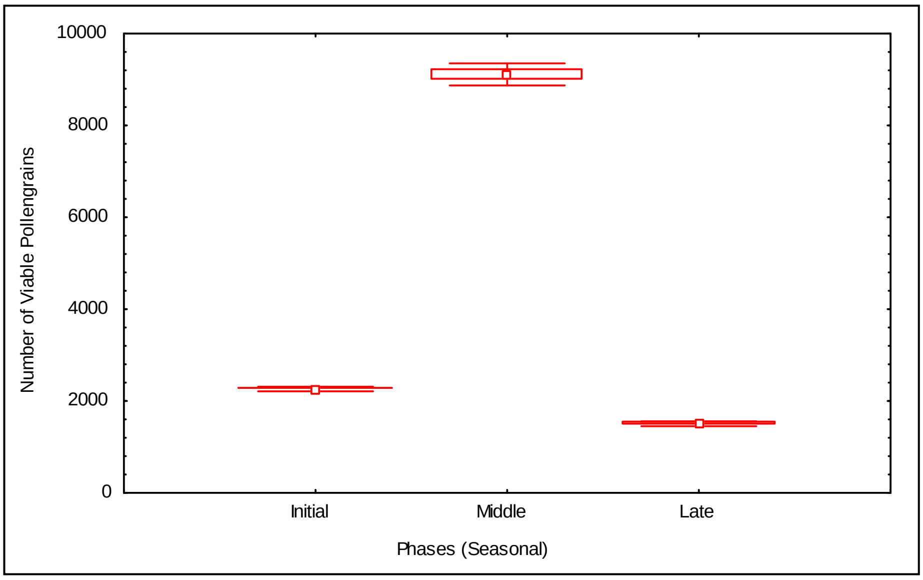


Figure.301: Mean pollen viability in different phases of the season



4.5.4. Pomology

4.5.4.1. Fruit Set

From the bagging experiment it was observed that percentage of fruits increased from initial phase [IP (33.71%) : (ip)=11.23%; (mp)=15.73%; (lp)=6.74%] to middle phase [MP (39.32%) : (ip)=13.48 %;

(mp)=17.97%; (lp)=7.86%] and then decreased to late phase [LP (26.96%) : (ip)=8.98%; (mp)=12.35%; (lp)=5.61%]. All non pollinated flowers were aborted (np=0.00). Percentage of fruits within each seasonal phase such as IP (p=0.00) (Figure 302); MP (p=0.00) (Figure 303); LP (p=0.00) (Figure 304) and between the seasonal phases were significantly different (Figure 305).

Figure.302: Percentage of fruits in diurnal phases (Initial seasonal phase)

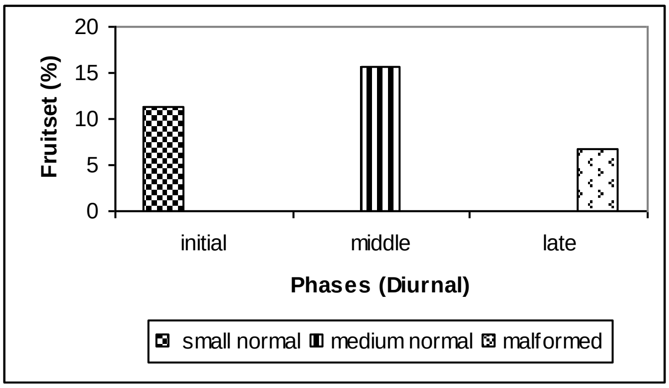


Figure.303: Percentage of fruits in diurnal phases (Middle seasonal phase)

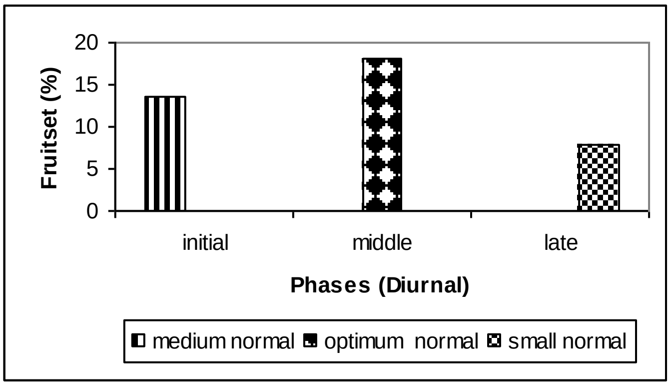


Figure.304: Percentage of fruits in diurnal phases (Late seasonal phase)

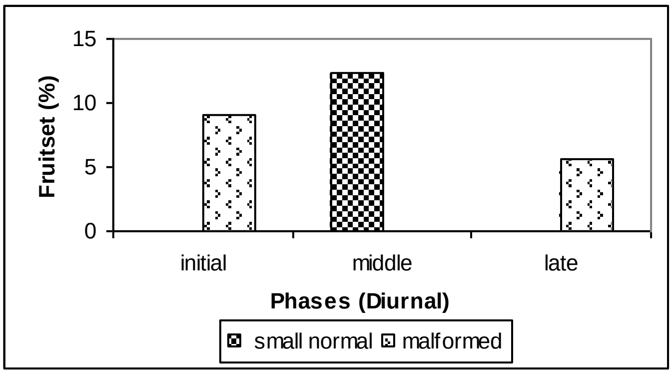
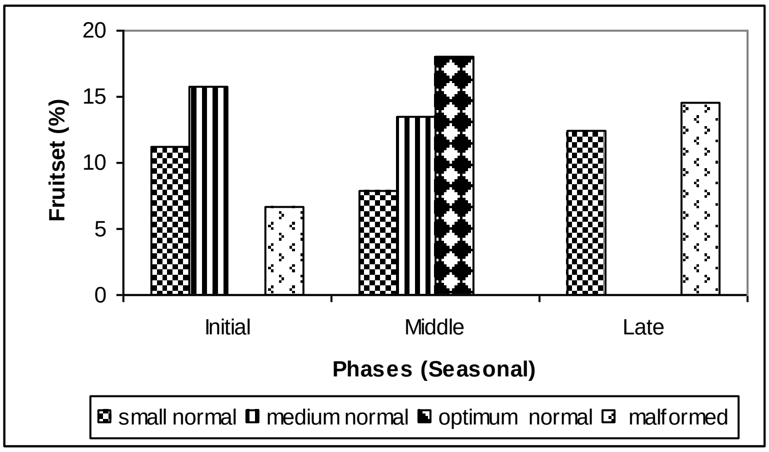


Figure.305: Percentage of fruits in different phases of season



4.5.4.2. Nature of Fruits

Fruits with varied shape and size were produced in the different phases of season. When size was measured in terms of length (l) and breadth (b) it was observed that fruits formed in different diurnal and seasonal phases were differed in the maximum size they attained. By comparing each other fruits with lb ≤ 20 cm. x15 cm. were included in small sized ones, ≤ 30 cm. x 20 cm. and ≤ 40 cm. x 30 cm. were included in the group of medium and optimum sized ones respectively. Also on the basis of shape the fruits were categorized into normal and malformed ones. So four categories like small normal, medium normal, optimum normal and malformed fruits were found when size and shape were considered together for the assessment of nature of fruits [IP (ip)=11.23% small normal; (mp)=15.73% medium normal; (lp)=6.74% malformed; MP (ip)=13.48% medium normal; (mp)=17.97% optimum normal; (lp)=7.86% malformed; LP (ip)=8.98% malformed; (mp)=12.35% small normal; (lp)=5.61% malformed] (Plate 11). All non pollinated flowers were aborted in all phases. Majority of fruits formed in the initial and middle phase were normal shaped and in late phase were malformed. Size and shape of the fruits varied significantly within seasonal phases IP (p=0.00) (Figure 302);

MP (p=0.00) (Figure 303); LP (p=0.00) (Figure.304) and between the seasonal phases (P=0.00) (Figure.305).

4.5.4.3. Weight of Fruits

Mean weight of fruits increased from initial phase, IP [(ip)=429±20.66 gm.; (mp)=1235.16±32.35 gm.; (lp)=79.08±82.61 gm.] to middle phase, MP [(ip)=1491.16±35.28 gm.; (mp)=3378.08±76.51 gm.; (lp)=249.08±220.67 gm.] and then decreased to late phase, LP [(ip)=255.83±189.15 gm.; (mp)=704.16±223.48 gm.; (lp)=48.75±60.25 gm.] of the day and season. As non pollinated flowers were aborted no weights were recorded. In middle diurnal phase of middle seasonal phase the average weight of fruit was highest (3378.08±76.51gm). In late diurnal phase of late seasonal phase the average weight of fruit was lowest (48.75±60.25 gm.). Mean weights of fruits within seasonal phases such as IP (p=0.00) (Figure 306); MP (p=0.00) (Figure 307); LP (p=0.00) (Figure 308) and between the seasonal phases were significantly different (p=0.00) (Figure 309).

Figure.306: Mean weight of fruits in diurnal phases (Initial seasonal phase)

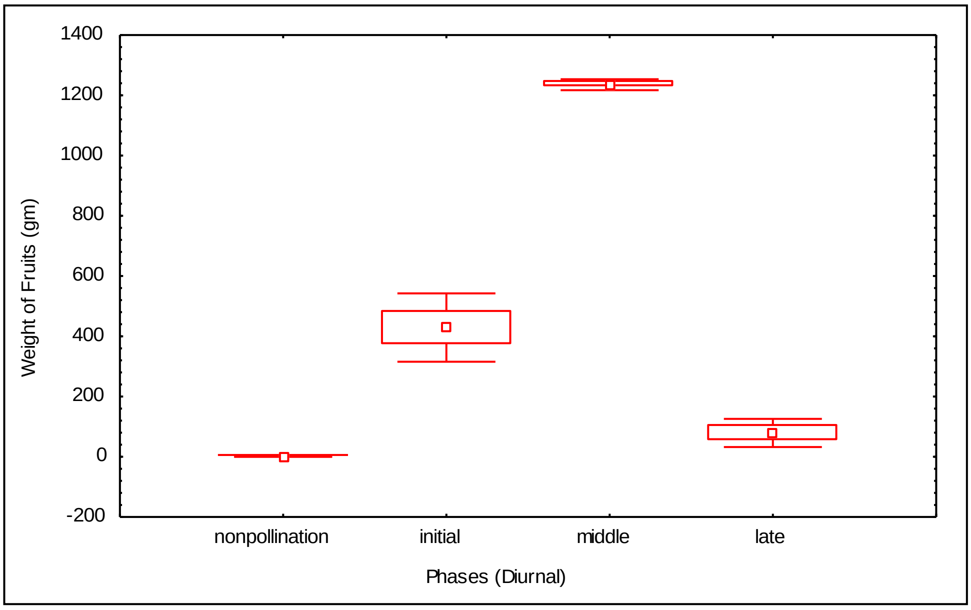


Figure.307: Mean weight of fruits in diurnal phases (Middle seasonal phase)

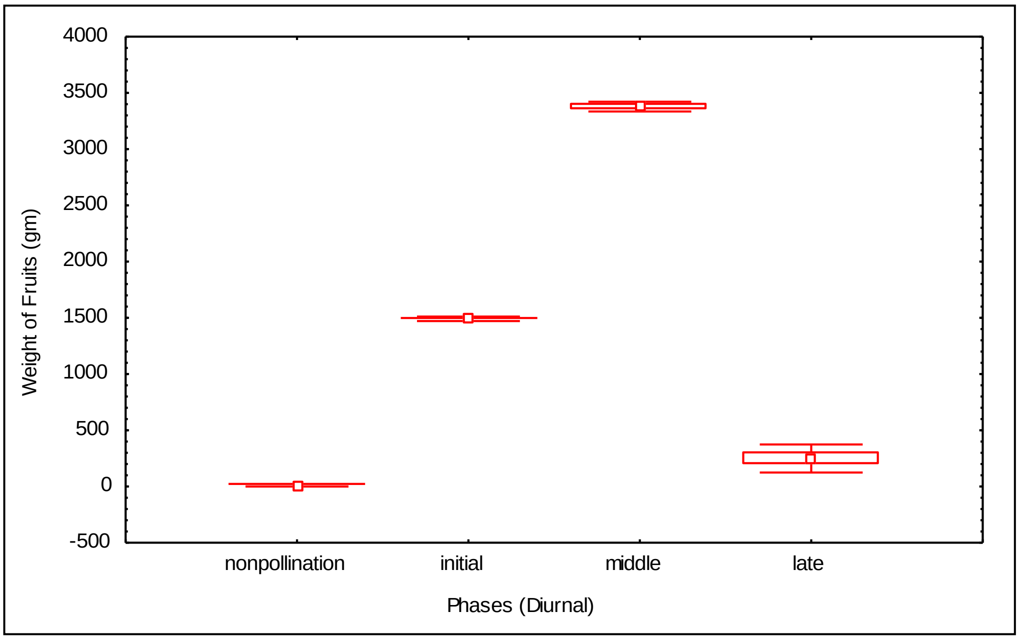


Figure.308: Mean weight of fruits in diurnal phases (Late seasonal phase)

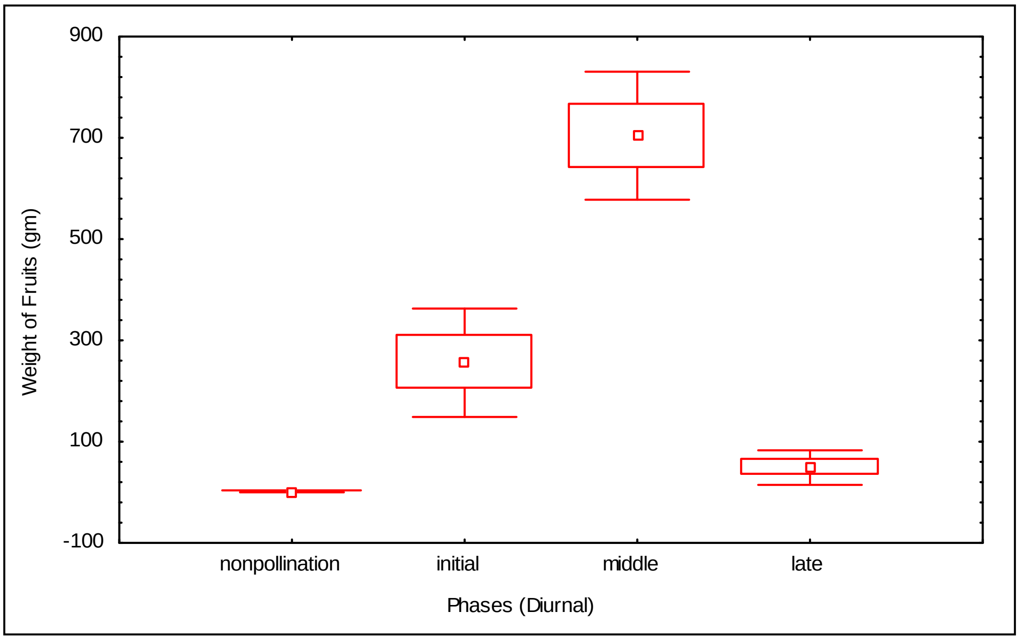
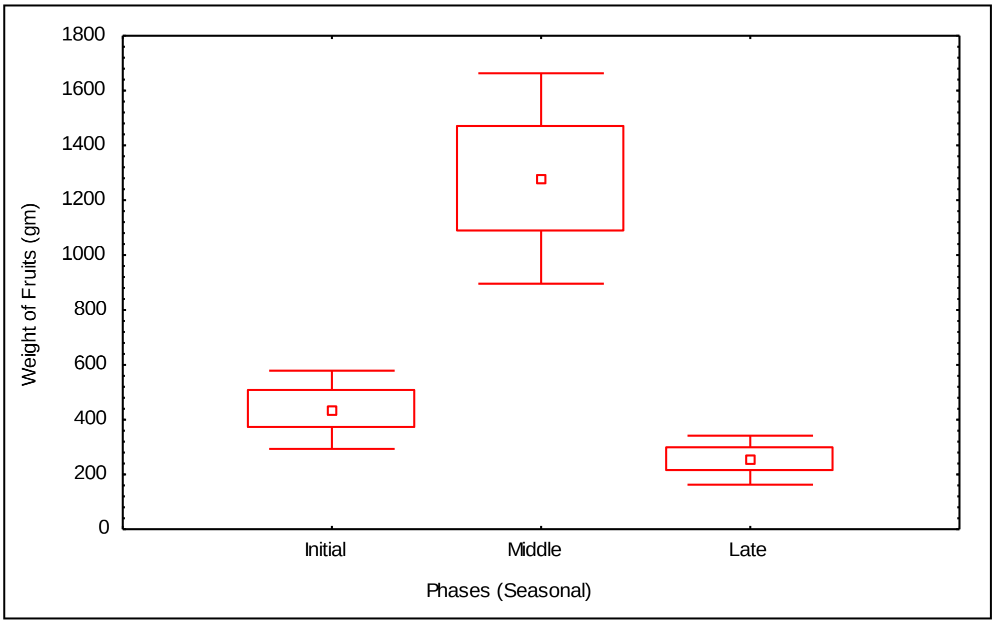


Figure.309: Mean weight of fruits in different phases of season



4.5.4.4. Number of Seeds

Mean number of seeds increased from initial phase [IP (ip=58.58±27.47; mp=171.16±7.19; lp=10.33±10.81) to middle phase [MP (ip=200±7.96; mp=474.75±16.34; lp=30.75±27.30)] and then decreased to late phase [LP (ip=30.41±22.50; mp=85.25±27.11; lp=5.41±6.72)] of the day and season. As non pollinated flowers were aborted no seeds were recorded. Maximum number of seeds were recorded in middle diurnal phase (474.75±16.34) of middle seasonal phase. In late diurnal phase of late seasonal phase minimum number of seeds (5.41±6.72) were recorded. Mean number of seeds within each seasonal phase such as IP (p=0.00) (Figure 310); MP (p=0.00) (Figure 311); LP (p=0.00) (Figure 312) and between the seasonal phases were significantly different (P=0.00) (Figure 313).

