DIVERSITY OF INSECT POLLINATORS AND IMPACT OF BEE POLLINATION ON PUMPKIN (*Cucurbita moschata* Duch. ex Poir)

THESIS SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

By

Bendangsenla Longkumer

Admn.No. Ph-306/20 Regn. No. Ph. D/ENT/00429

Department of Entomology,
School of Agricultural Sciences,
Nagaland University, Medziphema Campus- 797106
Nagaland

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DIVERSITY OF INSECT POLLINATORS AND IMPACT OF BEE POLLINATION ON PUMPKIN (CUCURBITA MOSCHATA DUCH. EX POIR)

BY

Name of Candidate- Bendangsenla Longkumer

Name of Supervisor- Dr. Hijam Shila Devi

Submitted

In partial fulfilment of the requirements for the Degree of Doctor of Philosophy in

Entomology of Nagaland University

Dedicated

to my

Beloved family

Nagaland University

November 2024

I, Bendangsenla Longkumer, hereby declare that the subject matter of this Thesis is the record of work done by me, that the contents of this Thesis did not form the basis of the award of any previous degree to me or to the best of my knowledge to anybody else, and that the thesis has not been submitted by me for any research degree in any other University/Institute.

This is being submitted to Nagaland University for the degree of Doctor of Philosophy in Entomology.

(Scholar)

(Head) (Supervisor)

NAGALAND UNIVERSITY
Medziphema Campus
School of Agricultural Sciences
Medziphema – 797106, Nagaland

Dr. Hijam Shila Devi
Associate Professor
Department of Entomology

CERTIFICATE – I

This is to certify that the thesis entitled "**Diversity of insect pollinators and impact of bee pollination on pumpkin (*Cucurbita moschata* Duch. ex Poir)**" submitted to Nagaland University in partial fulfillment of the requirements for the award of degree of Doctor of Philosophy (Agriculture) in Entomology is the record of research work carried out by Ms. Bendangsenla Longkumer Registration No Ph. D/ENT/0042 under my personal supervision and guidance.

The result of the investigation reported in the thesis have not been submitted for any other degree or diploma. The assistance of all kinds received by the student has been duly acknowledged.

Date :
Place :

……………………………..
Dr. HIJAM SHILA DEVI
Supervisor

NAGALAND UNIVERSITY
Medziphema Campus
School of Agricultural Sciences
Medziphema – 797106, Nagaland

CERTIFICATE – II

VIVA VOCE ON THESIS OF DOCTOR OF PHILOSOPHY IN ENTOMOLOGY

This is to certify that the thesis entitled **"Diversity of insect pollinators and impact of bee pollination on pumpkin (*Cucurbita moschata* Duch. ex Poir)"** submitted by Ms. Bendangsenla Longkumer, Admission No. Ph-306/20, Registration No. Ph.D./ENT/00429 to the NAGALAND UNIVERSITY in partial fulfilment of the requirements for the award of degree of Doctor of Philosophy in Entomology has been examined by the Advisory Board and External examiner on……………………

The performance of the student has been found **Satisfactory/Unsatisfactory.**

Member	Signature
1. Dr. Hijam Shila Devi (Supervisor & Chairman)	……………………….
2. .... (External Examiner)	………………………
3. Dean, SAS, NU (Pro Vice Chancellor Nominee)	…. ……………………..
4. Dr. Pankaj Neog	………………..………
5. Dr. Avinash Chauhan	……………………..
6. Dr. Narola Pongener	……………….……
7. Dr. T.Gohain	………………………..

Head
Department of Entomology

Dean
School of Agricultural Sciences

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Dated: *(Bendangsenla Longkumer)*

Place: Medziphema

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%	-	Per cent
/	-	Per
@	-	at the rate of
+	-	Plus
±	-	Plus, minus
=	-	Equal to
µ	-	micro
ºC	-	Degree Celsius
AM	-	Anti Meridiem
ANOVA	-	Analysis of Variance
CD	-	Critical difference
cm	-	Centimetre
et al	-	*et allia* (and others/Co-workers)
Fig	-	Figures
g	-	Gram
h	-	Hours
ha	-	Hectare
i.e.	-	*Id est* (that is)
ICAR	-	Indian Council of Agricultural Research
Kg	-	Kilogram
m	-	Metre
mm	-	Millimetre

Max.	-	Maximum
Min.	-	Minimum
Min	-	Minutes
MSL	-	Mean Sea Level
MT	-	Metric Tonnes
N	-	Nectar
No.	-	Number
NU	-	Nagaland University
OP	-	Open pollinated
P	-	Pollen
PH	-	Potential of Hydrogen
PM	-	Post Meridiem
RBD	-	Randomized Block Design
RH	-	Relative Humidity
S	-	Significance
NS	-	Non significance
SAS	-	School of Agricultural Sciences
SEM+/-	-	Standard Error of the Mean
Sl.no	-	Serial Number
Spp.	-	Species pluralis
T	-	Treatment
TSS	-	Total Soluble Solid
Viz	-	*Videlicet/namely*