Figure.310: Mean number of seeds in diurnal phases (Initial seasonal phase)

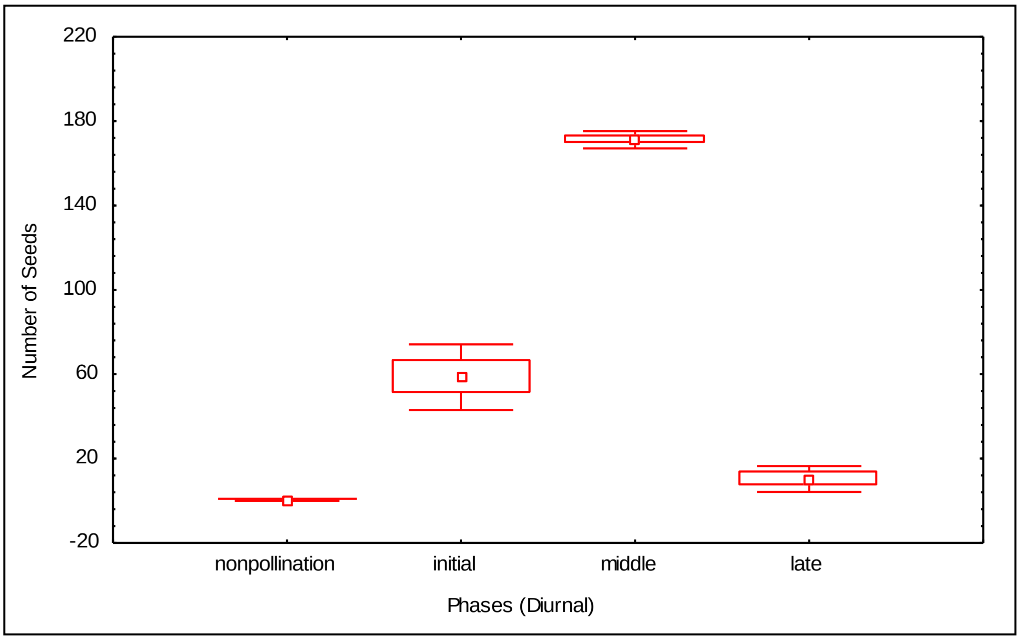


Figure.311: Mean number of seeds in diurnal phases (Middle seasonal phase)

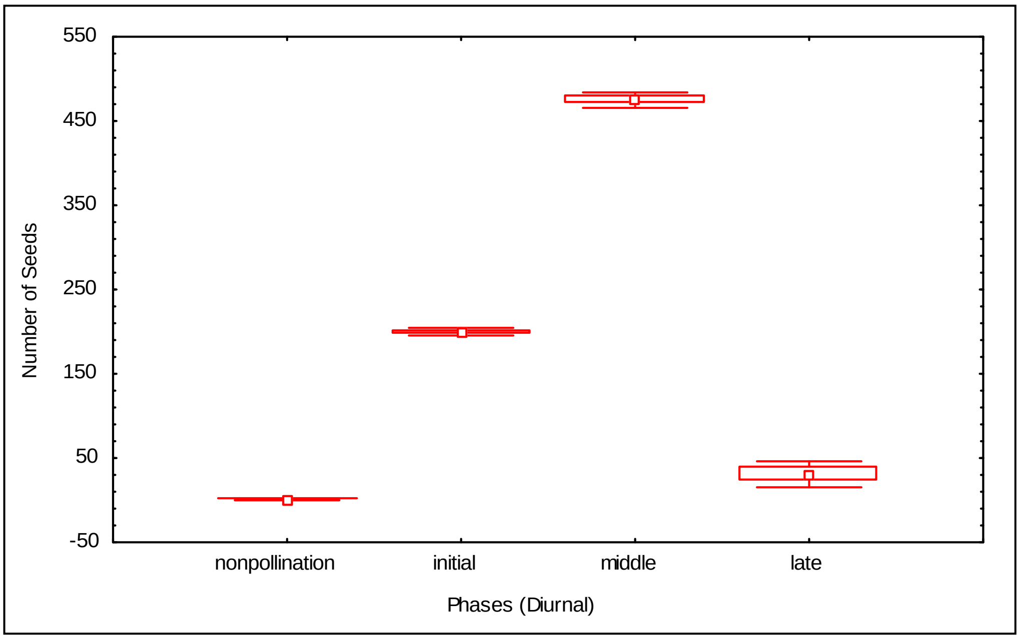


Figure.312: Mean number of seeds in diurnal phases (Late seasonal phase)

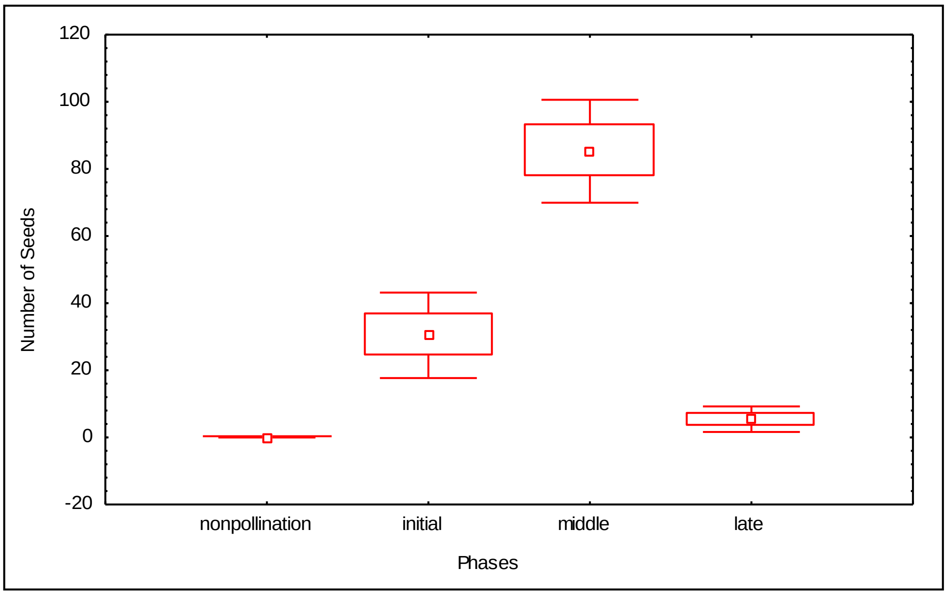
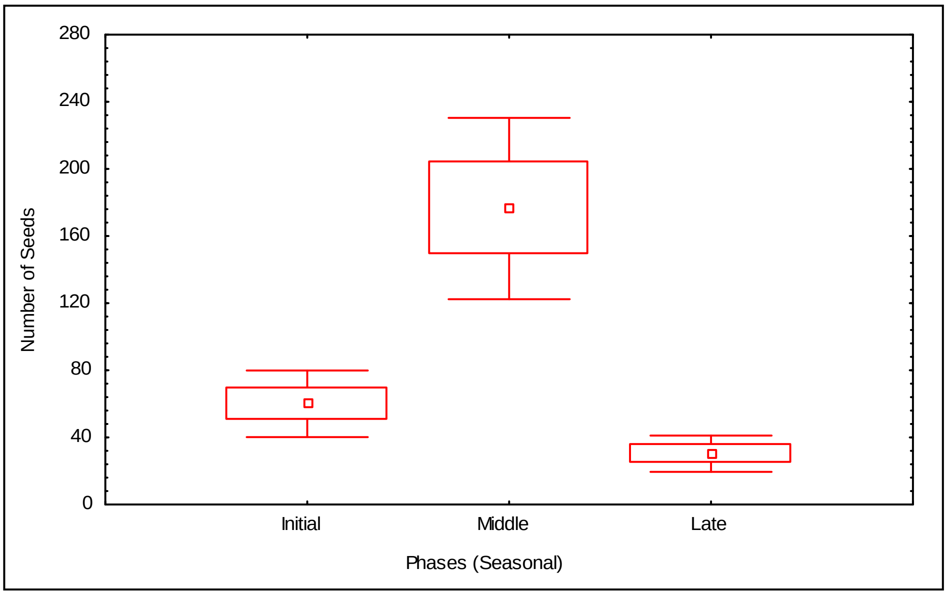


Figure.313: Mean number of seeds in different phases of season



4.5.4.5. Viability of Seeds

Mean number of viable seeds increased from initial phase of the season IP [ip=41.75±19.58; mp=145.58±6.17; lp=7.33±7.70] to middle phase of the season MP [ip=180.91±7.27; mp=458.41±17.89; lp=25±22.17] and then decreased to late phase LP [ip=16.41±12.18; mp=48.58±15.50;

lp=2.75±3.4] of the season. As non pollinated flowers were aborted no seeds were found. Maximum viable seeds were recorded in middle diurnal phase (458.41±17.89) of middle seasonal phase. In late diurnal phase of late seasonal phase least number of viable seeds (2.75±3.4) were recorded. Mean number of viable seeds within each seasonal phase such as IP (p=0.00) (Figure 314); MP (p=0.00) (Figure 315); LP (p=0.00) (Figure 316) and between the seasonal phases were significantly different (p=0.00) (Figure 317).

Figure.314: Mean number of viable seeds in diurnal phases (Initial seasonal phase)

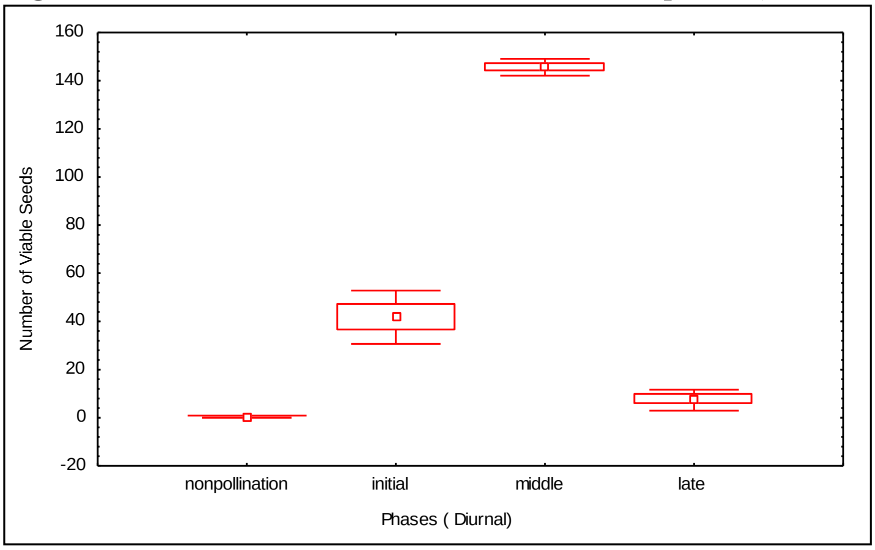


Figure.315: Mean number of viable seeds in diurnal phases (Middle seasonal phase)

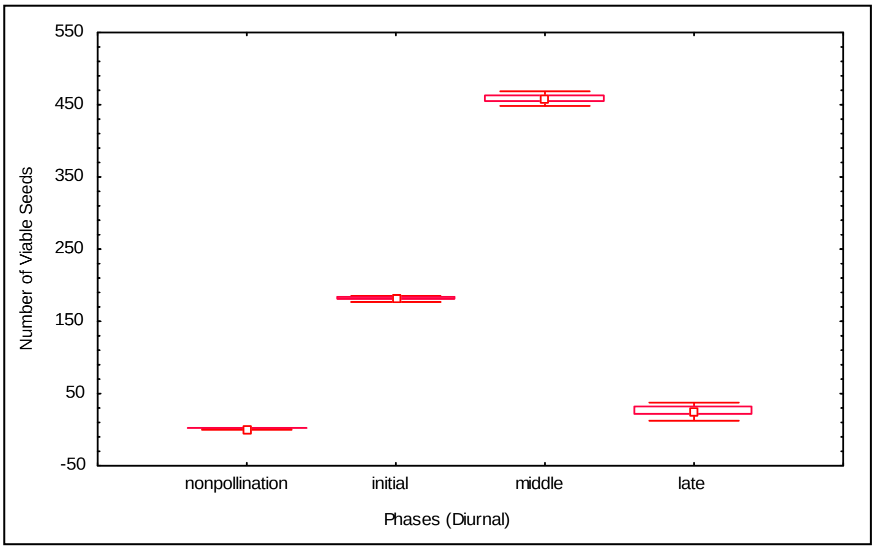


Figure.316: Mean number of viable seeds in diurnal phases (Late seasonal phase)

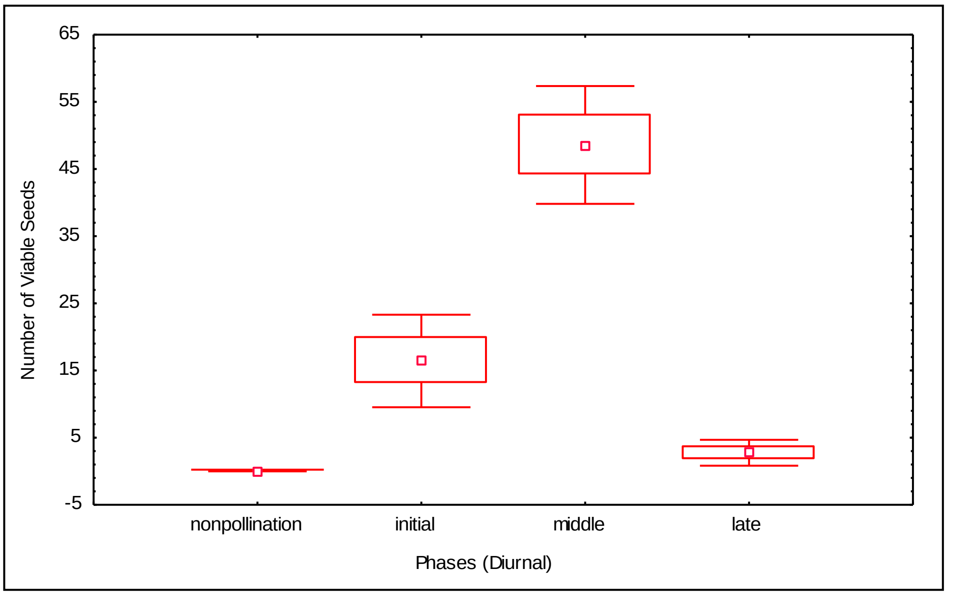
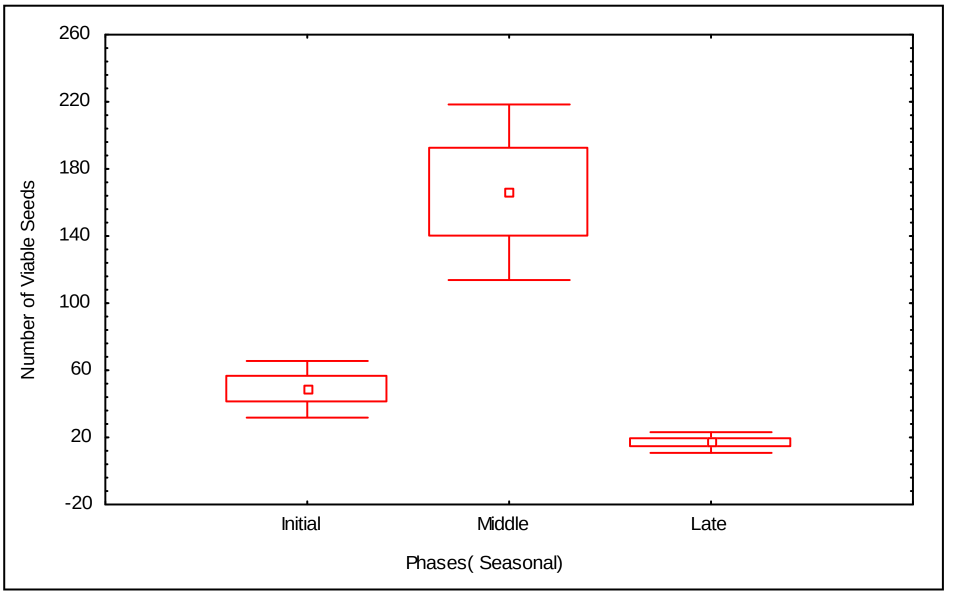


Figure.317: Mean number of viable seeds in different phases of season



4.5.5. Correlation

Positive correlation was observed between number of flowers and number of insects visited (r=0.98) (Figure 318), size of flowers and number of insects visited (r=0.98) (Figure 319), number of insects visited and number of pollen grains deposited (r=0.89) (Figure 320), duration of insect visit and number of pollen grains deposited (r=0.88) (Figure 321), number of pollen grains deposited and percentage of fruit set (r=0.78) (Figure 322), number of pollen grains deposited and weight of fruit (r=0.98) (Figure 323), number of pollen grains deposited and number of seeds (r=0.89) (Figure 324) and number of pollen grains deposited and number of seeds (r=0.90) (Figure 325).

Figure.318: Correlation between number of flowers /plant and number of insects visited

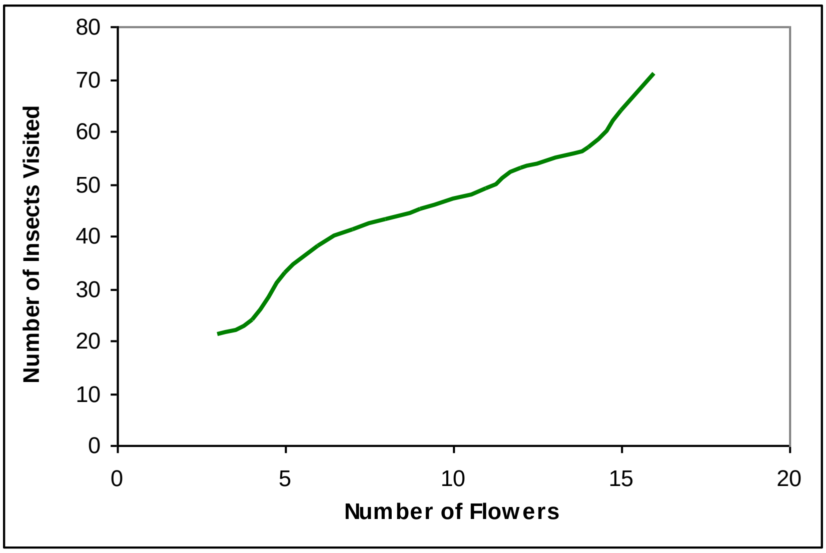


Figure.319: Correlation between size of flowers and number of insects visited

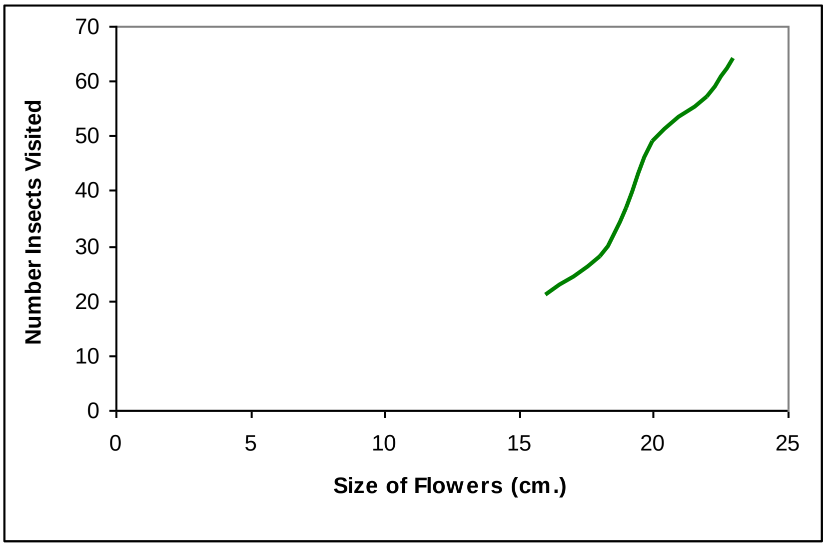


Figure.320: Correlation between number of insects visited and number of pollen grains deposited

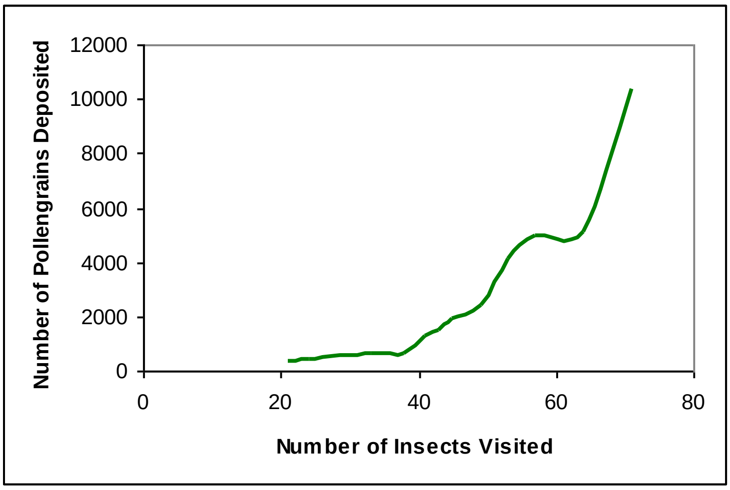


Figure.321: Correlation between duration of visit and number of pollen grains deposited

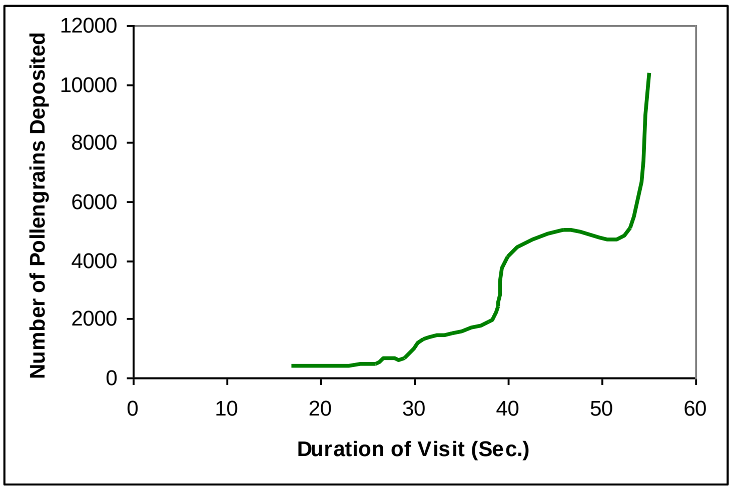


Figure.322: Correlation between number of pollen grains deposited and fruit set.