ABSTRACT

A research investigation entitled "Diversity of insect pollinators and impact of bee pollination on pumpkin (*Cucurbita moschata* Duch. ex Poir)" was undertaken with the objectives to study the diversity of insect pollinators on pumpkin, to find out the pollination efficiency index (PEI) of different pollinators and to determine the effect of bee pollination on productivity of pumpkin. The study was carried out at the experimental cum research farm, Department of Entomology, School of Agricultural Sciences, Nagaland University, Medziphema campus during the year 2022 and 2023. The experiment was laid out in Randomized Block Design with four replications and six treatments *viz*., *Apis mellifera*, *Apis cerana*, *Tetragonula iridipennis*, *Lepidotrigona arcifera* including open pollinated and control. The studies revealed that pumpkin flower attracted insects belonging to three orders which include Hymenoptera, Coleoptera and Diptera. The most abundant was found to be order Hymenoptera which includes pollinators like *Apis mellifera*, *Apis cerana, Apis florea, Apis dorsata, Tetragonula iridipennis*, *Lepidotrigona arcifera, Lasius niger, Xylocopa tenuiscapa* and *Xylocopa fenestrata.* The relative abundance, foraging rate and foraging speed was found to be highest in *Apis cerana* as compared to other pollinators. During 2022 and 2023, the diversity index of pollinators was calculated to be 1.64 and 1.61 respectively. From the pollination efficiency index (PEI) of the pollinators, it was revealed that *Apis cerana* had the highest pollination efficiency and the least efficiency was found to be *T. iridipennis* and *L. arcifera*. Experimental findings revealed that the bee pollinated plots were yielded higher on fruit setting as compared to natural pollination. *A cerana* pollinated crop had the maximum per cent fruit (77.50 %), fruit length (20.17 cm), healthy fruit (89.73%), number of seeds (162), weight of 100 seeds (15.63 g) and fruit weight (1.71 kg). However, crooked fruit (%) was recorded to be highest in open pollination. The *A. cerana* bee pollinated treatments resulted in significant increases in all parameters over control plots. The results evidently revealed that bee pollination significantly improved the quality and quantity of fruit production over control and is essential for fruit production in pumpkins.

Key words: *Cucurbita moschata*, foraging, pollination, pollinators, per cent increase, treatment

CHAPTER I

INTRODUCTION

INTRODUCTION

Pumpkin (*Cucurbita moschata* Duch. ex Poir.) is an annual summer vegetable belonging to the family Cucurbitaceae with its centre of origin believed to be South America. The term 'pumpkin' originates from the Greek word 'Pepon' denotes long melon (Bahadur and Singh, 2014). The edible portion of pumpkin is the pericarp of the fruit with a little portion of the mesocarp which is botanically known as 'pepo'. The matured as well as immature fruits are consumed as a vegetable while mature fruits are also used in making confectioneries and beverages. The flowers of pumpkin are considered to have higher nutritive value than fruits. Pumpkin fruits contain abundant minerals and vitamins, especially vitamin A, whereas the seeds are notably high in protein (40.27%), dietary fibre (34.59%) and ash content (44.5 %) (Ramjan *et al*., 2018).

Cucurbita spp. can adapt to wide range of soils and agroclimatic conditions but prefers low altitude, warm and humid conditions and well drained fertile loamy soil (Anonymous, 2016). A temperature range of 18-27 ^{o}C is considered optimum for pumpkin production. The optimum pH for pumpkin is in the range of 6.0 to 6.5, however, it can tolerate both slightly acidic as well as alkaline soil reaction. It requires continuous water supply but is sensitive to waterlogged conditions (Salehi *et al*., 2019). In India, pumpkin is cultivated across approximately 1,10,000 hectares yielding about 23.12 metric tonnes (Anonymous, 2022).

Pumpkin (Cucurbita moschata) is a monoecious, annual crop that thrives under long-day conditions. It grows as a climbing or trailing vine, with stems sometimes exceeding 10 meters in length (Hosen *et al*., 2021). The vines produce large showy flowers to attract pollinators during the early part of the day where wild pollinators can be seen foraging on flowers before dawn. The distinction between male and female flowers are based on colour, structure and

According to Yadav *et al*., 2010) female flowers tend to be longer, measuring about (6-12 cm), whereas male flowers range between 3-5 cm. Successful fruit set occurs when pollen is transfer from male (staminate) flowers to female (pistillate) ones (Hurd *et al.,* 1971). Since *Cucurbita pepo* flowers rely on insects for pollination, being entomophilous (insect-attracting) in nature, pollinators play a crucial role in this process. When an insufficient amount of pollen reaches the stigma, the number of seeds in the fruit tends to be reduced due to lack of pollination resulting in fruits with undesirable shape making the produce less marketable (Nepi and Pacini, 1993).

Pollination is defined as the movement of pollen from the anther to the stigma of the same or a different flower, and it may occur through self or cross-pollination . In most crops, this transfer is facilitated by various agents known as pollinators or pollination vectors. The process can happen through both living (biotic) and non-living (abiotic). Abiotic pollination usually involves wind (anemophily) or water (hydrophily), whereas biotic pollination is generally carried out by animals, such as insects (entomophily) and vertebrates (zoophily).

Pollinators are vital to the functioning of agricultural and natural ecosystems, as they enhance crop yields and maintain populations of flowering plants (Potts *et al.*, 2010). Very often insects are viewed as scourge of agriculture yet although insects particularly bees are crucial for pollination in many crops to set fruit (Klein *et al*., 2007). Pollinators are crucial to global agriculture, with around 30% of the world's food production depending directly or indirectly on their services (Kremen *et al*., 2002). They play a vital role in 8–9% of total global crop production, contributing more than $190 billion annually to the global economy (Gallai *et al*., 2009). Notably, the cultivation of pollinator-dependent crops has tripled in recent decades.

Role of pollinators is well appreciated in the cross pollination of important agro-horticultural crops. It improves uniform crops and quality of fruits by insect pollination. Among the cross-pollinated flowers, about 85% are dependent on insect pollination. Bees play a crucial role in enhancing crop production is well acknowledged and account for about 80% of pollination. Some social related Hymenopterans and honeybees obtain their food through pollen and nectar. The insect pollinators while foraging fortuitously retaliate the valuable services of pollination. The dominant pollinators are solitary bees (*Xyocopa, Andrena, Halictus*), stingless bees (*Trigona, Melipona*), bumble bees (*Bombus)* flies like (*Syrphus, Bombilius*) beetles, moth, thrips and ants. The majority pollinators of cucurbits belong to the insect's super-family Apoidea (Hymenoptera).