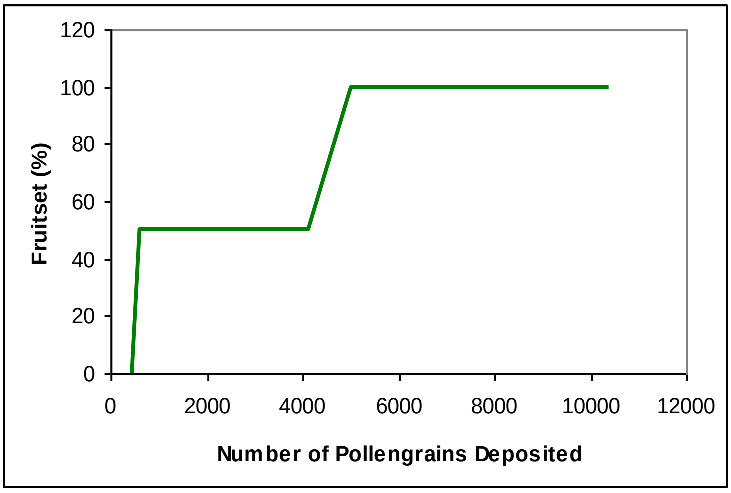


Figure.323: Correlation between number of pollen grains deposited and weight of fruit.

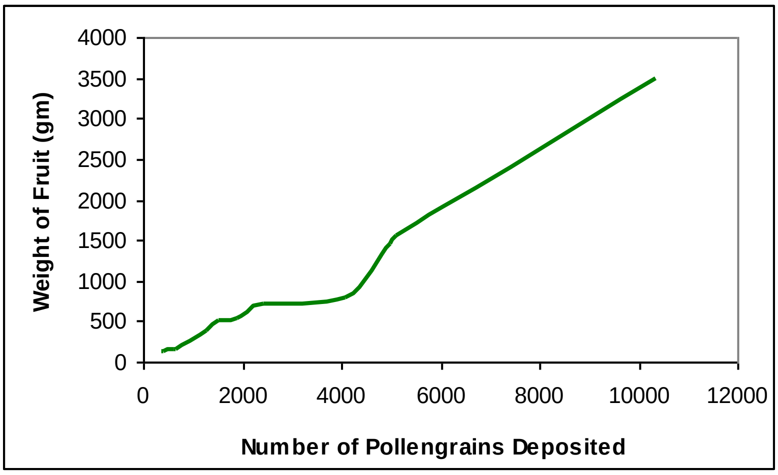


Figure.324: Correlation between number of pollen grains deposited and number seeds.

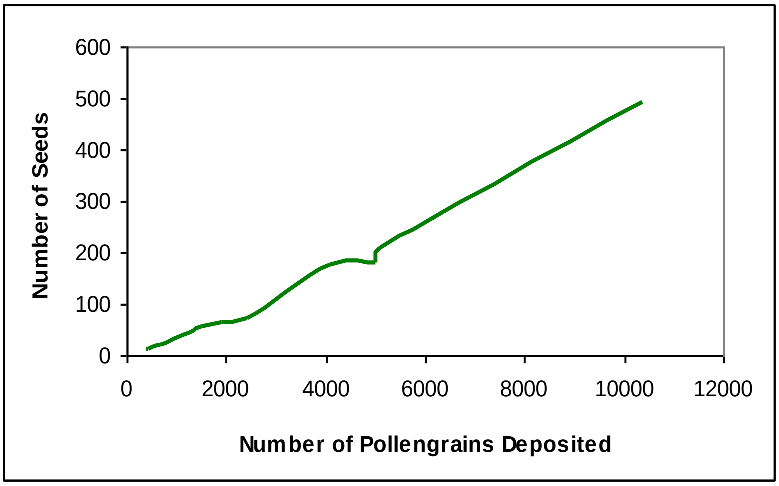


Figure.325: Correlation between number of pollen grains deposited and number of viable seeds.

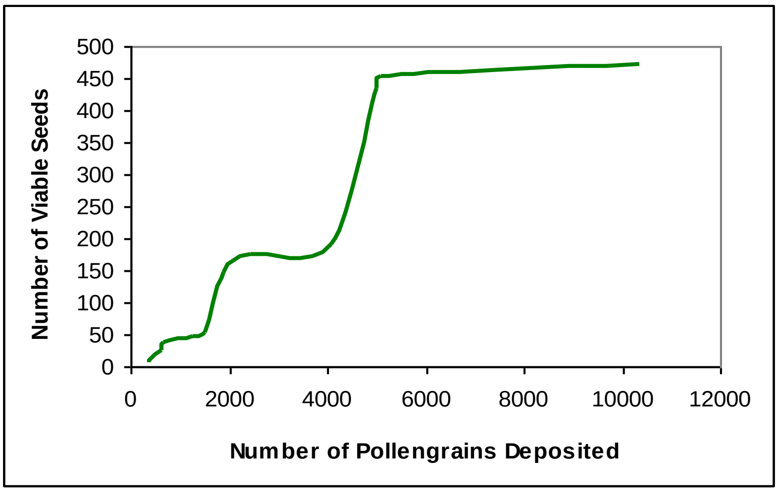


Plate 11

Pumpkin Fruit

Pumpkin Nonpollinated Ovary

Pumpkin Malformed Fruit

4.6. Interplant Comparison

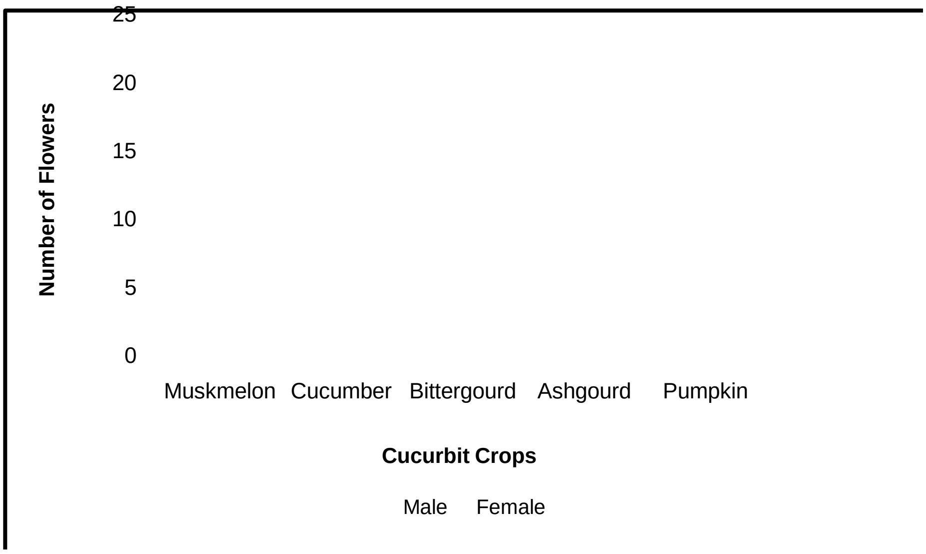
A comparison among the different cucurbits revealed commendable variability in all aspects of phenology, entomology, palynology and pomology. As highest pollination was observed in middle seasonal phase, data in that phase were taken into account for this interplant comparison.

4.6.1. Phenology

4.6.1.1. Number of Flowers

Highest number of male (♂) and female (♀) flowers /plant were observed in muskmelon [MP (♂=23.58±6.91, ♀=2.27±0.48)] which was followed by cucumber [(MP) (♂=21.09±4.19, ♀=2.07±0.51)], bittergourd [MP (♂=13.01±3.06, ♀=2.04±0.49)], ashgourd [MP (♂=9.67±2.62, ♀=2.02±0.37)] and pumpkin [MP (♂=8.00±1.98, ♀=2.01±0.62)] (Figure 326). Lowest number of flowers were found in pumpkin compared to other cucurbits.

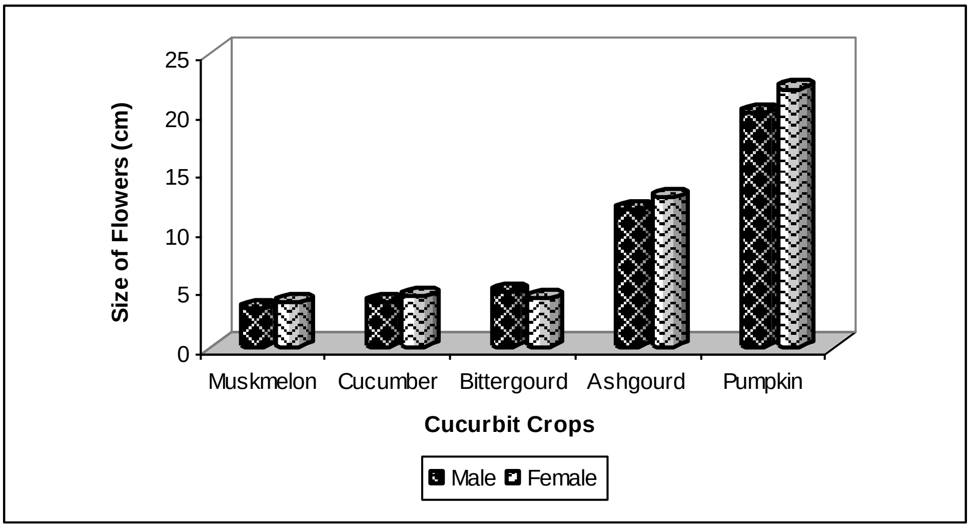
Figure.326: Mean number of male and female flowers produced /plant /day (Middle seasonal phase)



4.6.1.2. Size /Dimension of Flower

Large sized male (♂) and female (♀) flowers were found in pumpkin [MP (♂=19.88±0.87 cm., ♀=21.91±0.86 cm.)] which was followed by ashgourd [MP (♂=11.65±0.78 cm., ♀=12.65±0.78 cm.)], bittergourd MP (♂=4.60±0.50 cm., ♀=4.10±0.50 cm.), cucumber [(MP) (♂=3.73±0.39 cm., ♀=4.23±0.39 cm.)] and muskmelon [(MP) (♂=3.23±0.38 cm., ♀=3.73±0.38 cm.)] (Figure 327). Small sized flowers were observed in muskmelon compared to other cucurbits.

Figure.327: Mean size of male and female flowers produced (Middle seasonal phase)

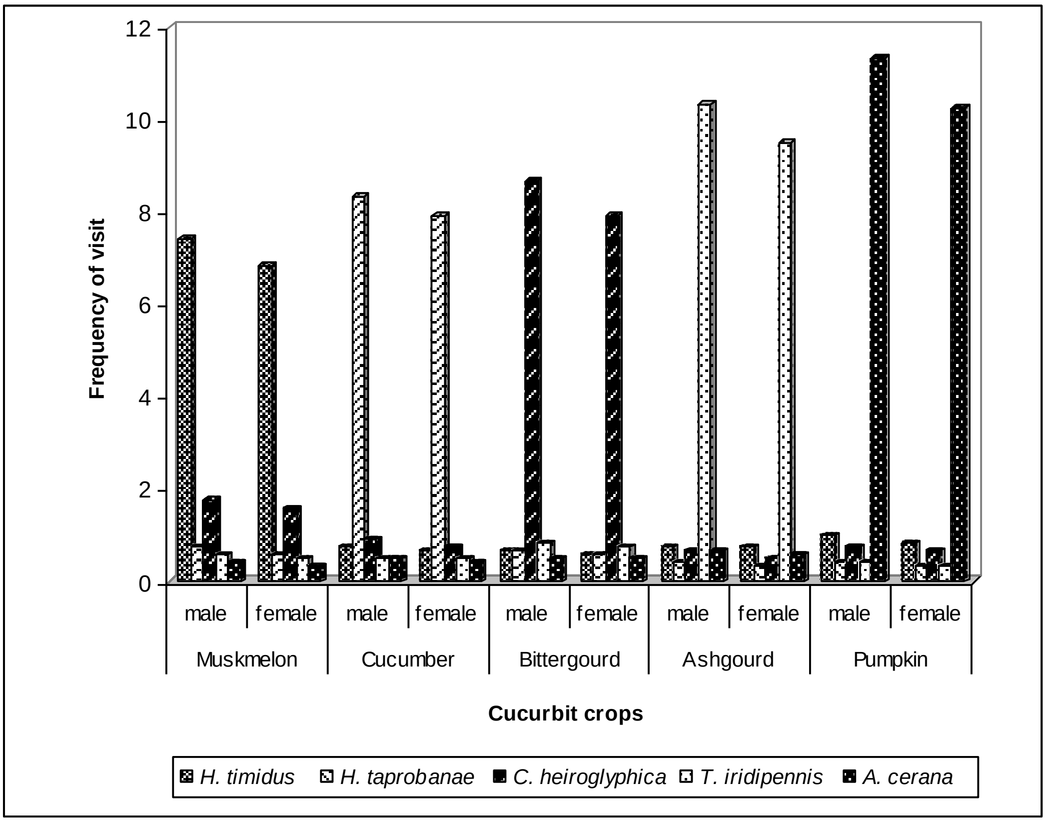


4.6.2. Entomology

4.6.2.1. Frequency of Pollinator Visit

The indigenous bees *Halictus timidus*, *Halictus taprobanae*, *Ceratina heiroglyphica*, *Trigona iridipennis and Apis cerana* were found to have higher frequency of flower visitation in muskmelon, cucumber, bittergourd, ashgourd, and pumpkin respectively. But these were regular visitors of all the crops. Higher frequency of visit was observed in middle diurnal phase of middle phase of season [Muskmelon : *Halictus timidus*, MP (mp) ♂=7.41, ♀=6.83; Cucumber : *Halictus taprobanae,* MP (mp) ♂=8.33, ♀=7.91; Bittergourd : *Ceratina heiroglyphica*, MP (mp) ♂=8.66, ♀=7.91; Ashgourd : *Trigona iridipennis,* MP (mp) ♂=10.33, ♀=9.5; Pumpkin : *Apis cerana* MP (mp) ♂=11.33, ♂=10.25]. Highest number of pollinators visited pumpkin flowers followed by ashgourd, bittergourd, cucumber and muskmelon (Figure 328).

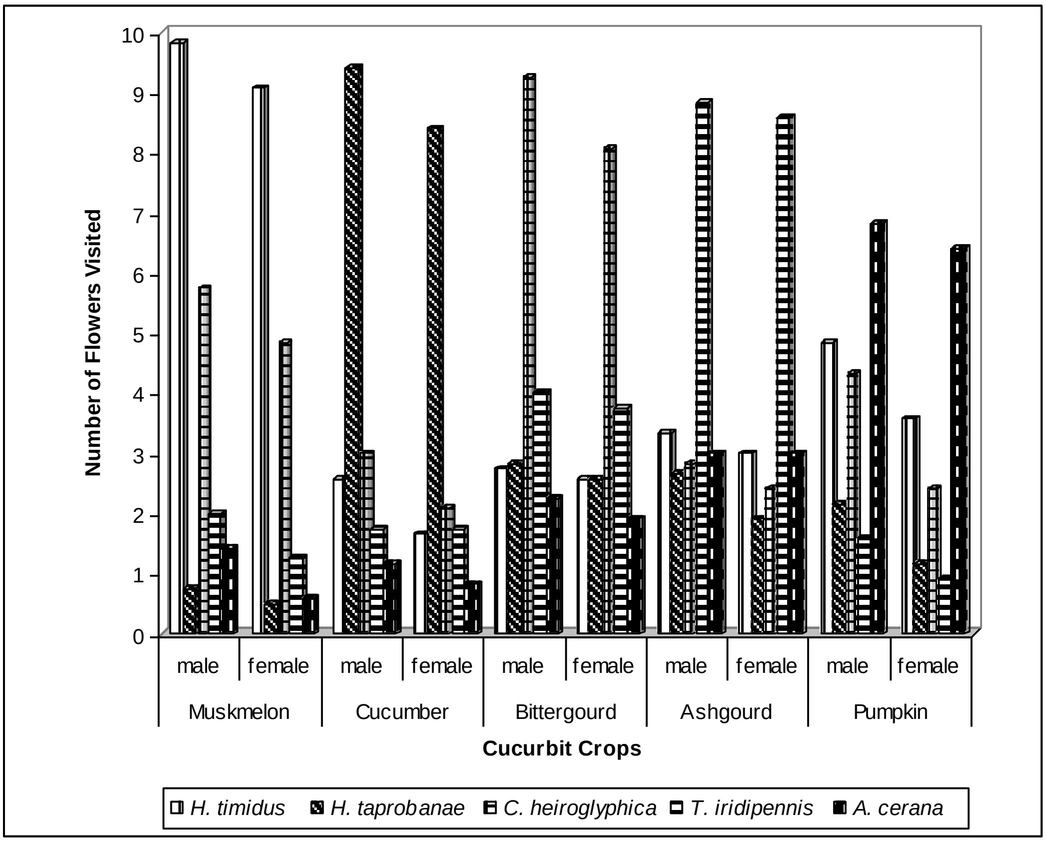
Figure.328: Frequency of pollinator (Species) visit /day (Middle seasonal phase)



4.6.2.2. Number of Flowers Visited by Pollinators

Highest number of flowers were visited in middle diurnal phase of middle phase of season [Muskmelon : *Halictus timidus,* MP (mp) ♂=9.83, ♀=9.08; Cucumber : *Halictus taprobanae,* MP (mp) ♂=9.41, ♀=8.41; Bittergourd : *Ceratina heiroglyphica,* MP (mp) ♂=9.25, ♀=8.08); Ashgourd : *Trigona iridipennis,* MP (mp) ♂=8.83, ♀=8.58; Pumpkin : *Apis* *cerana,* MP (mp) ♂=6.83, ♀=6.41]. More number of muskmelon flowers were visited by pollinators followed by cucumber, bittergourd, ashgourd and pumpkin (Figure 329).

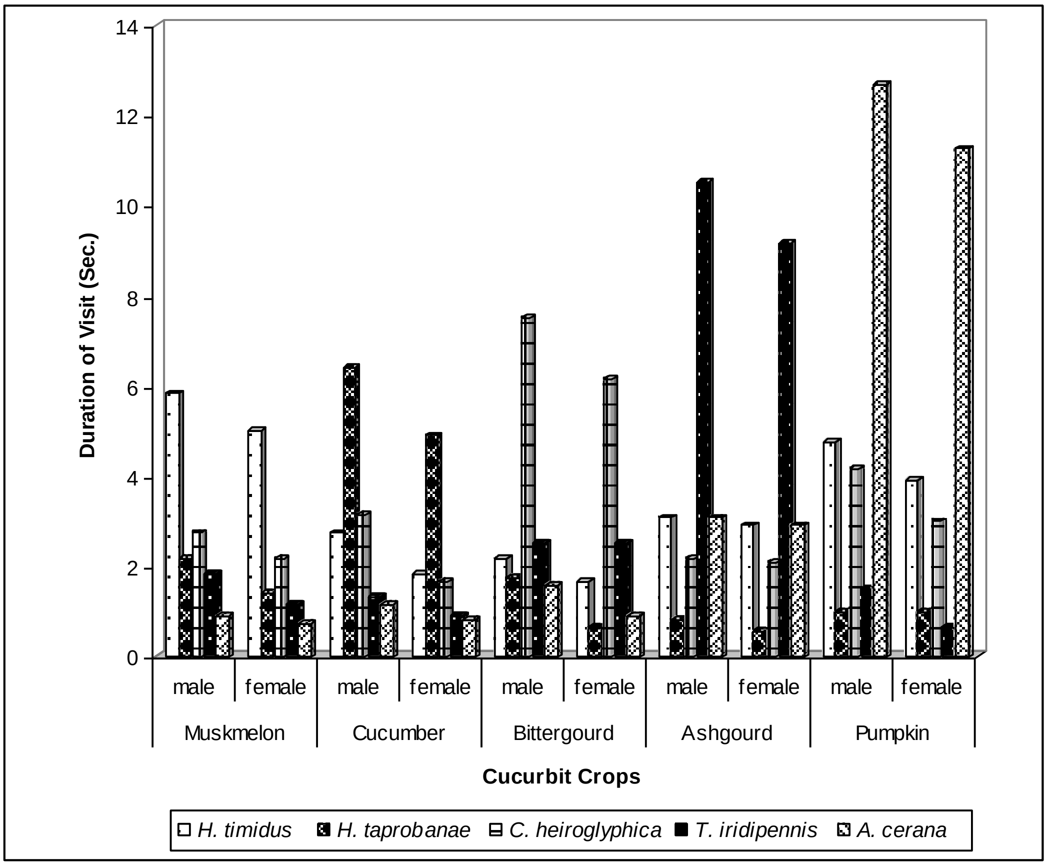
Figure.329: Mean number of flowers visited by pollinators (Species) /day (Middle seasonal phase)



4.6.2.3. Duration of Pollinator Visit

The pollinators took longest duration in initial diurnal phase of middle seasonal phase, [Muskmelon : *Halictus timidus,* MP (ip) ♂=5.83sec., ♀=5 sec.; Ccumber : *Halictus taprobanae,* MP (ip) ♂=6.41sec., ♀=4.91 sec.; Bittergourd : *Ceratina heiroglyphica,* MP (ip) ♂=7.5 sec., ♀=6.16 sec.; Ashgourd : *Trigona iridipennis,* MP (ip) ♂=10.5sec., ♀=9.16 sec.; Pumpkin : *Apis cerana,* (MP (ip) ♂=12.66 sec., ♀=11.25 sec.] (Figure 330). Longest duration of visit was observed in flowers of pumpkin which was followed by ashgourd, bittergourd, cucumber and muskmelon.

Figure.330: Mean duration of visit on flowers by pollinators (Species) in seconds (Middle seasonal phase)

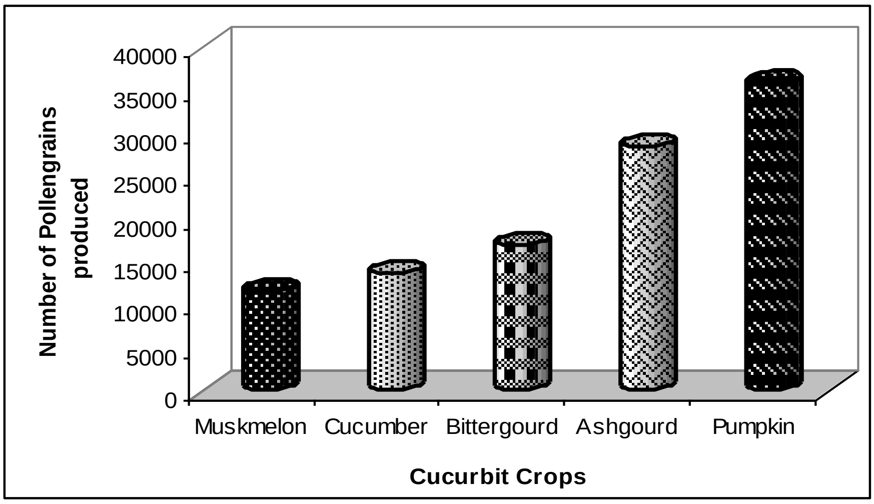


4.6.3. Palynology

4.6.3.1. Pollen Count

Highest pollen count was seen in pumpkin [MP (ip) (11501.33±15.44)] which was followed by ashgourd [MP (ip) (13708±26.01)], bittergourd [MP (ip) (16861.08±55.86)], cucumber [MP (ip) (28511.42±87.31)] and muskmelon [MP (ip) (35800.67±91.86)] (Figure 331). Lowest number was observed in muskmelon compared to other cucurbits.

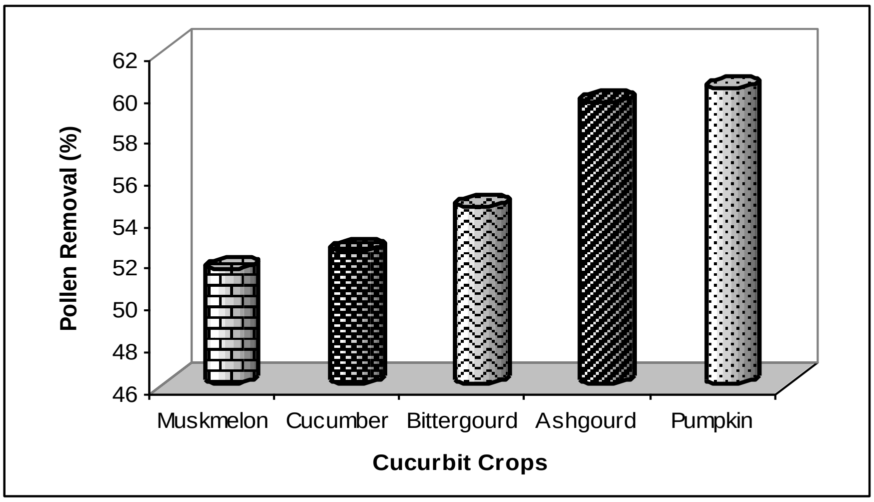
Figure.331: Mean pollen counts at anthesis (Middle seasonal phase)



4.6.3.2. Pollen Removal

Highest pollen removal was found in pumpkin [MP (60.14%)] which was followed by ashgourd [MP (59.47%)]; bittergourd [MP (54.49%)]; cucumber [MP (52.39%)] and muskmelon [MP (51.53%)] (Figure 332). Lowest percentage of pollen removal was observed in Muskmelon compared to other cucurbits.

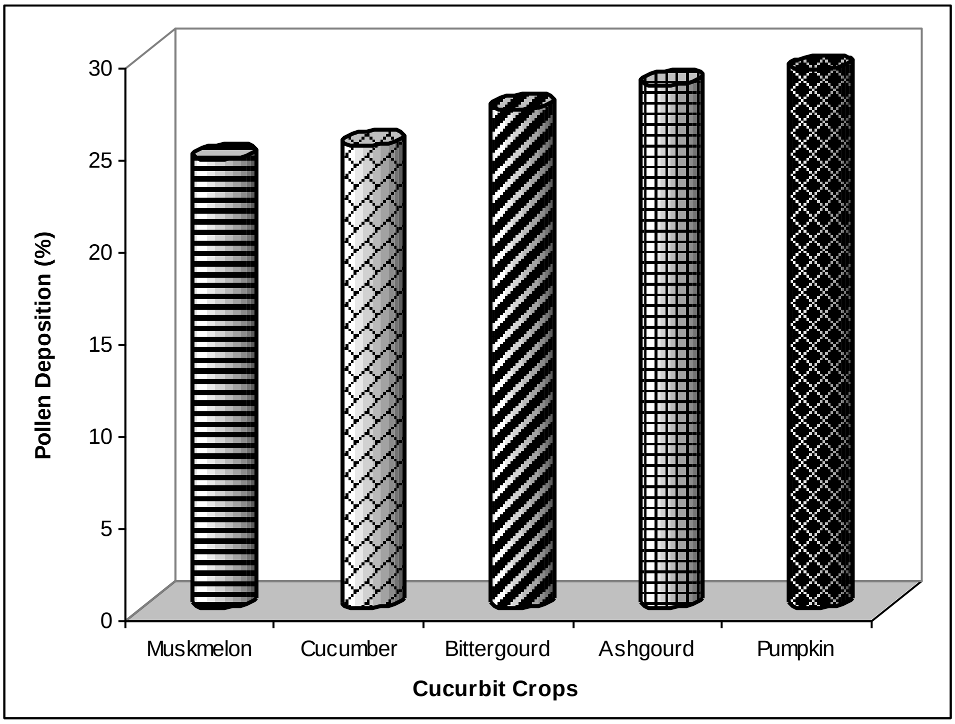
Figure.332: Percentage of pollen removal (Middle seasonal phase)



4.6.3.3. Pollen Deposition

Highest pollen deposition was seen in pumpkin [MP (29.21%)] which was followed by ashgourd [MP (28.37%)]; bittergourd [MP (27.07%)]; cucumber [MP (25.09%)] and muskmelon [MP (24.33%)] (Figure 333). Lowest percentage of pollen deposition was observed in muskmelon compared to other cucurbits.

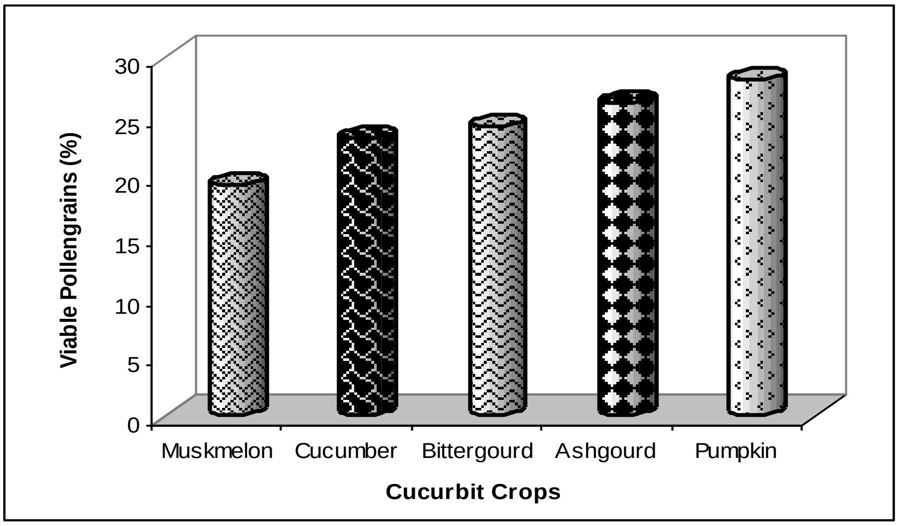
Figure.333: Percentage of pollen deposition (Middle seasonal phase)



4.6.3.4. Pollen Viability

Highest pollen viability was found in pumpkin [MP (28.07%)] which was followed by ashgourd [MP (26.12%)]; bittergourd [MP (24.09%)]; cucumber [MP (23.11%)] and muskmelon [MP (19.23%)] (Figure 334). Lowest percentage of pollen viability was recorded in muskmelon compared to other cucurbits.

Figure.334: Percentage of pollen viability (Middle seasonal phase)

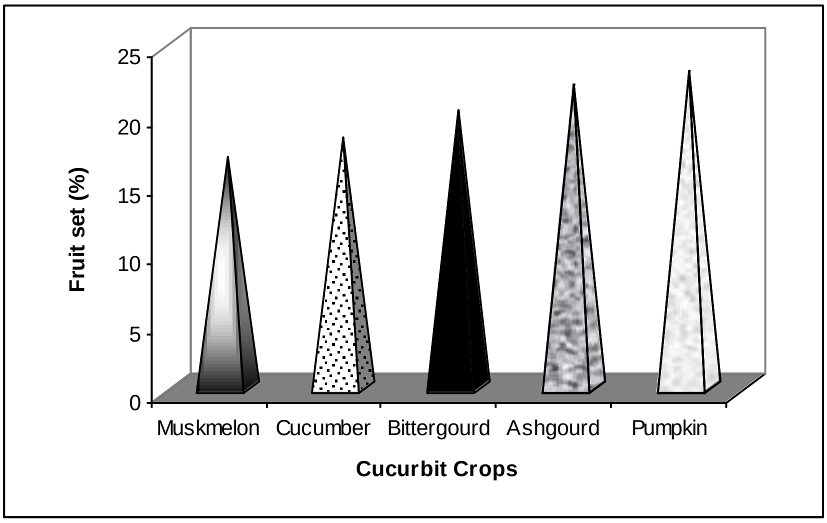


4.6.4. Pomology

4.6.4.1. Fruit Set

Percentage of fruit set was highest in pumpkin (22.99%) followed by ashgourd (21.96%), bittergourd (20.15%), cucumber (18.08%) and muskmelon (16.79%) (Figure 335). Lowest percentage of fruit set was recorded in muskmelon compared to other cucurbits. All non pollinated flowers were aborted.

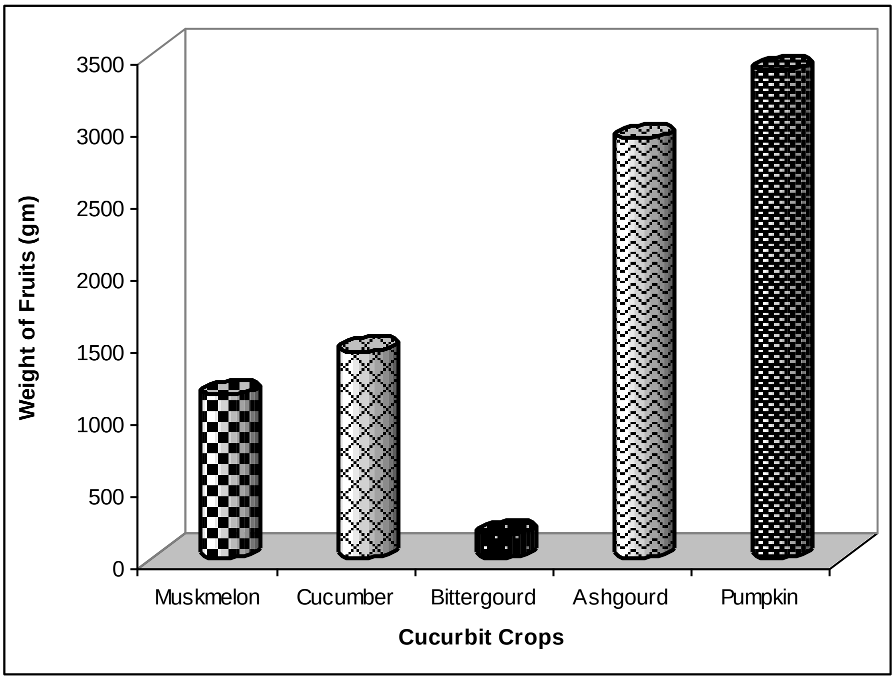
Figure.335: Percentage of fruits (Middle seasonal phase)



4.6.4.2. Weight of Fruits

Highest weight was seen in pumpkin [MP (mp)=3378.08±76.51gm.] which was followed by ashgourd [MP (mp)=2905.41±76.31gm.], cucumber [MP (mp)=1431.75±72.07 gm.], muskmelon [MP (mp=1129.66±52.67gm.)] and bittergourd [MP (mp)=156.91±8.63 gm.] (Figure 336). Lowest weight was found in bittergourd compared to other cucurbits.

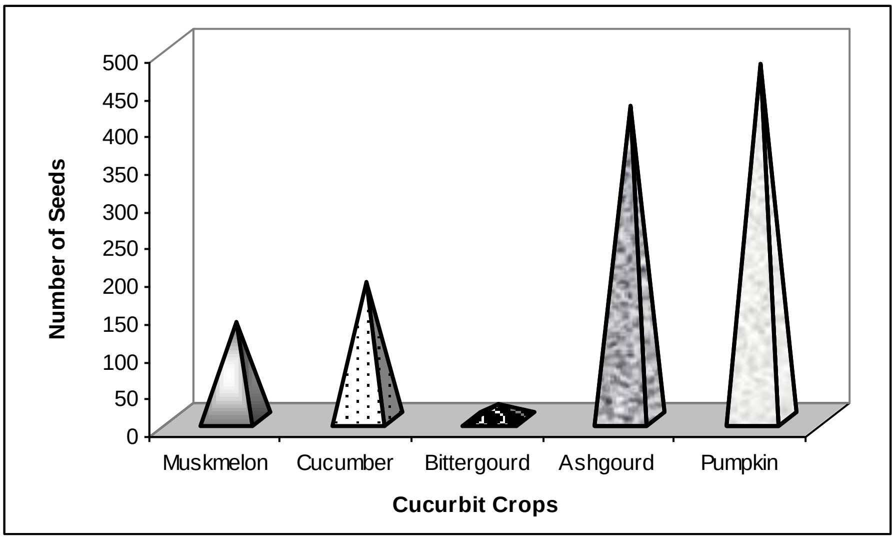
Figure.336: Mean weight of fruits (Middle seasonal phase)



4.6.4.3. Number of Seeds

Maximum number of seeds were formed in pumpkin [MP (mp=474.75±16.34)] which was followed by ashgourd [MP (mp=419.25±9.66)], cucumber [MP (mp=182.16±14.32)], muskmelon [MP (mp=130.91±13.31)] and bittergourd [(mp=20.75±2.30)] (Figure 337). Minimum number was found in bittergourd compared to other cucurbits.

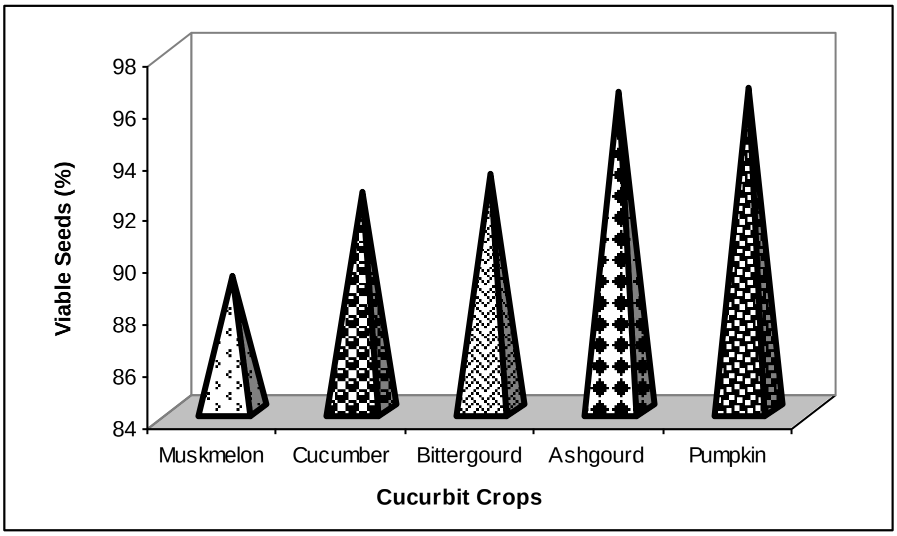
Figure.337: Mean number of seeds (Middle seasonal phase)



4.6.4.4. Viability of Seeds

Highest percentage of viable seeds were found in pumpkin [MP (96.55%)] which was followed by ashgourd [MP (96.32%)]; bittergourd [MP (93.15%)], cucumber [MP (92.45%)] and muskmelon [MP (89.18%)] and (Figure 338). Lowest percentage of viable seeds was found in muskmelon compared to other cucurbits.

Figure.338: Percentage of viable seeds (Middle seasonal phase)



CHAPTER 5

DISCUSSION

Pollination is a key concept in fruit production that must be understood inorder to maximize productivity and yield. From an applied stance, evaluation of the role of flower visitors is necessary to enable objective decisions to be reached over the choice of pollinators to maximize crop pollination (Torchio, 1990). The importance of insect pollination in the production of fruits and vegetables is well documented. Among the vegetable crops, the need for insect pollination of cucurbits has been known for years (Woyke and Bronikowska, 1984). Almost all commercially grown vine crops (Cucurbitaceae) rely on insect pollination to set fruit (Motes, 1977). The presence of large sticky pollen grains and an adhesive stigma further demonstrate the need for active transfer of pollen between flowers (Anderson, 1941; Sedgley and Scholefield, 1980). Cucurbit flowers remain open only for one day. Due to their unique flowering habit, there is only a small window of opportunity for pollination to occur. If they are not pollinated during that time, the flowers abort and drop from the vine. When pollination occurs but is incomplete, fruits do not develop properly (Motes, 1977).

The studies presented here describe the differential pollination rates as affected by time of day and season by any pollinator for cucurbits. The crops selected for this study were annual unisexual vine crops such as muskmelon, cucumber, bittergourd, ashgourd, and pumpkin which require insect pollination for fruit set and attract a wide variety of insect visitors to their flowers. Objectives of this study were to identify insect pollinators of these crops, their foraging dynamics in relation to different phenological and palynological aspects and to find out their efficiency as pollinators by studying different pomological aspects.