Bees are among the key pollinators and include a variety of types such as bumble bees, stingless bees, honey bees, solitary bees and other socially structured bee species. Approximately 1,00,000 distinct species contribute significantly to the pollination of nearly 2,50,000 species of wild flowering plants globally. Research on pollination shortfalls has shown that numerous wild plants species may face reduced reproductive success due to low pollinator visitation rates (Ingram *et al*., 1996). Among honeybees several species such *Apis florea*, *A. cerana, A. dorsata* and *T. iridipennis* are recognized as effective pollinating agents and are distributed worldwide (Zych *et al*., 2013).

The North Eastern region of India encompasses great potential in beekeeping. Notwithstanding the potential, rearing bees has clamped more traditional ways generally for consumption, despite its prominent possibilities as a pollinator. Beekeeping holds significant potential in Nagaland, offering opportunities for both sustainable livelihoods and ecological benefits. It is considered an ideal region for beekeeping due to its rich biodiversity and favourable climatic conditions. It is considered an ideal region for beekeeping due to its rich biodiversity and favourable climatic conditions. In particular, Nagaland hosts diverse species of honey bees (*Apis* spp.) as well as stingless bees like (*Tetragonula* and *Lepidotrigona*) indicating a promising potential for beekeeping in the region (Chauhan and Singh, 2021).

Therefore, considering its positive aspects and considering the potential of pollinators in pumpkin, the present studies "Diversity of insect pollinators and impact of bee pollination on pumpkin (*Cucurbita moschata* Duch. ex Poir)" were initiated to accomplish the following objectives:-

1. To study the diversity of insect pollinators on pumpkin.
2. To find out the Pollination Efficiency Index (PEI) of different pollinators.
3. To determine the effect of bee pollination on productivity of pumpkin.

CHAPTER II

REVIEW OF LITERATURE

REVIEW OF LITERATURE

The relevant literature pertaining to the present study are reviewed and presented below: -

2.1. To study the diversity of insect pollinators in pumpkin.

Pumpkin is a cross-pollinated crop and requires small bees for effective transfer of pollens from male to the female flowers (Sands, 1928).

Alen and Bradley (1966) reported bumble bees, carpenter bees, squash bees and honey bees including *A. mellifera* as natural pollinators of pumpkins. Honey bees were observed to be the largest group (7.2%) of pollinating agents in cucurbits.

The insect pollinators of pumpkin include bees, butterflies, ants and even beetles which while damaging the flower parts, incidentally, caused pollination. Out of all the insects, honey bees were the main contributor for the pollination in *Cucurbita moschata* (McGregor, 1976).

The adaptation of colour, nectar and scent were instrumental in attracting the insects and bringing about cross pollination in *Cucurbita moschata*. The daily flight activity varies with the time of the day and meteorological variables, especially wind, rainfall, temperature and relative humidity (Sarviva, 1985).

The study on the bee pollination of agricultural crops in the world showed that hundreds of species in more than 40 plants families were dependent at least partially on bees and other insects for pollination (Southwick,1995).

Thompson (2001) studied on the variety of visitation patterns among pollinators in relation to floral display and floral design in generalist pollination system and found that 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.

Gahlawat *et al*. (2002) reported that *A. mellifera* was the most abundant insect pollinator on cucumber flowers with 0.08, 2.58, 1.75 and 0.83 bee/m²/5 minutes at 0600 h, 0800 h, 1000 h and 1200 h of the day, respectively and peak foraging activity was observed at 1000 h of the day.

Kumar (2002) reported that twelve insect species belonging to 11 families under four orders were found visiting the blossom of wanga (*Cucumis melo melo*), tinda (*Praecitrullus fistulosus* L.) and cucumber (*Cucumis sativus* L.) at Hisar.Among these insect pollinators, *Mellisodes* sp*., Sarcophaga* sp*., A. mellifera* and *A.florea* were the most frequent insect pollinators on these cucurbitaceous crops with an abundance range of 1.38–1.74, 0.94-1.04, 0.55-1.03 and 0.40–0.65 bees /m²/5 minute, respectively.

Melendez *et al*. (2002) sampled more than 2000 bee specimens on fourteen fields of pumpkin, cucumber, and melon from five localities. The fourteen samples comprised bees of six families, 29 genera and 50 species composition per sample ranged between 10 and 27 species and abundance between 28 and 444 individuals. Seven species (six genera) of Apidae, Anthophoridae and Helicitidae comprised around 80% of all individuals collected.

Nidagundhi and Sattagi (2005) reported among the total visiting pollinators in bitter groud, *A. florea* was the most predominate species constituting 43% followed by *A. cerana* (26%), *A. dorsata* (13%) and other pollinators.

Pinkus–Rendon *et al.* (2005) reported that *Peponapis limitaris, Augochlora nigrocyana, A. mellifera and Partamona biteanata* were the most abundant bee species on staminate flowers of squash, (*Cucurbita moschata*) with per cent abundance of 80.0, 11.0, 7.0 and 2.0, respectively. While on pistillate flowers, *P. limitaris, P. bileanata, A. nigrocyana* and *A. mellifera* were the most abundant bee species with 70.0, 17.3, 8.7 and 4.0 percent, respectively.

Thapa (2006) found that over 50 species of insects visited flowers of 17 different species of selected crops during flowering periods. The visiting preferences of insects to flowers of different crops differed among the crop species and insect's species as well. Over 80% was performed by insects and bees contributed nearly 80% of the total insect pollination and therefore, they were considered the best pollinators.

Daniel *et al*. (2009) found that the higher the number of visits, up to 16, by *A. mellifera* to female flowers, the greater was the fruit set, fruit size and weight, and number of seeds in pumpkin.

Nicodemo *et al*. (2009) reported that *A. mellifera*, *Diabrotica* sp. (Germ.) and *Trigona spinipes* (fab.) were the most frequent insect visitors on the flowers of pumpkin plant. Among bee visitors, *A. mellifera* accounted for 73.4 percent and *Trigona spinipes* represented 26.6 percent of the total bee visitors. The peak activity for *A. mellifera* was noticed at 0800 h, for *T. spinipes* from 0900 h to 1000 h and for *Diabrotica species* from 1400 h to 1700 h with no overlapping of these peaks. Honey bees were reported as important pollinators of pumpkins.

Cristiane *et al*. (2010) estimated the general bee diversity at three locations. In total, 3.270 bees were sampled representing 50 species with 3.153 bees (24 species) counted during censuses on the flowers and 117 individuals of 30 species in the pan traps. The most abundant bee species was *A. mellifera* (32%) followed by squash specialist, *Peponapis fervens* (25%). They were the most abundant bee species in *Cucurbita* in these places.

Kumar and Jaiswal (2012) found that the inflorescence of coriander recruited seven species of insect pollinators namely, *A. florea*, *A. cerana*, *Camponotus compressus, Anthophora accidentalis, Aulacophora femoralis, Pelopidas mathias* and *Musca domestica*. The study showed that the ant *C. compressus* (34.39%), *A. femoralis* (30.90%) and *A. florea* (22.97%) were dominant pollinators of flower.

Pandian *et al.* (2012) observed seven insect visitors on pumpkins. Among seven insect visitors, the ant, *Componotus compressus* (34.39%) was most prevalent followed by cucurbits leaf beetle (33.90%).

A comprehensive two-year study was conducted to compare fruit yield and bee visits to flowers in pumpkin (*Cucurbita pepo* L.) fields that were either supplemented with *A. mellifera* hives, *Bombus impatiens* hives. These results suggest that supplementation with managed bees may not improve pumpkin production and that *A. mellifera* hives, *Bombus impatiens* are important pollinators of pumpkin (Petersen *et al.* 2013).

Mudssar *et al*. (2014) examined the pollinator diversity and the best native pollinators for pumpkin production and found that *Nomia* sp., *A. dorsata* and *Halictus* sp. were the most abundant pollinators with 189, 399 and 117 respectively. The single visit fruit set percentage also revealed *Nomia* sp. (36.66) as the best pollinator followed by the *A. dorsata* (23.33) and *Halictus* sp. (20.00).

Umama *et al*. (2016) conducted a study in the district Haripur to determine the diversity and relative abundance of insects in pumpkin. A total of 212 specimens belonging to 9 orders and 16 families as Coleoptera (Family: Chrysomelidae and Coccinellidae), Lepidoptera (Family: Noctuidae and Pyralidae), Hemiptera (Family: Anthocridae and Pentatomidae), Homoptera (Family: Aphididae and Cicadellidae) were collected.

Julier and Roulston (2009) stated that pumpkin (*C. pepo*) has great potential to be served by wild pollinators because of reliable and widespread group of bee species that were commonly associated with their flowers, including bumble bee (*Bombus* sp.) and in the Americas, two genera of specialist ground nesting bees (*Peponapis* and *Xenoglossa*).

Dorjay *et al.* (2017) conducted a study to determine the diversity and the abundance of pollinator fauna and observed that cucumber flowers attracted a wide variety of insects belonging to 4 different orders, 12 families and 21 species amongst which honeybee were the most dominant and comprised more than 74% of the total visiting insects.

Shankar (2017) conducted a research trial to determine diversity and abundance of pollinator fauna and their role on cucumber and bitter gourd production. Their abundance was in the order *A. mellifera >A. cerana>A. dorsata>A. florea*.

Pande and Verma (2016) conducted the efficiency of the pollinators of pumpkin based on their diversity, relative abundance and foraging activity. Total four pollinators were observed in field *viz*., bumble bee, little honey bee, Indian honey bee and Digger bee. Bumble bees were identified as the most abundant pollinator of pumpkin with 69.69 per cent mean relative abundance as other pollinators mean relative abundance was less than 25 per cent.

Lalita and Yogesh (2017) examined a total of 42 insect species visited pumpkin flowers, 8 were hymenopterans, 7 lepidopterans, 7 dipterans, 3 hemipterans, 2 orthopterans, 14 coleopterans and one belonged to order odonata. Among these, *Apis mellifera* L., *A. cerana* Fab and *A. florea* Fab, were the most abundant pollinators. The abundance of four honeybee species on flowers at different hours of the day differed significantly. *A. dorsata* was the most abundant visitor followed by *A. mellifera, A. cerana* and *A. florea.*

Rahaman *et al*. (2018) reported the foraging activities of insect visitors on cucumber (*Cucumis sativus* L.). The insect visitors in decreasing order of abundance were *Formica* spp *>A. mellifera >A. cerana >Syrphids >A. dorsata*. The bees spent significantly more time per flower during morning hours as compared to evening hours. Most pollen foragers were observed during morning hours (6.59/m^2/10 min) whereas nectar foragers were most active during afternoon hours (6.63/m^2/10 min).

Zulnorain *et al*. (2020) studied on both genus *Apis* and *Bombus* used for the pollination of vegetables, fruits and crops commercially. Honey bee could dispense 80% in insect pollination and are considered as a best pollinator towards crop pollination. Bumblebees were more efficient and competent pollinators due to their buzzing behaviour, efficiency to forage at low temperature and solitary colony structure.

2.2. To study the pollination Efficiency Index (PEI) of different pollinators visiting pumpkin.

Sanduleac (1959) found that cultivars of *Cucurbita maxima*, *C. pepo* and *C. moschata* were worked intensively by bees from 0600 to 1200 h daily and the numbers of bees reached a peak between 0800 and 0900 h, the male flowers were preferred to female flowers indicating that they were collecting pollen deliberately.

The efficiency of an insect pollinator has been attributed to its size, foraging behaviour and the amount of loose pollen grains adhering to its body (Bohart and Nye, 1960, Free 1993).