The results of the present study demonstrate the importance of insects in the pollination of cucurbits. It was found that insects belonging to three different orders such as Hymenoptera, Lepidoptera and Coleoptera were visiting the flowers of these crops. The relative contribution of Hymenoptera to these crops was major compared to other pollinators. Other visitors could be seen as complementary pollinators. The indigenous bees *Halictus taprobanae*, *Halictus timidus*, *Ceratina heiroglyphica*, *Trigona iridipennis* and *Apis cerana* were the major species found in this study had higher frequency of flower visitation in cucumber, muskmelon, bittergourd, ashgourd and pumpkin respectively and were regular visitors.This indicates that although the five cucurbit species share common pollinators, there is some specificity in the case of pollinators as the dominance shows. Crops like cucumber and muskmelon are believed to have originated in Central Asia (Robinson and Decker- Walters, 1997) and so these native species of bees have evolved better with cucurbits when compared to the European bees like *Apis mellifera* and *Bombus* spp. which were not found in this study. Tepedino (1981) opined that there may be indigenous flower visitors for native crop species that are at least as adequate as pollinators. According to Free (1993) bees such as the Asian honeybee (*Apis cerana* F.) and dwarf honeybee (*Apis florea* F.) are the prevalent ones compared to *A. mellifera*, in Asiatic cucurbit fields. Stanghellini *et al.* (2002 a) also stated that in their native ranges, cucumber and muskmelon plants may be visited and pollinated by bee species that are smaller in size than the European honeybees (*Apis mellifera* L.) or North American *Bombus* spp. But Connor and Martin (1969) have ruled that native bees cannot and should not be relied upon as pollinators. The results of this study oppose this conclusion, as these indigenous bees were regular and consistent pollinators of the crops under study. Practically all authorities give primary credit to the honey bee in pollinating cucurbits (Thompson *et al.*, 1955, Langridge, 1952; Nevkryta, 1953; Robinsons, 1952; Sanduleac, 1959; Verdieva and Ismarlova, 1960; Wiolfenbarger, 1962; Skrebtsova,1964). In the present study not only the honey bees but the solitary bees also were found to be the most frequent pollinators of these crops. This is in conformity with Jaycox *et al.* (1975), Alex (1957) and Rosa (1925) who identified solitary bees as pollinators of these crops. Michelbacher *et al.* (1964) also credit both honeybees and wild bees.

Not only hymenopterans but also coleopterans like *Aulacophora lewisii* and *Aulacophora foveicollis* and Lepidopterans like *Cephonodes picus* and *Macroglossum troglodytus* also have been identified as pollinators in the present study. This is supported by Tontz (1944), Annand (1926) and Durham (1928) who have identified insect groups such as ants, thrips and cucumber beetles respectively as possible pollinators of cucurbits. Hurd (1966) also stated that other insects such as cucumber scarabs, meloid beetles, flies and moths were involved in pollination but to a lesser extent than bees.

From this study it was found that the visitation rate of these pollinators vary in relation to various aspects of phenology of the crops like time of anthesis, number of flowers, gender of flowers and size of flowers. Day of first anthesis of male flowers was found earlier than the female flowers in all crops. Judson (1929) stated that the staminate flowers usually appear before the first pistillate flowers appear. The staminate flower phase might be just for attracting the insects till the pistillate flowers come, so that many insects would be evolved at the time of commencement of pistillate flower phase. This may help for avoiding the abortion of pistillate flowers due to non pollination. The likelihood that a flower will be visited during its lifespan by the pollinating insect depends not only on the pollinator community and pollinator frequency but also on flower longevity and attractiveness to pollinators (Faegri and Pijil, 1979; Free, 1993). Flowers of all the five different cucurbits studied here were short-lived, opening before or shortly after sunrise and completely wilted by noon or thereafter. These results are also similar to those studies in various vine crops like *Cucurbita pepo* (Amaral and Mitidier, 1966), cucumber, muskmelon and watermelon (Stanghellini *et al.,* 2002 a). Significant variation was observed in the times at which staminate and pistillate flowers of all five cucurbit species studied opened. Pistillate flowers generally opened earlier than the staminate flowers. This may be to synchronize pollen dehiscence with the receptivity of stigma, which in turn increase the likelihood of pollination (Faegri and Pijil, 1979; Free, 1993).

A quantitative approach to the seasonal and diurnal changes in number of foragers gives a detailed description of some aspects of the synchrony with phenology. Whatever be the time of opening of the flower, the commencement of insect visit was found shortly after sunrise and end by noon with maximum activity in the midphase of pollination period. According to Pandey and Yadava (1970) for effective cross pollination to occur, pollen availability and stigma receptivity must be synchronized with the time of visits by pollinators to the flowers. Seaton *et al*. (1936) also stated that stigma is receptive throughout the day but most receptive in the early morning and that several hundred pollen grains should reach the stigma for most effective pollination. The number of foragers changed significantly over the day and over the season. Willis and Kevan (1995) reported the same effect in pumpkin. Also in the studies of Stanghellini *et al.* (2002 a) the total number of bees increased over time of day on cucumber, muskmelon and watermelon. The middle phase of flowering received the largest number of visits. The decline at midday may have been due to excessive heat as opined by Pandey and Yadava (1970). Beetles were the earliest and latest visitors of the day and season in the present study, which is in contrast to the studies of Stanghellini *et al.* (2002 b) in which they found that the bees were the earliest and latest visitors of the day.

The present study illustrates the correlation between number of flowers and insect visit. For all crops, insect visit was found increasing as the number of male (♀) and female (♀) flowers produced /plant /day increased. Insect visit increased from initial phase (IP) of the season to middle phase (MP) of the season where maximum number of flowers were observed and then decreased to late phase (LP) of the season where minimum number of flowers were observed. For example, in muskmelon a mean of 8.19 and 7.11 insects visited the male (♂) and female (♀) flowers respectively per day when maximum number of flowers (♀=23.58±6.91, ♂=2.04±0.48) were produced in middle seasonal phase. In late phase only a mean of 5.69 and 4.36 insects had visited male (♂) and female (♀) flowers respectively per day when minimum number of flowers (♂=13.93±3.98, ♀=1.43±0.49) were produced. Much previous works attest to the importance of the number of open flowers for insect visitation (Levin and Kerster, 1969; Schall, 1978; Schmitt, 1983; Feinsinger *et al.* 1991; Kunin, 1993). Plants with large number of flowers receive more visits of pollinators which is in concordance with other studies (Stanton *et al.,* 1986;

Cruzan *et al.*, 1988; Hempel and Speiser, 1988; Thomson,1988; Klinkhamer *et al.*, 1989; Rodriguez- Robles *et al.*, 1992; Ohara and Higashi, 1994; Robertson and Macnair, 1995). Within each season, the visits of different insect groups varied. Significant difference (p=0.00) was found in the visitation rate of different order of pollinators. For example in pumpkin when a mean of 9.08 and 7.97 hymenopterans visited /day on male (♂) and female (♀) flowers respectively only a mean of 0.41 and 0.36 coleopterans and 0.11 and 0.11 lepidopterans visited /day on male (♂) and female (♀) flowers respectively. The same trend was seen in all crops under study and this is in concordance with the studies of Rozen and Ayala (1987) and Schemetkopv (1960). In the present study proportionate increase in number of visits by hymenopterans was also observed but not with coleopteran beetles. This points to the fact that the visit of beetles is not dependent on the flowers since they are not true pollinators. Ohashi and Yahara, (1998) also found that the mean number of insect visits increased significantly with the number of open flowers in the studies of *Cirsium purpuratum* and Thompson (2001) in *Jasminum fruticans*. According to them this will lead to an improvement of plant fitness through both male (pollen removal) and female (pollen deposition) function.

Studies of the response of pollinators to variation in number of flowers have revealed that foragers visit more flowers in plots with large number of flowers as reported by other workers (Geber, 1985; Andersson, 1988; Klinkhamer and Jong, 1990; Dreisig, 1995; Brody and Mitchell, 1997). Ohashi and Yahara (1999) suggested that pollinators are able to memorize and avoid the last few flowers that they visited, so that when the number of flowers in the plot is less than or equal to the number that can be memorized, the pollinator should visit every flower in the plot. The bees visited more number of flowers which is in concordance with the results of Cresswell (1990), Kadmon and Shmida (1992) that in both bumble bees and solitary bees, low rewards promote movement among inflorescences and they visit a significantly greater proportion of open flowers. Also their number was very high. Other groups of insects visited less number of flowers as their number was very less. The present findings, however indicate that bees were the predominant pollinator species of these cucurbit crops and that they exhibited better pollinating efficiency by visiting more number of flowers.

Gender of flower has been reported as a factor in unisexual species in determining the pollinator visit (Kay *et al*., 1984; Agren *et al.,* 1986; Bierzychudek, 1987; Schemske *et al.,*1996). But no significant variation in pollinator visit was found between pistillate and staminate flowers even though the staminate flowers normally outnumber the pistillate flowers in all crops. This was supported by Alex (1957) and Stephen (1970) who stated that pistillate and staminate flowers are about equally attractive in cucumbers. This was also observed by Battaglini (1969) in pumpkin.

The size of the flower was another factor in phenology influencing the insect visit in all crops as in the studies of Bell (1985), Eckhart (1991); Conner and Rush (1996). The size of male (♂) and female (♀) flowers produced per plant per day increased from initial phase (IP) of the season to middle phase (MP) of the season where maximum sized flowers were observed entailing increased visit in all crops. So that insect visit also increased in all crops. After that, visits decreased in the late phase (LP) of the season, where minimum sized flowers were observed. For example in Pumpkin 9.61 and 8.44 insects visited male (♂) and female (♀) flowers respectively per day when maximum sized flowers were produced (♂=19.88±0.87 cm., ♀=21.91±0.86 cm.) in middle seasonal phase (MP). In late phase (LP) only 7 and 5.66 insects visited male (♂) and female (♀) flowers respectively per day when minimum sized flowers (♂=17.01±1.16 cm., ♀=19.01±1.16 cm.) were produced. In all crops it was observed that pistillate flowers were larger than the staminate flowers except in bittergourd where staminate flowers were larger than the pistillate ones [IP (♂=3.13±0.46 cm, ♀=2.7±0.42 cm.); MP (♂=4.60±0.50 cm., ♀=4.10±0.50 cm.); LP (♂=3.44±0.54 cm., ♀=2.94±0.54 cm.)]. But insects showed no preference for staminate over pistillate flowers which is in conformity with the studies on cucumber by Amaral *et al.* (1963).

Corolla size had a significant effect on handling time by insects. As corolla size increased from IP to MP duration of visit also increased in all crops under study. Short duration of visit in the first produced flowers might be due to less floral resources. For example in pumpkin when corolla size increased from IP (♂=17.56±0.78 cm., ♀=19.52±0.79 cm.) to MP (♂=19.88±0.87 cm., ♀=21.91±0.86 cm.) cumulative duration of visit also increased from IP (♂=19.38 sec., ♀=15.47 sec.) to MP (♂=21.16 sec., ♀=16.38 sec.). This has similarity with the studies on *Jasminum fruticans* by Thompson (2001) in which a significant increase on handling time by short tongued bees and bumble bees with increasing flower size was obtained. But in all seasonal phases the duration of visit in initial phase of day (ip) was greater than all subsequent ones over the day, probably as a result of a decrease in the amount of floral resources.

Not only the number and size of flowers but also quality and quantiy of rewards per flower were the major factors in attracting the pollinators of flowers. The dynamics of pollinator behaviour have strong correlation with different palynological aspects such as number of pollen grains produced, removed, and deposited as well as their viability which in turn positively correlated with size of the flowers, time of the day and season. Pollen count and pollen viability were found increasing from initial phase (IP) to middle phase (MP) and then decreasing to late phase (LP) of the season. For example, in cucumber maximum number of pollen grains was found in the MP (13708±26.01) as the flowers attained their maximum size in that phase. Highest pollen viability (23.11%) was also found in this phase. Lowest pollen count (5575.58±8.73) and viability (9.21%) was found in the late phase (LP). But both pollen count and pollen viability decreased over the day. A similar trend was observed in all crops under study. Maximum number of pollen grains on anthers would be available during initial phase of day (ip) in all seasonal phases and exponentially decrease thereafter due to pollen removal as the studies on pumpkin by Willis and Kevan (1995), and on cucumber by Stanghellini *et al***.** (2002 a). But bees were constant foragers in cucurbits inspite of inequalities of quality, and quantity of rewards as in other studies (Wells *et al*., 1981; Wells and Wells, 1983).

Pollen mobilization is a key factor of paternal fitness and out crossing potential (Knapp *et al*., 1991; Waser and Price, 1983, 1991; Spira *et al*., 1992). In the present study it was found that pollen removal increased from initial phase of the day and season to middle phase and thereafter decreased to late phase. This was due to the variation in the number of insects. Thus the majority of pollen that was actually removed from flowers occurred within a relatively short time period after anthesis, when the crops were most receptive to pollination, which is in conformity with Stanghellini *et al***.,** (2002 a). Hundred percent pollen removal was not found in any crop under the study. Total amount of pollen removed was well below 100% of the total pollen produced. Only 82.54% (muskmelon), 84.93% (cucumber), 88.58% (bittergourd), 95.85% (ashgourd) and 98.91% (pumpkin) of the total pollen produced had been removed from the staminate flowers in the middle phase of flowering. This is similar to those of Stanghellini *et al***.** (2002 a) who found only 61% (cucumber), to 62% (muskmelon) and 81% (watermelon) of the total pollen produced had been removed from staminate flowers**.** But Mann (1953) reported 75% to 85% and 65% to 100% pollen removal from andromonoecious muskmelon and dioploid watermelon, respectively. But it is in contrast to the visual estimations of pollen removal from andromonoecious muskmelon by Orr and Eisikowitch (1988), which reached 100% before flower closure. Variability in pollinator number may influence the rate of pollen depletion from flowers. The amount of pollen remaining on flowers after anthesis suggest that a seizable proportion of the total pollen produced may not be available to bees which may be related to floral structure (Stanghellini *et al.,* 2002 a). Differences in temporal pollinator density and/or pollinator diversity have been suggested in both crop and natural plant setting, as primary factors influencing pollen removal and yield response (Cane et al., 1996; Fell, 1986).

Successful pollination of an insect pollinated plant depends upon not only its attractiveness to pollinators but also pollinator's ability to deposit enough compatible pollen on the flower's stigma (Utelli and Roy, 2001; Herrera, 1987). Efficiency of pollinators was judged based on the quantity of pollengrains they have deposited on stigmas (Primarck and Silander, 1975; Waser and Price, 1990). Rates of pollen deposition on stigmas by flower visitors can be measured readily, and can provide one indication of the pollination efficiency of visitors (Herrera, 1987; Snow and Roubik, 1987). Pollen deposition is considered of primary importance, as it is the very definition of pollinator effectiveness (Kearns and Inouye, 1993). The present study reveals that pollen deposition was greater in the middle phase of day and season as more number of insect visits were encountered in those phases. For example, in ashgourd highest pollen deposition was found in the MP (45.21%) and lowest pollen deposition in the late phase (LP) (27.36%). As the quantity of pollen grains on the stigma is correlated with the number of visits by pollinators (Silander and Primarck, 1978) and possibly with cumulative duration of these visits, more visits would result in more pollen grains germinating and fertilizing ovules, which could cause higher pollination rates as reported by Gingras *et al.* (1999).

The influence of insect pollinators and effect of pollen deposition were assessed by studying the pomological aspects such as quantity and quality of fruits and seeds. Amount of pollen deposited on stigmas, influence a flower's reproductive success (Galen and Stanton, 1989; Young and Stanton, 1990). In the present study most of the fruits were produced in initial phase (IP) and middle phase (MP) of season as visitation frequency increased from initial to middle. The number of fruits produced in middle seasonal phase was greater than that recorded in other phases. After that a decline in visit by pollinators and a concordant decline in fruit set was observed. In vine crops, the dependency of fruit set on insect pollination was well established (Free, 1993; Mcgregor, 1976). In the present study it was noted that fruit set varied with the diurnal phases also, it being larger in the middle phase (mp) than in the first as visitation frequency increased from initial to middle. Overall fruit set was smaller in the late phase flowers than in the early phase. For example, in bittergourd highest fruit set was found in the middle diurnal phase (mp) of MP (20.51%) and lowest fruit set in the late diurnal phase (lp) of LP (5.12%). The increased insect visitation and subsequent increase in fruit set found in these studies was comparable to the results obtained by other researchers working with various vine crops (Mcgregor and Todd, 1952; Mcgregor, 1950; Cauto and Calmona, 1993). The relationship between fruit set and insect number was significant in this study which is in conformity with Stanghellini *et al.* (1998). Davis *et al.* (1970) indicated that honeybees were more effective if they were moved to the cucumber field after flowering had started. Free (1968) also found that pollination by honeybees increased fruit set in strawberries. Similar studies on cauliflower and cabbage (Verma and Partap, 1993) have shown that bee pollination increased the yield. The effectiveness of honeybees was further demonstrated by a significant increase in fruit set by Aras *et al.* (1996) in lowbush blue berry. In this study, the rate of pollination was positively correlated with both the number and the cumulative duration of visit which in turn correlated with fruit set. Flowers that had the greatest number of visits and highest cumulative durations of visits had the greatest number of fruits, which is in conformity with the studies on cucumbers by Gingras *et al*. (1999). They stated that the number and cumulative duration of honeybee visits to the flowers are important to pollination and influence quantity of fruit production. According to them fruiting was positively correlated with the number of visits by honeybees. Flowers that produced fruits in cucumbers had been visited more frequently than those did not set fruit. Moreover, the cumulative duration of visit to flowers, which fruited, was greater than that to flowers that did not. According to Chagnon *et al.* (1989) the correlation between the accumulate time of visits to flowers and the percentage of fertilized achenes in resulting strawberries for honeybees was significant, but this relationship was not significant for small indigenous bees as found in this study. Pollinators thus play an important role in the maximum production of a cucurbit crop because the number of visit and cumulative duration of visits to flowers is correlated positively to pollination rate which itself correlated to the number of fruits produced.

The studies demonstrate the absolute necessity of insect pollination on fruit set in the cucurbit species studied as there was 100 percent abortion of all pistillate flowers that received no entomophilous visitation when they were covered with nylon nets. As visit number increased, there was a highly significant decrease in the number of flowers that aborted. The results showed that percentage of fruit set was much higher in insect pollinated plants than in those isolated from insect visits. So insect pollination is essential for maximum yield as stated by Abrol (1989 a) in the studies on strawberry.

Total abortion of female flowers in the absence of bee visitation found in these experiments confirms the results of other studies on cucumber (Rahmlow, 1970; Morris, 1968; Seaton *et al.*,1936), watermelon (Spangler and Moffett, 1979; Adlerz, 1966), cantaloupe (Iselin *et al.*, 1974; Rosa, 1924) and squash (Skinner and Lovett, 1992; Cauto *et al.*, 1990). The fact is that non pollinated cucurbit flowers, with the exception of those of parthenocarpic cultivars, will not produce fruit (Free, 1993; McGregor, 1976). The numbers of fruit set on the bagged inflorescences were almost negligible, where as there was some set on every unbagged inflorescence, indicating the effectiveness of pollinating insects **(**Pandey and Yadava, 1970). The studies of Stanghellini *et al*. (1997) also demonstrate the absolute necessity of insect pollination on fruit set in non parthenocarpic cucumber and water melon varieties as there was 100 percent abortion for all pistillate flowers that received no entomophilous visitation.