Hurd (1966) noted that depending upon the weather and season, the flowers of most cucurbits open sometime before daylight or shortly thereafter, and in hot weather, they wither and close by 0800 to 0900 hour, otherwise they remain open until noon.

The amount of loose pollen grains on the body of an insect varies on different body parts. Usually, it may be twice on bee's thorax as on its abdomen. In cucumber, honey bees exhibit no preference for staminate vs. pistillate flowers (Stephan, 1970).

Brantjes and Leemans (1976) noticed that large sized insects were effective in pollination of flowers due to their body contact with anthers and stigma as compared to small size insects, which often missed their contact with anthers and stigma while foraging for floral rewards.

Insects visited the flowers of crops to seek nectar and pollen. Probably most of them transfered pollen and so contributed to pollination. However, relatively few were consistently good pollinators. The different criteria to be used for evaluating the relative efficiency of insect visitors were abundance, foraging behaviour, loose pollen carrying capacities, multiplicities of bee visitors and morphometrical characters, *i.e.*, body size, tongue length, pollen collecting apparatus and hairiness. Bees, with corbiculae and hairy bodies are well-adapted for pollen transport (Fageri and Vander, 1979).

Heard (1999) who recorded that honey bees, carpenter bees, bumble bees, halictid bees and stingless bees were occasional important pollinators of cucurbit crops like bitter gourd, watermelon and cucumber crops and largely visited by stingless bee, followed by other insect visitors.

Reddy (1983) reported the number of nectar gatherers was highest in the morning 06:00 to 08:00 hr and the second peak was from 12:00 to 16:00 hr whereas the pollen gatherers were highest in the late morning between 09:00 to 12:00 hr under Bangalore conditions.

The density of insects on blossom depends on several factors like shape, size, colour, availability of floral rewards and weather condition (Mevetty *et al*.,1989).

Bees are the most versatile, active and best-known pollinators of most agricultural and horticultural crops. An effective pollinator makes sequential visits to the flower, carries pollen and transfered them from anther to stigma during a visit (Corbet *et al*., 1991).

Abrol (2002) observed that peak foraging occurred between 10.00 and 12.00 hr in case of *A. cerana* and between 11.00 to 14.00 hr in case of *A. mellifera*. This revealed that *A. mellifera* needs a higher temperature threshold for intense foraging activity than *A. cerana*. On average, 2 to 13 bees in case *of A. cerana* and 5 to 280 bees in case of *A. mellifera* per 5 branches foraged during different hours of the day.

Canto-Aguilar and Parra-Tabla (2000) reported that females and males of *Peponapis limitaris* and *A. mellifera* were the main pollinators of *C. moschata* flower. On an average, female and male of *P. limitaris* entrapped 4879.5 and 1608.2 pollen grain, respectively in a single bee visit on *Cucurbita moschata* flower and single female of *P. limitaris* transferred the maximum quantity of pollen grains (481.4) on to the stigma of female flower, while male of *P. limitaris* transferred 177.0 pollen grain. Whereas, *A. mellifera* on an average, entrapped 1282.9 pollen grain and transferred 253.4 pollen grains on to the stigma of female flower.

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

Rorry (2000) reported that the honey bee activity was highest between 1100 and 1300 h when temperature averaged from 21 to 25 ºC in cucumber

White (2001) tested the flower constancy of the stingless bee, *Trigona carbonaria* by examining the composition of the pollen loads of individual foragers over time and found that 88% of the samples comprised of pure loads (97% or more of one pollen type). The pattern is consistent with that of highly social bees.

Kumar (2002) reported that the mean foraging activity duration of *Mellissodes* sp. was the highest (263.39 minute) on wanga (*Cucumis melo melo*) flowers followed by *Sarcophaga* sp., *A. florea* and *A. mellifera* with mean foraging activity duration of 225.38, 157.88 and 156.86 seconds, respectively. In the case of tinda (*Praecitrullus fistulousus* L.), the mean foraging activity duration was the highest (226.01 minutes) of *Melissodes* sp. followed by *Sarcophaga* sp. (201.54 minutes), *A. mellifera* (182.67 minutes) and *A. florea* (167.10 minutes).

Kumar (2004) at Hisar, observed that foraging speed (time spent/flower) of *A. mellifera* on cucumber flowers was the highest during 0900-1000 h followed by 1000-1100 h and it was the lowest during 1300-1400 h of the day during Rabi cucumber under polyhouse condition.

Rusta *et al*. (2003) reported that the behaviour of nectar forager on staminate flower differed according to body size. Large size bees foraged for nectar mostly in the afternoon after nectar sugar concentration reached a high value, while smaller bees foraged for nectar throughout the day.

Zaitoun *et al*. (2003) showed that the pollen collection in the Jordanian desert by the honeybee workers recorded very less in winter months (December-January) and the number increased during March to June, doubled peaks of pollen foraging bees appeared during this period.

Gowda *et al*. (2005) found that foraging activity of *A. cerana* was greater in summer and winter and autumn than in winter and monsoon period. Time of greater flight activity varied from season to season.

Herrera *et al*. (2000) reported that pollinator interactions were one of the most pervasive mutualisms in nature as most flowering plants rely, at least in part, on insects or animals for reproduction. This study revealed that Hymenopteran bees (*A. mellifera*, *A. cerana* and *A. dorsata*) are efficient pollinators followed by Lepidoptera, Coleoptera and Hemiptera.

Saravanan and Alagar (2007) worked on the foraging activity of *Trigona irridipennis* in Tamil Nadu, India. The peak flight activity was observed in the morning hours. Majority of the foragers devoted to collect nectar.

Daniel *et al*. (2009) evaluated to determine the diversity of insects visiting its flowers, the time and type of provision obtained and the effect of the visits on fruit set, fruit size and weight and number of seeds. *A. mellifera* L. accounted for 73.4% of the visits made by bees collecting pollen during 34.5 s per flower and nectar in 43.9 s and 29.3 s from female and male flowers respectively. *Trigona spinipes* (Fabr.) collected only nectar during a mean time of 60.5 s per flower and represented 26.6 % of the visits by bees.