This study also revealed that percentage of fruits with greater growth and normal shape was in the middle diurnal phase (mp) of middle phase (MP) of season. It was due to greater number of pollinators and higher pollen deposition. Malformed fruits was higher in late pollination phase as compared to those in other phases. For example, in bittergourd maximum fruits with optimum size and normal shape were found in middle diurnal phase of MP (20.51%) and majority of malformed fruits were found in the late phase LP (14.09%). Flowers that received inadequate pollination resulted in the formation of malformed fruits as stated by Hodges and Baxendale (1995). Anderson (1941) also stated that malformed fruits in cucumbers were the result of poor pollination resulting from too few bee visits per flower. Higher frequencies of insect visit resulted in more number of maximum sized fruits in the plots at harvest which was in concordance with the studies of Free (1968) who found that pollination by honeybees increased percentage of well formed fruits in strawberry. Nye and Anderson (1974) also reported that plots of strawberry caged with honeybees produced fewer malformed fruits. So it is very clear that insect pollination is essential for fruit quality, which is in conformity with the studies on strawberry by Abrol (1989 a).

The weight of fruits was also found increasing from initial phase to middle phase and decreasing to late phase of the day and season for each crop which is found to be directly correlated with the pollinator visit and pollen deposition. For example, in ashgourd, weight of fruit was found increasing from IP (1171.58±370.77 gm.) to MP (2905.41±76.31 gm.) and decreasing to LP (49.91±39.66 gm.). This is in conformity with the studies on pumpkin and squash by Hayase (1953) who stated that the fruit weight increased in proportion to the amount of pollen deposited on the stigma. Gingras *et al.* (1999) also said that the rate of pollination was correlated positively with the weight of cucumbers. Steinhauer (1970) reported that the average fresh weight of cucumbers produced per unit area were greater when cucumber fields were visited by honeybees. The same was true of pickling cucumbers (Warren, 1961). In studies on berries by Aras *et al.* (1996) plots characterized by higher number of honeybees produced berries that were more than two times the weight of the blue berries produced in plots with few or no visits. Similar results were obtained by comparing the production of cucumbers from cages with and without honeybees (Alex, 1957; Kauffeld and Williams, 1972)

The numbers of seeds were also found increasing from initial phase to middle phase and decreasing to late phase of the day and season for each crop in this study. Increased seed set in middle phase as a result of insect pollination could be due to greater number of pollinators in the plots and greater number of ovules they contain. Reduction in seed set in late phase was due to reduction in pollen deposition compared to middle phase and reduction in insect number. For example in pumpkin increased seed set in middle phase (474.75±16.34) due to increased pollen deposition and decreased seed set in late phase (5.41±6.72) due to decreased pollen deposition were found. This is in concordance with Hayase (1953) who stated that the seed number increased in proportion to the amount of pollen deposited on the stigma. As insect visits increased there was a highly significant increase in the number of mature seeds that developed. So efficiency of pollinators has so often determined the number of seeds the flowers set (Schemske and Horvitz, 1984; Motten, 1986; Young, 1988), According to Stanghellini *et al*., (2002 a) variable bee densities likely affect seed setting patterns also. In the study of cucumbers, as visit number increased there was a highly significant increase in the number of mature seeds that developed (Stanghellini *et al*., 1998). Numerous studies have been made on the influence of honeybee visitation on seed production in cucurbit crops (Avila *et al*., 1989; Bohn and Davis, 1964; Collison, 1976; Connor, 1969; Eischen and Underwood 1991; Fischer and Pomeroy,1989; Gaye *et.al*., 1991; McGregor *et al*.,1965; Stanghellini, 1996). Increased bee visitation increased watermelon seed production (Brewer,1974; Goff, 1937). Bee pollination also significantly increased the number of seeds per pod in the experiment of Partap and Verma (1994) on strawberries.

When the quality of seeds was assessed by their germination ability, the number of viable seeds were found increasing from initial phase to middle phase and decreasing to late phase of the day and season for each crop. The results indicate an increase in the percentage of viable seeds at increased number of insects. For example in pumpkin more viable seeds were found in the middle diurnal phase (458.41±17.89) of middle seasonal phase due to highest number of insect visits (♂=9.61 /day.; ♀=8.44 /day). According to Kevan and Eisikowitch (1990) cross pollination by insects increased the germinability of the resulting seeds in Canola (*Brassica napus* L.). Similar studies on cauliflower and cabbage (Partap and Verma, 1994) have shown that bee pollination enhanced the quality of the seeds of these crops.

In all crops studied, it was found that maximum pollination took place in the middle diurnal phase of middle phase of season. This phase is most attractive in terms of higher frequency of visit of insects, greater pollen removal and greater pollen deposition. As a result of this other parameters studied like number, size and weight of fruits were maximum for these crops in this phase. The high diversity and high frequency of pollinators observed during the present study has resulted in better pollination of the cucurbits. As Harder and Thomson (1989) have opined, the ideal situation for plants would be when numerous pollinators approach the display, each removing only small amounts of pollen. Direct correlation was found between yield and number of insects especially bees. Honeybees like *Apis cerana* and *Trigona iridipennis* were found as frequent visitors as they are specially tuned to these crops. The dominance of bees other than *Apis* spp. in the present study site is an indicator of a habitat with minimal human interference. According to Batra (1967) bees other than *Apis* spp. are remarkably scarce at areas where constant human interference, intensive grazing and harvesting the sparse wild vegetation. An additional factor limiting the population of wild bees according to her is their competition for food with numerous active workers of *Apis* spp. The study site in Madayi is comparatively less disturbed habitat, with sacred groves and wood lots around the agricultural fields with mixed cropping which may lead to conservation and increase in native wild pollinators. These studies also help in identifying new bee pollinators other than the species that are commonly encountered as pollinators of targeted crops. Torchio (1990) and Stephen (1955) much earlier had recommended the development of habitat management program as one method to increase numbers of native species in natural as well as agricultural ecosystems. By keeping bee hives in the fields of cucurbits we can enhance the crop yield. This is regular practice in European countries where apiculturists will be invited to keep the hives in crop fields to enhance the fruit and vegetable production. Such practice has not been started in our state. More studies in this direction are necessary to standardize the parameters.

SUMMARY

Influence of insect pollination in selected cucurbitaceous crops (muskmelon, cucumber, bittergourd, ashgourd and pumpkin) was evaluated from May 2002-October 2005.

Regular visitors found on these crops were *Halictus timidus, Halictus taprobanae, ceratina heiroglyphica, Trigona iridipennis* and *Apis cerana.*

Complimentary visitors are *Amegilla parhypate, Apis dorsata, Apis florea, Braunsapis picitarsis, Ceratina smaragdula, Xylocopa tenuiscapa, Xylocopa aestuans, Cephonodes picus, Macroglossum troglodytus, Aulacophora lewisii* and *Aulacophora foveicollis.*

Highest pollination was taken place in the middle diurnal phase of middle seasonal phase.

Pollination was found highest at the time of higher number of flower production, larger flower size and higher pollen production.

Increased Insect pollination resulted in increased fruit set in all crops under study.

Insufficient pollination resulted in malformed fruits. More normal optimum sized fruits were produced from the flowers with higher pollination rate.

Underlying these changes there were increase in weight of fruits, number of seeds and viability of seeds with increase in pollination.

REFERENCES

Aagren, J. 1996**.** Population size, pollinator limitation, and seed set in the self- incompatible herb *Lythrum salicaria*. *Ecology*, **77**(6):1779-1790.

Abelson, P. H. 1971**.** Opportunities in Plant Science. *Science*, **172**(3989): Editorial page.

Abrol, D. P. 1987. Influence of thermal and energetic constraints on the pollination activity of carpenter bee *Xylocopa pubescens*. *Environ. Ecol*., **5**(1):90-93.

Abrol, D. P. 1989 a. Studies on ecology and behaviour of insect pollinators frequenting strawberry blossoms and their impact on yield and fruit quality. *Trop. Ecol*., **30**(1):96-100.

Abrol, D. P. 1989 b. Insect pollinators of cherry (*Prunus avium* L.). *J. Anim. Morphol. Physiol.*, **36**(2):243-245.

Abrol, D. P. 1991 a. Conservation of pollinators for promotion of agricultural production in India. *J. Anim. Morphol. Physiol*., **38**(1-2):123-139.

Abrol, D. P. 1991 b. Pollination of brinjal flowers [*Solanum melongena* L.] by bumble bees. *J. Anim. Morphol. Physiol*., **38**(1-2):95-98.

Abrol, D. P. 2005. Pollination Energetics. *Journal of Asia Pacific Entomology*, **8**(1):3-14.

Abrol, D. P. and D. R. Kotwal. 1996. Insect pollinators of linseed (*Linum usitatissimum* Linn.) and their effect on yield components. *Journal of Animal Morphology and Physiology*, **43**(2):157-161.

Abrol, D. P. and R. P. Kapil. 1998. Studies on Abundance and importance of insect pollinators for oilseed production. *Journal of Insect Science*, **9**(2):172-174.

Adegas, J. E. B. and R. H. N. Cauto.1992. Entomophilous pollination in rape (*Brassica napus* L. var oleifera) in Brazil. *Apidologie*, **23**(3):203-209.

Adlerz, W.C. 1966. Honeybee visit numbers and watermelon pollination. *J. Econ. Entomol.*, **59**:28-30.

Agren, J.; Elmqvist, T. and A. Tunlid. 1986. Pollination deceit, floral sex ratios and seedf set in dioecious *Rubus chamaemorus* L. *Oecologia*, **70**:332-338.

Aguilar, M. A. C and V. P. Tabla. 2000. Importance of conserving alternative pollinators: assessing the pollination efficiency of the squash bee, *Peponapis limitaris* in *Cucurbita moschata* (Cucurbitaceae). *Journal of Insect Conservation*, **4**(3):203-210.

Alcorn, S. M.; Mcgregor, S. E. and G. Olin. 1962. Pollination requirements of the Organ-pipe Cactus. *Cactus and Succulent Jour.*, **34**:134-138.

Alex, A. H. 1957. Honeybee aid pollination of cucumbers and cantaloupes. *Glean. Bee Cult.* **85**(7):398-400.

Amaral. E. and I. J. Mitidier. 1966. Pollination of squash. *Anais da Escola Superior de Agricultural "Lutz de Queriroz"* Sao Paulo Univ., *Piracicaba,* Brazil, **23**:121-128.

Amaral. E., Mitidieri, J. and R. Vencousky. 1963. Studies on the activites of *Apis mellifera* L. while visiting the flowers of *Cucumis sativus* L. *Olericultura* (Brazil), **3**:181-193.

Ambrose, J. T.; Schultheis, J. R.; Bambara, S. B. and W. Mangum. 1995. An evaluation of selected commercial bee attractants in the pollination of cucumbers and watermelons. *Am. Bee J.*, **135**(4):267-272.

Anderson, W. S. 1941. Growing cucumbers for pickling in Mississippi. *Bull. Miss. Agric. Exp. Stn.*, **355**:17.

Andersson, S. 1988. Size Dependent pollination efficiency in *Anchusa officinalis* (Boraginaceas) causes and consequences. *Oecologia* (Berl.), **76**:125-130.

Annand, P. N. 1926. Thysanoptera and the pollination of flowers. *Am. Nat.* **60**:177-182.

Antonelli, A. L.; Mayer D. F.; Burgett, D. M. and T. Sjulin. 1988. Pollinating insects and strawberry yields in the Pacific Northwest. *Am. Bee J.*, **128**(9):618-620.

Aras, P.; De Oliveira, D. and L. Savole. 1996. Effect of a honeybee (Hymenoptera:Apidae) gradient on the pollination and yield of lowbush blueberry. *J. Econ. Entomol.*, **89**(5):1080-1083.

Arita, L. H. and J. K. Fujii. 1992. Quantity and seasonal variation of pollen types collected by honeybees at two localities on the island of Hawaii. *Proc. Hawaii. Entomol. Soc.*, **31**:119-124.

Avila, C. J., Martinho, M.R. and J. O. G. De Lima. 1989. Time of effective pollination in fields producing hybrid seed of squash (*Cucurbita pepo* var.melopepo). *Anais Soc. Entomol. Brasil.*, **18** (suppl.):23-32

Babu, G. V. S.; Bhatt, S. C. and S. C. Pandeya. 1987. Pollination Ecology of *Solanum sysimbrifolium* Lamk. *Proc. Indian Acad. Sci., Plant Sci.*, **97** (4):295-300.

Bagnara, D. and C. Vincent. 1988. The role of insect pollination and plant genotype in strawberry fruit set and fertility. *J. Hortic. Sci.,* **63**(1):69-75.

Bagnoli, B. 1975. Contribution to the knowledge of insect fauna pollinating Sunflower. *Redia*, **56**:135-145.

Baker, H. G. and P. D. Hurd. Jr. 1968. Intrafloral Ecology. *Ann. Rev. Ent.* **13**:385-414.

Barthell, J. F.; Thorp, R. W.; Randall, J. M. and A. M. Wenner. 2001. Promotion of seed set in yellow star-thistle by honeybees: Evidence of an invasive mutualism. *Ecological Applications,* **11**(6):1870-1883.

Batra, S. W. T. 1967. Crop pollination and the flower relationships of the wild bees of Ludhiana, India (Hymenoptera:Apoidea). *J. Kansas Entomological Society*, **40**:164-177.

Battaglini, M. B. 1969. The importance opf honeybees for fertilizing *Cucurbita pepo*. *Apicolt.,* **35**(1):9-12.

Bell, G. 1985. On the function of flowers. *Proc. R. Soc. Lond. B.,* **224**:223-265.

Benedek, P.; Prenner, J. and E. Wilhelm. 1977. Fertilization and seed setting of red clover as affected by the time of insect pollination. *Noverytermeles*, **26**(2-3):155-167.

Bhattacharya, A. 2004. Flower visitors and fruitset of *Anacardium Occidentale*. *Annales Botanici Fennici*, **41**(6):385-392.

Bierzychudek, P. 1987. Pollinators increase the cost of sex by avoiding female flowers. *Ecology*. **68**:444-447.

Bohart, G. E. 1972. Management of wildbees for the pollination of crops. *Ann. Rev.Entomol*. **17**:287-312.

Bohn, G. W. and G. N. Davis. 1964. Insect pollination is necessary for the production of muskmelons (*Cucumis melo* var.reticulates). *J. Apic. Res*. **3**:61-63.

Brewbaker, J. L. and B. H. Kwack. 1963. The essential role of calcium ion in pollen germination and pollen tube growth. *Am. J. Bot.* 50:859-865.

Brewer, J. W. 1974. Pollination requirements for watermelon seed production. *J. Apic. Res.* **13**(3):207-212.

Brody, A. K. and Mitchell, R. J. 1997. Effects of experimental manipulation of inflorescence size on pollination and predispersal seed predation in the hummingbird pollinated plant *Ipomopsis aggregata*. *Oecologia*, **110**:86-93.

Bruner, J. M. 1966. Management-a strategic agricultural resource. *Ariz. Business Bul.*, **13**(10):10-18.

Cane, J. H.; Schiffhauer. D. and L. J. Kervin. 1996. Pollination, foraging and nesting ecology of the leaf cutting bee *Megachile* (Delomegachile) *addenda* (Hymenoptera: Megachilidae) on cranberry beds. *Ann. Entomol. Soc. Amer.*, **89**:361-367.

Carthew, S. M. 1993. An assessment of pollinator visitation to *Banksia spinulosa*. *Aust. J. Ecol.*, **18** (3):257-268.

Cauto, R. H. N. and R. C. Calmona. 1993. Entomophilous pollination in Cucumber (*Cucumis sativus* L. var. Aodai Melhorada). *Naturalia (*Sao Paulo*)*, **18**:77-82.

Cauto, R. H. N.; Periera, J. M. S. and L. A. Cauto. 1990. Effects of pollination in *Cucurbita pepo* (summer squash). *Cientifica*, **18**(1):21-27.

Chagnon, M.; Gingras, J. and A. De Oliveira. 1989. Effect of honey bee (Hymenoptera: Apidae) visits on the pollination rate of strawberries. *J. Econ. Entomol*., **82**(5):1350-1353.

Chagnon, M.; Gingras, J. and D. de Oliveira. 1991. Honeybee (Hymenoptera: Apidae) foraging behaviour and raspberry pollination. *J. Econ. Entomol.*, **84**(2):457-460.

Chagnon, M.; Gingras, J. and D. De Oliveira. 1993. Coplementary aspects of strawberry pollination by honey and indigenous bees (Hymenoptera). *J. Econ. Entomol.*, **86**(2):457-460.

Chand, H.; Singh, R. and S. F. Hameed. 1994. Population dynamics of honeybees and insect pollinators on Indian mustard, *Brassica juncea* L. *J. Entomol. Res*., **18**(3):233-239.

Chang. S. Y. 1990. The importance of honeybee on crop pollination. *Chin. J. Entomol. Spec. Publ.*, **5**:77-83.

Cheng, Chi- Tung. 1996. Effects honeybees on pollination and fruit set of cantaloupe. *Chin. J. Entomol*., **16**(1):25-33.

Collison, C. H. 1976. The interrelationships of honeybee activity, foraging behaviour, climatic conditions and flowering in the pollination of pickling cucumbers, *Cucumis sativus* L. *Ph.D Thesis;* Michigan State University, USA.

Conceicao Da; Eltamara, S.; Delabie Jacques. H. C.; Costa Neto and De O. Antonio. 2004. The Entomophily of the coconut tree in Question: The evaluation of pollen transportation by ants (Hymenoptera : Formicidae) and bees (Hymenoptera : Apoidea) in inflorescence. *Neotropical Entomology*, **33**(6):679-683.

Conner, J. K. and R. Neumeier. 1995. Effects of black mustard (*Brassica nigra*) population size on the taxonomic composition of pollinators. *Oecologia*, **104**(2):218-224.

Conner, J. K. and S. Rush. 1996. Effects of flower size and number on pollinator visitation to wild radish, *Raphanus raphanistrum*. *Oecologia*, **105** (4):509-516.

Connor, L. J. 1969. Honey bee pollination requirements of hybrid cucumbers, *Cucumis sativus* L. *M.Sc. Thesis*, Michigan State Univ., East Lansing.*Abstr. In Amer. Bee J.,* **114**(12):457.

Connor, L. J. and E. C. Martin. 1969. Honey bee pollination of cucumbers. *Amer. Bee Jour.*, **109**:389.

Corbet, S. A.; Fussell, M.; Ake, R.; Fraser, A.; Gunson, C.; Savage, A. and K. smith. 1993. Temperature and pollinating activity of social bees. *Ecol. Entomol.*, **18** (1):17-30.

Crane, E. 1972. Beekeeping in the balance. *Bee World* [Editorial.], **53**:3-4.

Crepet, W. L. 1984. Advanced (constant) insect pollination and mechanisms: pattern of evolution and implications vis-à-vis angiosperm diversity. *Annals of the Missouri Botanical Garden*, **71**:607-630.

Cresswell, J. E. 1990. How and why do nectar foraging bumble bees initiate movements between inflorescences of wild bergamot *Monarda fistulosa* (Lamiaceae). *Oecologia*, **82**:450-460.

Cresswell, J. E.; Bassom, A. P.; Bell, S. A.;Collins, S. J. and T. B. Kelly. 1995. Predicted pollen dispersal by honeybees and three species of bumble bees foraging on oil seed rape: A comparison of three models. *Funct. Ecol.*, **9** (6):829-841.

Cruzan, M. B.; Neal, P. R. and M. F. Wilson. 1988. Floral Display in phyla incisa: consequences for male and female reproductive success. *Evolution*, **42**:505-515.

Dag, A. and D. Eisikowitch. 1999. Ventilation of greenhouses increases honey bee foraging activity on melon, *Cucumis melo*. *Journal Of Apicultural Research*, **38**(3-4):169-175.

Dashad, S. S. and J. K. Sharma. 1994. Foraging rates of insect visitors on blooms of various cultivars of apple (*Malus domestica* Borkh). *Ann. Biol.*, **10**(1):75-79.

Dashad, S. S.; Sharma, J. K. and P. R. Yadav. 1994. Loose pollen grains carrying capacity of insect visitors apple bloom. *Ann. Biol.*, **10**(1):173-175.

Davis, L. B; Laster, M. L. and G. M. Campbell.1970. Study shows new bees better for cucumber fields. *Miss. Farm Res*., **33**(6):1-2

Dedig, S. and K. Delaplane. 2003. Honeybee (Hymenoptera: Apidae) Pollination of rabbiteye blueberry *Vaccinium ashei* var. 'Climax' is pollinator density dependent. *Journal of Economic Entomology*, **96**(4): 1215-1220.

Dibble, A. C. and F, A. Drummond. 1997. Floral syndrome in *Amelanchier nantucketensis* (Rosaceae).Floral density, bee activity, and characterization of andropetaly. *Canadian Journal of Botany*, **75**(11):1851-1859.

Dogterom. M. H.; Matteoni, J. A. and R. C. Plowright. 1998. Pollination of greenhouse tomatoes by the North American *Bombus vosnesenskii* (Hymenoptera: Apidae).*Journal of Economic Entomology*, **91**(1):71-75.

Dreisig, H. 1995. Ideal free distributions of nectar foraging bumble bees. *Oikos*, **72**:161-172.

Durham. G. B. 1928. Pollen carriers in summer squash. *Jour. Econ. Ent.*, **21**:436.

Eckhart, V. M. 1991. The effects of floral display on pollinator visitation varyn among populations of *Phacelia linearis* (Hydrophyllaceae). *Evol. Ecol.*, **5**:370-384.

Eischen, F. A. and B. A. Underwood. 1991. Cantaloupe pollination trials in the Lower Rio Grande Valley. *Amer. Bee J.* **131**:77.

Elberling, H. and J. M. Olesen. 1999. The structure of a high latitude plant-flower visitor system: the dominance of flies. *Ecography*, **22**(3):314-323.

Faegri, K., and L, van der Pijil. 1979. The principles of pollination Ecology , *3rd Rev. Ed.* Pergamon Press, Oxford. pp:244.

Feinsinger, P.; Tiebout, H. M. I., B. E. Young. 1991**.** Do tropical bird pollinated plants exhibit density dependent interactions field experiments? *Ecology*, **72:**1953-1963.

Fell, R. D. 1986. Foraging behaviour of *Apis mellifera* L. and *Bombus* spp. on oilseed sunflower (*Helianthus annuus* L.). *J. Kan. Entomol. Soc*., **59**:72-91.

Fischer, R. M. and N. Pomeroy. 1989. Pollination of greenhouse musk melons by Bumble bees (Hymenoptera: Apidae). *J. Econ. Entomol*., **82**(4):1061-1066.

Free, J. B. 1968. The pollination of strawberries by honey bees. *J. Hort. Sci.*, **43**:107-111

Free, J. B. 1993. Insect pollination of crops, *2nd. Ed.* Academic press, London, U. K. pp:544

Fritz, A. L. and L. A. Nilsson. 1994. How pollinator –mediated mating varies with population size in plants. *Oecologia*, **100**(4):451-462.

Galen, C. and M. L. Stanton. 1989. Bumble bee pollination and floral morphology: factors influencing pollen dispersal in the alpine sky pilot, *Polemonium viscosum* (Polemoniaceae). *American Journal of Botany*.,**76**:419-426.

Gaye, M. M.; Maurer, A. R. and F. M. Seywerd. 1991. Honey bees placed under row covers affect muskmelon yield and quality. *Scientia Hort*., **47**:59-66.

Geber, M. A. 1985. The relationship of plant size to self pollination in *Mertensia ciliata. Ecology,* **66**: 762-772.

Genty, P.; Garzon A.; Lucchini, F. and G. Delvare. 1986. Entomophilous pollination of the oil palm in Tropical America. *Oleagineux*, **41**(3):99-112.

Gingras, D.; Gingras, J and D.De Oliveira. 1999. Visits of Honeybees (Hymenoptera :Apidae) and their effects on Cucumber yields in the field. *Journal of Economic Entomology*, **92** (2):435-438.

Goff, C.C. 1937. Importance of bees in the production of watermelons.

Florida Entomol., **20**:30-31.

Goldblatt, P.; Manning, J. C. and P. Bernhardt. 1997. Notes on the pollination of *Gladiolus brevifolius* (Iridaceae) by bees (Anthophoridae) and bee mimicking flies (Psilodera : Acroceridae). *Journal of The Kansas Entomological Society*, **70** (4):297-304.

Goulson, D. 1994. A model to predict the influence of insect flower constancy on interspecific competition between insect pollinated plants. *J. Theor. Biol.*, **168** (3):309-314.

Goulson, D. 1999. Foraging strategies of insects for gathering nectar and pollen, and implications for plant ecology and evolution. *Perspectives In Plant Ecology, Evolution And Systematics*, **2**(2):185-209.

Goulson, D. 2000. Why do pollinators visit propotionally fewer flowers in large patches. *Oikos*, **91**(3):485-492.

Grant, V.; and K. A. Grant. 1965. Flower Pollination in the phlox family. Columbia University Press, New York and London. pp:180

Grewal, G. S. and A. S. Sidhu. 1978. Insect – pollinators of some cucurbits in Punjab. *Indian J. Jgric. Sci.*, **48** (2):79- 83.

Guidry, N. P. 1964. Graphic summary of world agriculture. *U. S. Dept. Agr. Misc. Pub.*, **705**:64

Guitian, P.; Guitian, J. and L. Navarro. 1993. Pollen transfer and diurnal versus nocturnal pollination in **Lonicera etrusca**. *Acta Oecol.*, **4**(2): 219-227.

Gupta, J. K.; Reddy M. C. M. and J. Kumar. 1990. Pattern of nectar secretion in wild cherry, *Prunus puddum* Roxb., and the associated foraging behaviour of *Apis cerana indica* F and *Apis mellifera* L. *Apidologie*, **21** (1):11-16.

Haq, M.; Rafie -ul- din, M. and A. Ghaffer. 1978. Effect of on fruit bearing in kinnow mandarin (*Citrus reticulate*), and physical and chemical properties of the fruit. *J. Apic. Res*., **17**(1):47- 49.

Harder, L. D. and Thomson, J. D. 1989. Evolutionary options for maximizing pollen dispersal in animal-pollinated plants. *American Naturalist*, **133**:323-344

Harlan, J. R. 1971. Genetics of disaster. *Agron. Abs., Ann. Mtg. Amer. Soc. Agron.*, pp:7

Hayase, H. 1953. Cucurbita crosses IV. The development of squash fruit as affected by placement of pollen on stigma. *Hokkaido Nat1. Agr. Expt. Sta. Res. B.*, **64**:22-25.

Heard, T. A. 1994. Behaviour and pollinator efficiency of stingless bees and honeybee on macadamia flowers. *J. Apic. Res.*, **33** (4):191-198.

Hempel, P. S. and B. Speiser. 1988. Effects of inflorescence size on pollination in *Epilobium angustifolium*. *Oikos*, **53**: 98-104.

Herrera, C. M. 1987. Components of pollinator "quality" comparitive analysis of a diverse insect assemblage . *Oikos*, **50**:70-90.

Herrera, C. M. 1989. Pollinator abundance, morphology and flower visitation rate: Analysis of the "quantity"component in a plant pollinator system. *Oecologia*, **80** (2):241-248.

Higo, H. A.; Rice, N. D.; Winston, M. L. and B. Lewis. 2004. Honeybee (Hymenoptera:Apidae) distribution and potential for supplementary pollination in commercial tomato greenhouses during winter. *Journal of Economic Entomology*, **97** (2):163-170.

Hodges, L. and F. Baxendale. 1995. Bee pollination of cucurbit crops. Nabraska Cooperative Extension (NF 91-56).

Hof, L. and W. Lange. 1998. The influence of insect pollination on yield components in *Dimorphotheca pluvialis*. *Genetic Resources And Crop Evolution*, 45 (5):441-446.

Hoffman De, G. and J. C. Watkins. 2000. The foraging Activity of Honeybees *Apis mellifera* and non-*Apis* bees on Hybrid sunflowers

(*Helianthus annuus*) and its influence on cross pollination and seed set. *Journal of Apicultural Research*, **39**(1-2):37-45.

Holm, S. N. 1966. The utilization and management of bumblebees for Red Clover and alfalfa seed production. *Ann. Rev. Ent.*, **11**:155-182.

Howpage, D.; Spooner- Hart, R. N. and V. Vithanage. 2001. Influence of honeybee (*Apis mellifera*) on Kiwifruit pollination and fruit quality under Australian conditions. *New Zealand Journal of Crop And Horticultural Science*, **29**(1):51-59.

Hurd, P.D. Jr. 1966. The pollination of pumpkins, gourds and squashes (Genus *Cucurbita*). *Bee World*, **47**(1): 97-98.

Inoue, K.; Maki, M. and M. Masuda. 1995. Different responses of pollinating bees to size variation and sexual phases in flowers of Campanula. *Ecol. Res*., **10**(3):267-273.

Iselin, W. A., Jensen, M. H. and H. G. Spangler. 1974. The pollination of melons in air inflated greenhouses by honeybees. *Environ. Entomol*. **3**(4):664- 666.

Ish-Am, G. and D. Eisikowitch. 1998. Mobility of honey bees (Apidae, *Apis mellifera* L.) during foraging in Avocado orchards. *Apidologie*, **29**(3): 209-219.

Iwasa, V.; De Jong, T. J. and P. G. L. Klinkhamer. 1995. Why pollinators visit only a fraction of the open flowers on a plant: the plant's point of view. *J. Evol. Biol*., **8** (4):439-459.

Jaycox, E. R., Guynn, G., Rhodes, A. M. and J. S. Vandemark. 1975. Observation on pumpkin pollination in Illinois. *Amer. Bee. J*., **115**(4):139-140.

Jennersten, O.; Berg, L. and C. Lehman. 1988. Phonological differences in pollinator visitation, pollen deposition and seed set in the sticky catchfly, *Viscaria vulgaris*. *J. Ecol*., **76** (4):1111-1132.

Johnson, S.G.; Delph, L. F. and C. L. Elderkin. 1995. The effect of petal size manipulation on pollen removal, seed set, and insect- visitor behaviour in *Campanula americana*. *Oecologia*, **102**(2):174-179.

Jones, T. P.; Clinch, P. G. and D. A. Briscoe. 1976. Effect of honeybee saturation on the pollination of of Chinese gooseberries variety 'Hayward'. *New Zealand Journal of Experimental Agriculture*, **4**(2):255-256.

Judson, J. E.1929. The morphology and vascular anatomy of the pistillate flower of the cucumber. *Amer. Jour. Bot.* 16:69-89.

Jugtani, T. K.; Rustamani, M. A.; Hussain, T.; Talpur, M. A and H. B. Baloch. 1993. Preliminary studies on insect pollinators of fennel, *Foeniculum vulgare* P. Miller in Sindh, Pakistan presented at Proceedings Of Pakistan Congress Of Zoology. Vol.13, Published by Zoological Society Of Pakistan, Lahore (Pakistan), Ahmad, M.; Shakoori, A. R. (eds.) pp:201-204.

Jyothi, J. V. A. 2004. Pollination of guava (*Psidium guajava* L.) by Honeybees (*Apis cerana indica* F.) at east Godavari District, Andhrapradesh. *Environment and Ecology*, **22** (2):365-368.

Kadmon R and A. Shmida. 1992. Departure rules used by bees foraging for nectar : a field test. *Evol. Ecol.*, **6**:142-151.

Kauffeld, N. M. and P. H. Williams. 1972. Honeybees as pollinators of pickling cucumbers in Wisconsin. *Am. Bee J.*, **112** : 252-254.

Kay, Q. O. N., Lack, A. J., Bamber, F. C., and C. R. Davies, 1984. Differences between sexes in floral morphology, nectar production and insect visits in a dioecious species, *Silene dioica*. *New Phytol.*, **98**:515-529.

Kearns, C.A; and D.W. Inouye.1993. Techniques for pollination biologists. Univeersity Press of Colorado; Niwot, CO, USA, pp:583.

Kevan, P. G. 1974. Pollination, pesticides and environmental quality. *Bioscience*, **24**:198-199.

Kevan, P. G. and D. Eisikowitch. 1990. The Effects of insect pollination in Canola (*Brassica napus* L.CV. O.A.C. Triton) seed germination. *Euphytica*, **45**:39-41.

Kevan, P. G. and T. P. Phillips. 2001. The economic impacts of pollinator declines: An approach to assessing the consequences" *Conservation Ecology*, **5**(1):8.

Kevan, P. G.; Clark, E. A. and V. G. Thomas. 1990 a. Insect pollinators and sustainable agriculture. *Am. J. Alternative Agric.*,**5**:13-22.

Kevan, P. G.; Clark. E. A. and V. G. Thomas. 1990 b. Pollination: A crucial ecological and mutualistic link in agroforestry and sustainable agriculture. *Proc. Entomol. Soc. Ont.*, **121**:43-48.

Kitroo, A. and D. P. Abrol. 1996. Studies on abundance, diversity and importance of native pollinators for fruit production in Litchi (*Litchi chinensis* Sonn.). *Journal of Animal Morphology And Physiology*, **43**(2):149-156.

Klein, A. M.; Steffan-Dewenter, I. and T. Tscharntke. 2003. Bee Pollination and Fruit set of *Coffea arabica* and *C. canephora* (Rubiaceae). *American Journal of Botany*, **90**(1):153-157.

Klinkhamer, P. G. L. and T. J. De Jong. 1990. Effects of Plant size, plant density and sex differential nectar reward on pollinator visitation in the protandrous *Echium vulgare* (Boraginaceae). *Oikos*, **57**:399-405.

Klinkhamer, P. G. L., De Jong, T. J. and G. J. De Bruyn. 1989. Plant size and pollinator visitation in *Cynoglossum officinale*. *Oikos*, **54**:201-204.

Klug, M. and G. Buenemann. 1985. The efficiency of solitary bees as pollinators of Pome fruits.1. Bee behaviour during blossom visits. *Gartenbauwissenschaft*, **50** (5):212-216.

Knapp, S. J., Tagliani, L. A. and B. H. Lui. 1991. Outcrossing rates of experimental populations of *Cuphea lanceolata*. Plant Breeding

106:334-337.

Knuth, P. 1906-1909. Handbook of flower pollination.Clarendon, London (Translated by J.A.Davis).

Kumar, M. and R. Singh. 2001. Initiation –Cessation and period of foraging activity of honeybees on sunflower. *Journal of Entomological Research*, **25** (2):141-143.

Kunin, W. and Y. Iwasa. 1996. Pollinator foraging strategies in mixed floral arrays: Density effects and floral constancy. *Theor. Popul. Biol*., **49**(2):232-263.

Kunin, W. E. 1993. Sex and the single mustard: Population density and pollinator behaviour effects on seed set . *Ecology*, **74**:2145-2160.

Kunin, W. E. 1997. Population size and density effects in pollination: pollinator foraging and plant reproductive success in experimental arrays of *Brassica kaber*. *J. Ecol*., **85**(2):225-234.

Langridge, D. F. 1952. Pollination Experiment on Pumpkins. Agricultural Department's work. *Austral. Bee Jour*., **33**:84.

Langridge, D. F. and R. D. Goodman. 1977. A study on pollination of lupins (*Lupinus angustifolius*). *Aust. J. Exp. Agric. Anim. Husb*., **17**(85):319-322.

Langridge, D. F.; Jenkins, P. T. and R. D Goodman. 1977. A study on pollination of dessert peaches cv. Crawford. pp:697-699.

Lehrer, M. 1997. Honey bee's use of spatial parameters for flower discrimination. *Israel Journal of Plant Sciences*. **45**(2-3):157-167.

Levin, D. A. and H. W. Kerster. 1969. The dependence of bee mediated pollen and gene dispersal upon plant density. *Evolution*, **23**:560-571.

Levin, M. D. 1967. Pollination. in beekeeping in the United States. *U. S. Dept. -Agr., Agr. Handb*. **335**:77-85.

Levri, M. A. 1998. The effect of timing of pollination on the mating system and fitness of *Kaimia latifolia* (Ericaceae). *American Journal of*

Botany, **85**(11):1626-1630.

Mann, L. K. 1953. Honeybee activity in relation to pollination and fruit set in the cantaloupe (*Cucumis melo*). *Amer. J. Bot.*, 79:57-62.

McGregor, S. E. 1950. Activity of honeybees on cantaloupes. *Rep. Ia. St. Apiar.* **1950**:140-142.

McGregor, S. E. 1976. Insect pollination of cultivated crop plants. *Agriculture Handbook*, **496**:306-312.USDA, Washington, DC.

McGregor, S. E., and F. E. Todd. 1952. Cantaloupe production with honeybees. *J. Econ. Entomol.*, **45**(1):43-47.

Mcgregor, S. E.; Alcorn, S. M. and G. Olin. 1962. Pollination and pollinating agents of the Saguaro. *Ecology*, **43**:259-267.

McGregor, S. E.; Levin, M. D. and R. E. Foster. 1965. Honey bee visitors and fruit set of cantaloupes. *J. Econ. Entomol.*, **58**:968-970.

Michelbacher, A. E., Smith. R. F. and P. D. Hurd Jr. 1964. Bees are essential in pollination of squashes, gourds and pumpkins. *Calif. Agr.*, **18**(5):2-4.

Minckley, R. L.; Cane, J. H.; Kervin, L. and T. H. Roulston. 1999. Spatial predictability and resource specialization of bees (Hymenoptera: Apoidea) at a superabundant, widespread resource. *Biological Journal of The Linnean Society*, **67**(1):119-147.

Mishra, R. C.; Kumar, J. and J. K. Gupta. 1988. The effect of mode of pollination on yield and oil potential of *Brassica campestris* L. var. sarson with observations on insect pollinators. [AICRP (Honeybees), *J. Apic. Res*., **27**(3):186-189.

Mohr, N. A. and S. C. Jay. 1988. Nectar and pollen collecting behaviour of honeybees on canola (*Brassica campestris* L. and *Brassica napus* L.). *J. Apic. Res*., **27**(2):131-136.

Moller, A. P. 2000. Developmental stability and pollination. *Oecologia*, **123** (2):149- 157.

Morimoto, Y.; Gikunku, M. and P. Maundu. 2004. Pollinators to the bottlegourd (*Lagenaria siceraria*) observed in Kenya. *International Journal of tropical insect science*, **24**(1):79-86.

Morris, H. 1968. pollination of cucumbers. *Glean. Bee Cult.* **1**:14-16.

Motes, J. E. 1977. Pickling cucumbers: Production harvesting. Mich. St. *Univ. Ext. Bull.* **837**:8.

Motten, A. F. 1986. Pollination ecology of the spring wildflower community of a temperate deciduous forest . *Ecol. Monogr*, **56**:21-42

Nansen, C. and S. Korie. 2000. Determining the time delay of honeybee (Apis mellifera) foraging response to hourly pollen release in a typical pollen release in a typical pollen flower (*Cistus salvifolius*). *Journal of Apicultural Research*, **39**(3-4):93-101.

Neira, M. C.; Lobos, N. S.; Riveros, M. G.; Carrillo, R. Li.; Pessot, R. Z. and N. B. Mundaca. 1997. Entomofauna associated with flowers of raspberry (*Rubus idaeus* L., cv Meeker) and evaluation of pollination activity apis mellifera L. under the influence of a pheromonal attractant. *Revista Chilena De Entomologia*, **24**:37- 44.

Nevkryta, A. N. 1953. Insects pollinating cucurbit crops. *Kiev Akad. Nauk. Ukrain SSR.* pp:92.

Njoroge, G. N.; Gemmill, B.; Bussmann, R.; Newton, L. E. and V.W. Ngumi. 2004. Pollination ecology of *Citrullus lanatus* at Yatta, Kenya. *International Journal of Tropical insect science*, **24**(1):73-77.

Nye, W. P. and J. L. Anderson. 1974. Insect pollinators frequenting strawberry blossomsand the affect of honeybees on yield and fruit quality. *J. Amer. Soc. Hort. Sci*., **99:** 40-44.

O'Neil, P. 1999. Selection on flowering time: An adaptive fitness surface for nonexistent character combinations. *Ecology*, **80** (3):806-820.

Ohara, M. and S. Higashi. 1994. Effects of inflorescence size on visits from pollinators and seed set of *Corydalis ambigua* (Papaveraceae).

Oecologia, **98**(1):25-30.