The efficiency of pollinators was measured in terms of different parameters such as visitation frequency, time spent per visit, pollen harvest and deposition and fruit and seed set in their single or multiple visits (Ne’eman *et al*., 2010).

Worker bees began foraging activities as early as dawn and ended by dusk depending on weather conditions and availability of forage. Peak foraging times happened simultaneously during dry season when the forage sources were abundant (Kwapong *et al*., 2010).

Danaraddi *et al*. (2011) reported foraging behaviour of *T. iridipennis* varied significantly at different hours of the day and month. Only one peak of activity of outgoing bee and incoming bee with and without pollen occurred between 1000 h and 1200 h during all season.

Anooj (2012) observed that *Ceratina* sp. was the most efficient pollinator with pollination index (71838.20) followed by *A. mellifera* (48800.00) on *Luffa aegyptica* flower.

Ghazi *et al*. (2014) reported that the highest outgoing of foragers was observed during the morning hours and the least number of foragers was observed during the late evening hours.

Azmi *et al*. (2015) observed that the most effective time for foraging activity of *L. terminata,* was found to be in the morning (0800-1030 hrs) and late afternoon (1400-1800 hrs). Their observations showed that colour, odour and size of the flowers and pollen grains were the main factors in attracting the *L. terminata* foragers.

Pisanty *et al*. (2016) studied the Pollinator species visitation rates as well as single-visit fruit set efficiencies. Pollinator's visit frequencies were affected by surrounding land use, location within field, time throughout the season, and time of day. Pollinator's fruit set efficiencies were affected by ovary size and time of day.

Rani (2017) reported that *A. mellifera* spent maximum time (10.30 sec/flower) whereas, *A. florea* spent least time (2.51 sec/flower). All the four bee species *viz*., *A. mellifera*, *A. cerana*, *A. dorsata* and *A. florea* foraged on summer squash flowers. The number of loose pollen grains sticking to the body of *A. cerana* was registered maximum (1977) followed by *A. mellifera* (1650), *A. dorsata* (1600) and *A. florea* (1480). Maximum pollination efficiency was recorded in *A. cerana* followed by *A. mellifera*, *A. dorsata* and *A. florea*.

Carillo *et al*. (2018) recorded high pollen collection by *A. mellifera* in the early morning hours and low amount of pollen collection during the afternoon time. The mean foraging rate during the afternoon hours (36.02 foragers/min) were higher than the morning hours (17.66 foragers/min).

Layek and Karmakar (2018) worked on the foraging activity of Indian stingless bee (*Tetragonula iridipennis*) and found that maximum foraging activity noted during 9.00 -11.00 a.m.

Borketey *et al*. (2018) observed that most of the foraging activities of bees often occurred in the morning from 6:00-11:00 am but from their activities reduced drastically 12:00 p.m. onwards. Fruit set, fruit size, weight and number of seed increased as the number of visits by *A. mellifera* also increased.

Jasvir and lec (2018) reported on the pollination efficiency of various *Apis* spp on parental lines of *Brassica napus* L., plots raised for hybrid seed productions *A. cerana* visited a greater number of flowers/min., followed by *A. mellifera* and *A. dorsata*. The foraging rate of *A. florea* was significantly low. They revealed that *A. cerana* was recorded as most efficient pollinator in case of *B. napus*.

Oliverio *et al*. (2018) found that higher visitation rate to female *C. moschata* flowers by *A. mellifera* and *Peponapis* bees to staminate flowers. Mean visitation rate by *Peponapis* female bees was 17 times higher than visitation rate by male bees.

Nancy *et al*. (2019) found ten species of insects belong to seven families in three orders (Lepidoptera, Diptera and Hymenoptera) as pollinator. The abundance of the pollinator species ranged from 0.1±0.1 to 2.2±0.3 per 30 sweeps. The cabbage butterfly and ant showed statistically similar and higher abundance compared to other insect pollinators. The foraging durations of the frequently abundant pollinators ranged from 16.8 ± 2.2 to 36.6 ± 4.4 s per flower and ant spent the longest duration.

Darclet *et al*. (2019) studied the biodiversity of pollinators in Italian pumpkin. They found that the most frequent insect in the flowers was Africanized honey bee (79.25%) followed by stingless bee *Trigona spinipes* (20.75%). The honey bee visited the flowers from 7:00 a.m. to 1:00 p.m. and preferred to collect nectar in male flowers (61.0%) when compared to pollen in male flowers (23.3%) and nectar in female flowers (16.7%).

Bisui *et al*. (2019) worked on foraging activity of Indian Dammer bee *T. iridipennis* (=*Trigona iridipennis*) and found that pollen foraging activity varied month - wise and day- time wise. Greater activity noted in March-April. The highest number of returning pollen foragers were observed in late morning.

Chauhan *et al.* (2019) reported maximum activity of pollinators on ash gourd at 1000 hr which was found to decrease after 1200 hr and ceased at 1800 hr.

Umesh *et al.* (2020) reported that pollinators of pumpkin consisted of a total of 7 species. Among honey bees, *A. dorsata* proved to be the dominant one (67.40%) followed by *A. florea* (14.28%). *A. dorsata* activity was observed from 0600-1300hrs with peak activity at 0800-0900 hrs.

McGrady *et al*. (2019) identified 37 species of bees foraging commercially pumpkin fields. Among them, honey bees (*Apis mellifera* L. (Hymenoptera: Apidae)], squash bee [*Eucera (Pepo napis*) Say, Dorchin (Hymenoptera: Apidae] and bumble bees [*Bombus* spp., primarily *B. impatiens* Cresson (Hymenoptera: Apidae)] were the most active pollinator taxa responsible for over 95% of all pollination visits.