Ohashi, K. and T. Yahara. 1998. Effects of Variations in flower number on pollinator visits in *Cirsium purpuratum* (Asteraceae). *Am. J. Bot.*, **85**:219-224.

Ohashi, K. and T. Yahara. 1999. How long to stay on, and how often to visit a flowering plant ?- a model for foraging strategy when floral displays vary in size. *Oikos*, **86**:386-392.

Oidroyd, B.; Rinderer, T. and S. Wongsiri. 1992. Pollen resource partitioning by *Apis dorsata, A. cerana, A. andreniformis* and *A. florea* in Thailand. *J. Apic. Res.*, **31**(1):3-7.

Olesen, J. M. and E. Wamcke. 1989 a. Temporal changes in pollen flow and neighbourhood structure in a population of *Saxifraga hirculus* L. *Oecologia*, **79**(2):205-211.

Olesen, J. M. and E. Wamcke. 1989b. Flowering and seasonal changes in flower sex ratio and frequency of flower visitors in a population of Saxifraga hirculus. *Holarct. Ecol.*, **12**(1):21-30.

Ordway, E.; Buchmann S. L.; Kuehl R. O. and C. W. Shipman. 1987. Pollen dispersal in buffalo gourd, *Cucurbita foetidissima* (Cucurbitaceae) by bees of the genera Apis, *Peponapis* and *Xenoglossa* (Hymenoptera:Apidae, Anthophoridae). *J. Kans. Entomol. Soc.*, **60**(4):489- 503.

Orr, N. and D. Eisikowitch.1988. Interaction between melon (*Cucumis melo*) flowers and honeybees under extreme desert conditions in Israel. *Apidologie*.**19**:85-96.

Palanichamy, P. S.; Baskaran, S. and A. Mohandoss. 1995. Insect pollination of the moringa plant *Moringa concanensis* nimmo Linn. *Environ. Ecol.*, **13**(1):47-51.

Pandey, R. S. and R. P. S. Yadava. 1970. Pollination of Litchi (*Litchi chinensis* by insects with special preference to honey bees. *Journal* *of Apicultural Research,* **9**(2):103-105.

Partap, U. and L. R. Verma. 1994. Pollination of radish by *Apis cerana*. *J. Apic. Res*., **33**(4):237-241.

Parthiban, M.; Baskaran, S. and A. Mohandoss. 1994. Insect pollination of the chrysanthemum, *Chrysanthemum indicum* Linn. *Environ. Ecol*., **12**(1):9-13.

Pelletier, L.; Brown, A.; Otrysko, B. and J. N. McNeil. 2001. Entomophily of the cloudberry (*Rubus chamaemorus* L.). *Entomologia Experimentalis ET Applicata*, **101**(3):219-224.

Pintaudi, C. A.; Stort, M. N. S. and M. A. M. Morales. 1990. Pollination of *Xylobium squalens* Lindi. (Orchidaceae). *Naturalia* (Sao Paulo), **15**:67-80.

Pomeroy, N. and R. M. Fischer. 2002. Pollination of Kiwifruit (*Actinidia delicosa*) by Bumblebees (*Bombus terrestris*):Effect of bee density and patterns of flower visitation. *New Zealand Entomologist*, **25**:41-49.

Posey, A. F.; Katayama, R. W. and J. G. Burleigh. 1986. The abundance and daily visitation patterns of bees (Hymenoptera : Apoidea) on oil seed sunflower, *Helianthus annuus* L. in Southeastern Arkansas. *J. Kans. Entomol. Soc*., **59** (3):494-499.

Prakash, D. S.; Baskaran, S. and A. Mohandoss. 1993. Insect pollination of the guava, *Psidium guajava* Linn. *Comp. Physiol. Ecol*., **18** (2):60-64.

Primarck, R. B. and J. A. Silander. 1975. Measuring the relative importance of different pollinators to plants. *Nature*, **255**:143-144.

Quagliotti, L. and F. Marletto. 1987. Research on the pollination of runner bean (Phaseolus coccineus L.) for dry grain production. *Adv.Hortic. Sci*., **1:**3-49.

Rademaker, M. C. J. and T. J. De Jong. 1998. Effects of flower number on estimated pollen transfer in natural populations of three hermaphroditic species: an experiment with fluorescent dye. *Journal of Evolutionary Biology*, **11**(5):623-641.

Rahmlow, H. J. 1970. Cucumbers need the honeybee. *Glean. Bee Cult*. **98**(10):585- 587, 634.

Raj, D. and V. K. Rana. 1994. Time spent by *Apis mellifera* L. and *Apis cerana indica* F. foragers on rapeseed bloom. *J. Entomol. Res*., **18**(4):335-339.

Raj, D.; Rana, V. K. and N. Devi. 1993. Comparative studies on pollen loads and pollen constancy of *Apis mellifera* L. and *Apis cerana indica* F. on rapeseed. *J. Entomol. Res.*, **17**(1):43-48.

Rana, V. K.; Raj, D. and R. J. Kaushik. 1997. Comparative forging activity of *Apis mellifera* L. and *Apis cerana indica* F. on rapeseed bloom. *Entomol. Res.*, **21**(1):59-64.

Rao, C. B. and C. S. Reddi. 1994. Reproductive ecology of *Cochlospermum religiosum*. *Trop. Ecol.*, **35**(2):209-218.

Regal, R. 1977. Ecology and evolution of flowering plant dominance. *Science*, **196**: 622 - 629.

Rehman, K.; Hussain, T.; Soomro, A. H. and R. D. Khuhro. 1990. Pollinators' activities on Mango inflorescence. in Proceedings of Pakistan Congress of Zoology, **10**:143-146.

Robertson, A. W and M. R. Macnair. 1995. The effect of floral display size on pollinator service to individual flowers of *Myosotis and Mimulus*. *Oikos*, **72**:106-114.

Robinson, R.W., and D. S. Decker Walters. 1997. Cucurbits. CAB Intl. New York.

Robinsons, F. A. 1952. The use of honey bees in production of cucurbits in Florida. *Amer. Bee Jour.*, **92**:326-328.

Rodriguez- Robles, J. A., Melendez, E. J. and J. D. Ackerman. 1992.

Effects of Display size flowering phenology and nectar availability on effective visitation frequency in *Comparettia facalta* (Orchidaceae). *American Journal of Botany,* **79**:1009-1017.

Rosa, J. T. 1924. Fruiting habit and pollination of cantaloupe. *Proc. Amer. Soc. Hort. Sci.,* **21**:51-57.

Rosa, J. T. 1925. Pollination and fruiting habit of the watermelon. Proc. *Amer. Soc. Hort. Sci***. 21**:51-57.

Rozen, J. G., and R. Ayala. 1987. Nesting biology of the squash bee *Peponapis utahensis* (Hymenoptera: Anthophoridae, Eucerini). *Journal of the New York Entomological Society,* **95**(1):28-33.

Sanduleac, E. 1959. Data on the entomophilous pollination and the selection of cucurbitaceae. *Lucr. Stiint Stat. Cent. Seri. Apic.***, 1**:129-132.

Schall B. 1978. Density dependent foraging on *Liatris pychnostachya*. *Evolution,* **32**:452-454.

Schemetkopv, M. F. 1960. Cucumber: pollinating activity of bees in greenhouses. *Pchelovodstvo,* **37**(1):28-31.

Schemske D.; Agren, J.; J. le Corf. 1996. Deceit pollination in the monoecious neotropical herb *Begonia oaxacana* (Begoniaceae). In: Lloyd D.G.B, Barrett S.C.H. (eds) Floral Biology. Studies on floral evolution in animal pollinated plants. Chapman and Hall, New York., pp:292-318.

Schemske, D., C. C. Horvitz. 1984. Variation among floral visitors in pollination ability: a precondition for mutualism specialization. *Science*, **225**: 519-521.

Schmitt, J. 1983. Density dependent pollinator foraging, flowering phenology amd temporal pollen dispersal patterns in *Linanthus bicolor*. *Evolution,* **37**:1247- 1257.

Seaton, H. L.; Hutson, R. and J. H. Muncie. 1936. The production of cucumbers for pickling purposes. *Spec. Bull. Mich. Agr. Exp. Stn*., **273**: 31.

Sedgley, M., and P. B. Scholefield. 1980. Stigma secretion in the watermelon before and after pollination. *Bot. Gaz*., **141**(4):428-434.

Silander, J. A. and R. B. Primarck. 1978. Pollination intensity and and seed set in the evening primrose (*Oenothera fruticosa*). *Am. Midl. Nat.*, **100**:213-216.

Singh, B.; Kumar, M.; Sharma, A. K. and L. P. Yadav. 2004. Effect of bee pollination on yield attributes and seed yield of tori (*Brassica campestris* var.Toria). *Environment and Ecology*, **22**(3):571-573.

Singh, M. P.1984. Studies on the activity of some insect pollinators on jujube (*Zizyphus mauritiana* Lamk.). *Entomon*, **9** (4):287-290.

Singh, R. P. and P. N. Singh. 1992. Impact of bee pollination on seed yield of mustard seed. *J. Apic. Res*., **31**(3-4):128-133.

Skinner, J. A., and G. Lovett. 1992. Is one visit enough? Squash pollination in Tennessee. *Amer. Bee J.*, **132** (12):815.

Skrebtsova, N. D. 1964. Use of pollinating activity of honey bees for developing hybrid vegetable seed. *Trud. Nauch Issled. Inst. Pchelovod. Selsk. Khoz. Rybnoe*, pp: 223-245.

Slaa, E. J.; Cevaal, A. and M. J. Sommeijer. 1998. Floral constancy in *Trigona* stingless bees foraging on artificial flower patches:a comparative study." *Journal of Apicultural Research*, **37**(3):191-198.

Snow, A. A. and D. W. Roubik.1987. Pollen deposition and removal by bees visiting two tree species in Panama. *Biotropica*, **19**: 57-63.

Souza, D. T. M and R. H. N. Cauto. 2002. Pollination by insects in three orange [*Citrus sinensis* (L.) Osbeck] cultivars. *Cientifica*, **30**(1-2):79-87.

Spangler, H. G. and J. O. Moffett. 1977. Honey bee visits to tomato flowers in polyethylene greenhouses. *Am. Bee j.*, **117**(9):580-582.

Spangler, H. G., and J. O. Moffett. 1979. Pollination of melons in greenhouses. *Glean. Bee Cult.*, **107**:17-18.

Spira, T. P.; Snow, A. A.; Whigham D.F. and J. Leak. 1992. Flower visitation, pollen deposition, and pollen tube competition in *Hibiscus moscheutos* (Malvaceae). *Am. J. Bot.*, **79**:428-433.

Spira, T. P.; Snow, A. A. and M. N. Puterbaugh. 1996. The timing and effectiveness of sequential pollinations in *Hibiscus Moscheutos*. *Oecologia*, **105**(2):230-235.

Stanghellini, M. S. 1996. The effect of bee type and bee visit number in the pollination of cucumber and watermelon. *Msc. Thesis,* North Carolina State Univ., Raleigh.

Stanghellini, M. S.; Ambrose, J. T. and J. R. Schultheis. 1997. The effects of honey bee and bumble bee pollination on fruit set and abortion of cucumber and water melon. *Am. Bee J.*, **37**(5):386-391.

Stanghellini, M. S.; Ambrose, J. T. and J. R. Schultheis. 1998. Seed production in watermelon: A comparison between two commercially available pollinators. *Hort. Sci.*, **33**:28-30.

Stanghellini, M. S.; Ambrose, J. T. and J.R. Schultheis. 2002 b. Diurnal activity, floral visitation and pollen deposition by honeybees and bumblebees on field grown cucumber and watermelon. *Journal of Apicultural Research*, **41**(1-2):27-34.

Stanghellini, M. S.; Schultheis, J. R. and J. T. Ambrose. 2002 a. Pollen mobilization in selected Cucurbitaceae and the putative effects of pollinator abundance on pollen depletion rates. *J. Amer. Soc. Hort. Sci.*, **127**(5):729-736. .

Stanton, M. L.; Snow, A. A. and S. N. Handel. 1986. Floral evolution: attractiveness to pollinators increases male fitness. *Science*, **232**:1625-1626.

Steinhauer, A. L. 1970. Honey bee pollination of cucumbers in Maryland.

Am. Bee J., **110**:12-13.

Stephen, W. A. 1970. Honey bees for cucumber pollination. *Am. Bee J.*, **110**: 132-133.

Stephen, W. P. 1955. Alfalfa population in Manitoba. *J. Econ. Entomol.* **48**: 543-548.

Stone, G. N. and P. G. Willmer. 1989. Pollination of cardamom in Papua New Guinea. *J. Apic. Res*., **28**(4):228- 237.

Suryanarayana, M. C.; Mohanarao G. and T. S. M. S. Singh. 1992. Studies on pollen sources for *Apis cerana* Fabr. and *Apis mellifera* L. bees at Muzaffarpur, Bihar, India. *Apidologie*, **23**(1):33-46.

Svendsen, O. 1990. Experiments on the importance of honey bees for the pollination of spring rape (*Brassica napus*). *Tidsskr, Planteavl*, **94**(2):141-148.

Talpur, M. A.; Rustamani, M. A.; Hussain, T.; Baloch, H. B.and I. B. Khushk. 1993. Insect pollinators associated with safflower presented at: Proceedings Of Pakistan Congress Of Zoology. Vol.13, Published by Zoological Society of Pakistan, Lahore (Pakistan), Ahmad, M.; Shakoori, A. R. (eds.), pp:523-528.

Tanda, A. S. 1985. Floral biology, pollen dispersal, and foraging behaviour of honeybees in okra (*Abelmoschus esculentum*). *J. Apic. Res.*, **24**(4):223-227.

Tepedino,V. J. 1981.The pollination efficiency of squash bee (*Peponapis pruinosa)* and the honeybee (*Apis mellifera*) on summer squash (*Cucurbita pepo*). *Journal of the Kansas Entomological Society*, **54**(2):359-377.

Thompson, J. D. 2001. How do visitation patterns vary among pollinators in relation to floral display and floral design in a generalist pollination system. *Oecologia*, **126**(3):386-394.

Thompson, R. C.; Doolittle, S. P. and D. J. Caffrey. 1955. Growing

Pumpkins and squashes. *U. S. Dept. Agr. Farmer's Bul.*, **2086**:30.

Thomson, J. D. 1988. Effects of Variation in inflorescence size and floral rewards on the visitation rates of traplining pollinators of *Aralia hispida*. *Evol. Ecol.*, **2**:65-76.

Thurston, H. D. 1969. Tropical Agriculture- A key to the world food crisis. *Bioscience*, **19**:29-34.

Tontz, C. 1944. Ants pinch hit for bees. Glean. *Bee Cult.,* **72**:482.

Torchio, P. F. 1990. Diversification of pollination strategies for U.S. crops. *Environ. Entomol.,* **19**(6):1646-1656.

Torchio, P. F. 1991. Bees as crop pollinators and the role of solitary species in changing environments. *Acta Hortic*., **288**:49-61.

Torchio, P. F. 1994. The present status and future prospects of non-social bees as crop pollinators. *Bee World*, **75**:49-53.

Totland, O. 1994. Influence of climate, time of day and season, and flower density on insect flower visitation in alpine Norway. *Arct. Alp. Res*.,**26** (1):66-71.

Totland, O. and I. Mathews.1998. Determinants of pollinator activity and flower preference in the early spring blooming *Crocus vernus*. *Acta Oecologica*, **19**(2):155-165.

Tyler, E. E., and Haseman, L. 1915. Farm bee-keeping. *Mo. Agr. Expt. Sta. Bul.* **138** :40.

Utelli, A. B. and B. A. Roy. 2000. Pollinator abundance and behaviour on *Aconitum lycoctonum* (Ranunculaceae) : an analysis of the quantity and quality components of pollination. *Oikos*, **89**:461-470.

Vaissiere, B. E. and R. Froissart. 1996. Pollination of cantaloupes under spunbonded row cover by honeybees (Hymenoptera: Apidae) in West Africa. *J. Econ. Entomol*, **89**(5):1213-1222.

Vaissiere, B. E.; Rodet, G.; Cousin, M.; Botella, L. and J. P. T. Grossa. 1996. Pollination effectiveness of honeybees (Hymenoptera: Apidae) in a Kiwifruit orchard. *J. Econ. Entomol*., 89(2):453-461.

Vaughton, G. and M. Ramsey.1998. Floral display, pollinator visitation and reproductive success in the dioecious perennial herb *Wurmbea dioica* (Liliaceae). *Oecologia*, **115**(1-2):93-101.

Verdieva, M. G. and M. K. Ismarlova. 1960. The influence of bee pollination on the increase of the crop from seed squash. *Pchelovodstvo*, **37**(9): 4041.

Verma L.R. and Dulta P. C. 1986. Foraging behaviour of *Apis cerana indica* and *Apis mellifera* in pollinating apple flowers. *J. Apic. Res*., **25**(4):197-201.

Verma, L. R. and R. S. Rana. 1994. Further studies on the behaviour of *Apis cerana* and *Apis mellifera* foraging on apple flowers. *J. Apic. Res*., **33**(3):175-178.

Verma, L. R. and U. Partap. 1993. Asian hive bee *Apis cerana* as a pollinator in vegetable seed production: *An awareness handbook.* ICIMOD;Kathmandu, Nepal. pp:52.

Viswanathan, G. and C. Thiagarajan. 1994. Behaviour of honey bees as pollinators. *J. Ecotoxicol. Environ. Monit*., **4**(3-4):253-257.

Walters, B. B. and E. W. Stiles. 1996. Effect of canopy gaps and flower patch size on pollinator visitation of Imapatiens capensis. *Bull. Torrey Bot. Club*, **123**(3):184-188.

Warren, L. O. 1961. Pollinating cucumbers with honey bees. *Ark. Farm Res.* **10** (2):7.

Waser, N. M. and M. V. Price. 1983. Optimal and actual outcrossing in plants, and the nature of plant-pollinator interaction. pp.:341-359. In: C.E. Jones and R.J. Little (eds.). *Handbook of experimental pollination* biology. Van Nostrand Reinhold Co., New York.

Waser, N. M. and M. V. Price.1990. Pollination Efficiency and effectiveness of Bumble bees and hummingbirds visiting *Delphinium* *nelsonii*, *Collectanea Botanica* (Barcelona) **19**:9-20.

Wells, H. and P. H. Wells. 1983**.** Honeybee foraging: Optimal Diet, minimal uncertainity or individual constancy behaviour? *Journal of Animal Ecology*, **52**:829-836.

Wells, H.; Wells, P. H. and D. M. Smith. 1981. Honey bee responses to reward size and colour in an artificial flower patch. *Journal of Agricultural Research*, **20**:172-179.

White, D. 2001. Flower constancy of the stingless bee *Trigona carbonaria* Smith (Hymenoptera: Apidae: Meliponini).*Australian Journal of Entomology*, **40**(1):61-64.

Willemstein, S. C. 1987. An evolutionary basis for pollination ecology. *E. J. Brill*, Leiden.

Willis, D. S. and P. G. Kevan. 1995. Foraging Dynamics of *Peponapis pruinosa* (Hymenoptera: Anthophoridae) on pumpkin (*Cucurbita pepo*) in Southern Ontario. *Canada Entomol.*, **127**(2):167-175.

Wilson, P. and M. Stine. 1996. Floral constancy in bumble bees:Handling efficiency or perceptual conditioning?. *Oecologia*, **106**(4):493-499.

Wiolfenbarger, D. O. 1962. Honeybees increase squash yields. *Fla. Agr. Expt. Sta. Sunshine State Agr. Res. Rpt*., **7**(1):15, 19, 310.

Woyke, H. W. and K. Bronikowska. 1984. The influence of honeybee population on pickling cucumber yield. In V International Symposium on Pollination, Versailles, 27-30 september 1983. Les Colloques de I'INRA, Paris. pp:323-327.

Young, H. J. 1988. Differential importance of beetle species pollinating *Dieffenbachia longispatha* (Araceae). *Ecology*, **69**: 832-844.

Young, H. J. and M. L. Stanton. 1990. Influences of floral variation on pollen removal and seed production in wild radish. *Ecology*,**71** (2):536-547.