Singh and Mall (2020) studied the pollination efficiency of different bee species on *Cucumis sativus* and recorded a maximum pollination index of 512565.7 in *A. mellifera* as compared to 428160.2 by *A. dorsata* and 320718.5 by *A. cerana*. They also documented the maximum bee abundance of 5.14 bees/m^2/5 min by *A. dorsata* at 0800-1000 h followed by 5.00 bees/m^2/5 min at 0600-0800 h, 4.14 bees/m^2/5 min at 1000-1200 h and the lowest abundance observed at 1600-1800 h. Another species of honey bee *i.e*. *A. mellifera* was also recorded maximum abundance of 6.57 bees/m^2/5 min at 0800-1000 h, followed by 6.28 bees/m^2/5 min at 0600-0800 h, 5.00 bees/m^2/5min at 1200-1600 h and lowest abundance of 4.85 bees/m^2/5 min at 1600-1800 h. In *A.cerana* the maximum abundance of 5.14 bees/m^2/5 min was recorded at 0800-1000 h followed by 4.71 bees/m^2/5 min at 0600-0800 h, 4.57 bees/m^2/5 min at 1200-1600 h and the lowest abundance 4.42 bees/m^2/5 min recorded at 1600-1800 h.

Sudhanshu *et al*. (2021) evaluated the foraging speed of different insect pollinators on flower of castor *Ricinus communis* cv, GCH-7 and DCH-177. *A. cerana*

F. had maximum foraging speed (6.26 sec/flower) followed by *Apis mellifera* L. (5.12 sec/flower), *A. dorsata* F. (4.20 sec/flower) and *A. florea* F. (3.74 sec/flower). The least foraging speed was observed with *Xylocopa iridipenni*s Lepeletier (2.67 sec/flower). Data taken at different time intervals in a day indicated that the peak foraging speed of pollinators was between 10.00-12.00 hr, while the least one was at 16.00-18.00 hr.

Layek *et al*. (2021) compared treatments with open-pollinated, hand-pollinated and the addition of two managed pollinator species to estimate the yield enhancement potential of managed stingless bees and western honey bees and their impact on native pollinator species. Floral visitors like ants, bees, butterflies, beetles and wasps were reported to visit the flowers either for nectar, pollen, and/or floral tissue. The establishment of *A. mellifera* colonies and stingless bees, *T. iridipennis* colonies was found to increase the yield in watermelon.

2.3. To determine the effect of bee pollination on productivity of pumpkin.

Many investigations had consistently confirmed that yield levels can be increased to an extent of 100-150 per cent in cucurbitaceous crop through good management of pollinators (Melnichenko and Khalifman, 1960).

Cervancia and Bergonia (1991) found that per cent fruit set of bee-pollinated and open pollinated (uncaged) plants did not differ significantly in Phillipines but was about twice that of non-pollinated plant. They further observed that fruits were heavier (0.87 kg) and more uniform than those of open pollinated plants (0.6 kg), while fruits from non-pollinated plants were the shortest and the lightest (0.36 kg).

Hernandez and lemus (1999) observed higher pumpkin yield (weight/ha) in plots nearest to hives which gradually decreased as the distance from the hive increased.

Walters and Taylor (2006) have reported an increase in fruit set, size, weight and number of seeds per fruit in pumpkin in the presence of managed honey bee (*A. mellifera*) pollination.

Maria *et al*. (2010) observed that the amount of pollen deposited on the stigma by the honey bees varied according to the number of visits from 53 grains with one visit to 1,253 grains with 12 visits and the mean number of grains in each visit varied from 53 to 230 grains. The percentage of established fruits was higher (100%) when the flowers received 12 visits to *A. mellifera*, corresponding to a load of 1253 pollen grains.

Pavana (2010) found that the maximum fruit set was (74.00%) in open pollination + hand pollination followed by open pollination (72.50%) and hand pollination (58.38%) in bitter gourd. The least or zero per cent fruit set was observed without insect pollination treatment. He further observed that the average fruit weight was maximum (104.52 g) under open pollination + hand pollination treatment, which was significantly higher than the mean fruit weight under open pollination (79.82 g) and hand pollination (65.61 g).

Artz and Nault (2011) showed that flowers with higher honey bee visits resulted in more seeds per fruit and that squash bee visitation had no effect on the number of seeds.

Cane *et al*. (2011) found that five or more visits by male squash bees resulted in a successfully pollinated flower with seed set comparable to that of an open pollinated flower

Malek and Chowdhury (2011) experimented with the possibility of increasing the yield of pumpkin by supplementing different levels of irrigation and methods of pollination. The highest yield (26.84 t/ha) was achieved from 15 days interval irrigation compared to the control treatment (17.92 t/ha). The combined treatment natural-plus-artificial pollination and irrigation at 15 days interval resulted in the highest production (13.69 t/ha) which was about 50% more yield than that of natural pollination and control irrigation.

Jayaramppa *et al*. (2011) noted that the number of fruits per plot, mean fruit diameter, length and weight, were higher in *Luffa acutangula* crop sprayed with bee attractants when compared to the untreated crop, thus, ascertaining the role of honey bees increase in yield parameter.

Lucas *et al.* (2013) observed positive associations of fruit set with flower visitation by wild insects in 41 crop systems worldwide. In contrast, fruit set increased significantly with flower visitation by honey bees in only 14%. Overall, wild insects pollinated crops more effectively and increased in wild insect visitation enhanced fruit set by twice as much as an equivalent increase in honey bee visitation. Visitation by wild insects and honey bees promoted fruit set independently.

Garibaldi *et al*. (2013) observed that native bees have been shown to benefit yields of crops such as alfalfa (*Medicago sativa*) (for seed), almonds, apples, blueberries (*Vaccinium* spp.), cherries, coffee (*Coffea* spp.), pumpkins (*C. pepo*), strawberries (*Fragaria* × *ananassa*) and watermelon.

Ali *et al*. (2014) reported that in *C. pepo*, single visit efficacy in terms of fruit set percentage was the highest in *Nomia* sp. (36.66) followed by *A. dorsata* (23.33) and *Halictus* sp. (20.0).

Petersen *et al*. (2014) found that supplementing pumpkin fields with *B. impatiens* colonies, regardless of stocking density, did not increase fruit weight, seed set or *B. impatiens* visit to pumpkin flowers. Fruit weight and seed set did not differ between hand and open pollinated treatments.

Sandipan (2017) conducted a systematic study about the increase in the seed yield of niger crop in relation to honeybees (*A. mellifera*). The seed yield and gross returns were considerably higher in first location of Natural plot/open pollinated with beehive (*A. mellifera*) in all the 3 years data with the maximum seed yield with the gross return obtained in this treatment.

Lalita *et al*. (2018) observed that the mean fruit weight, fruit length. fruit diameter, number of seeds per fruit, seed test weight, seed germination percentage, seed vigour I and vigour II were maximum in open-pollination + hand-pollination with 2725.70 g, 37.05 cm, 43.08 cm, 457, 88.88g, 90.75 %, 3058.93 and 5.24, respectively followed by open pollination and hand-pollination in pumpkin (C-1076). Similarly, Mean fruit weight, fruit length, fruit diameter, number of seeds per fruit, seed test weight, seed germination percentage, seed vigour I and seed vigour II were maximum with 2131.20 g, 27.87 cm, 48.32 cm, 407, 85.91 g, 82.75 per cent, 3006.98 and 5.18, respectively in open pollination + hand-pollination followed by open-pollination and hand-pollination in C1106 cultivars. Hence in both cultivars of pumpkin, open-pollination + hand-pollination were the best treatment followed by open pollination and hand pollination.

Nancy *et al*. (2019) found that production of fruit, seed set and yield of insect pollinating plot in winter and summer seasons were 6.4 ± 0.3 and 4.8 ± 0.2 plant $^{-1}$, 84.8 ± 2.7 and 62.6 ± 1.0 fruit $^{-1}$, and 18.5 ± 0.8 and 16.7 ± 0.7 t ha $^{-1}$, respectively. The findings indicated that the native insect pollinators increased the production of fruit, seed and yield of sweet gourd.

Sonja *et al*. (2021) determined the yield dependence of Hokkaido pumpkin in Germany on insect pollination by quantifying: (1) the relationship between pollen receipt and fruit set and (2) the cumulative pollen deposition of each pollinator group. It was found that approximately 2500 pollen grains per flower were needed to maximize fruit set. At the measured rates of flower visitation, it was estimated that bumblebees or honeybees could individually achieve maximum crop yield.

Reddy *et al.* (2021) evaluated the role of stingless bee, *T. iridipennis*, *A. mellifera* and *A. cerana* in pollination of brinjal at Nagaland, India. The maximum pollination efficiency index was found highest for *A. cerana* (21). The weight of fruit (96.30 g), diameter (56.54 cm), healthy fruits (53.89 %) was observed to be maximum with *A. cerana*. However, fruit length (15.10 cm), fruit yield (48.33 %) and seed weight (5.79 g) were found to be at par in all the pollination treatments.

CHAPTER III

MATERIALS AND METHODS

MATERIALS AND METHODS

Research entitled, "Diversity of insect pollinators and impact of bee pollination on pumpkin (*Cucurbita moschata* Duch.ex Poi)''was experimented. This chapter outlines the materials and methods used in the study.

3.1. General Information:

3.1.1. Experimental site:

The investigation undertaken in this study was conducted at the experimental research farm of the Department of Entomology, School of Agricultural Sciences, Nagaland University, Medziphema Campus, during the kharif seasons of 2022 and 2023. The study site is situated at 23° 45' 43'' N latitude and 93° 53' 04'' E longitude, at an elevation of 310 meters above mean sea level.

3.1.2. Climatic and weather conditions:

The farm used for experimentation is positioned in a humid subtropical region, receiving an average annual rainfall of 2000 to 2500 mm. During summer, the average temperature varies between 21°C and 30°C.while winter temperatures seldom drop below 8°C. The relative humidity varies from 35.6% to 96.3%. Detailed meteorological data recorded during the study period are provided in Tables 3.3 and 3.4.

3.1.3. Soil condition:

The experimental site's soil was characterized as well-drained sandy loam with an acidic reaction, exhibiting a pH range between 4.4 and 4.6

3.2 Design and Experimental layout:

A Randomized Block Design (RBD) was employed for the experiment, comprising six treatments with four replications. Each plot measured 4 m × 4 m, Plants were spaced 2 meters apart between rows and 0.8 meters within rows, allowing for 8 plants per plot. A detailed description of the experimental field layout and design is provided in Table 3.1

Table.3.1. Experimental details of crop and agronomical parameters.

Crop	**Pumpkin**
Variety	Arjun 55
Experimental design	Randomized Block Design (RBD)
Number of treatments	6
Number of replications	4
Total number of plots	24
Number of plants/plots	8
Row to row spacing	2 m
Plant to plant spacing	0.8 m
Size of the plots	4 m ×4 m

3.3. Treatment details:

The trial was conducted in different plots, one colony of *A. mellifera*, *A. cerana, T. iridipennis* and *L. arcifera* were shifted in respective treatment. In open pollination, the plots were uncovered with net and in control, no pollinators were allowed to enter (Table:3.2)

Table. 3.2. Treatment details

T	Treatments	Total
T1	*A. mellifera*	(1 colony /net)
T2	*A. cerana*	(1 colony /net)
T3	*T. iridipennis*	(1 colony /net)
T4	*Lepidotrigona arcifera*	(1 colony /net)
T5	Open pollination	(All insect visitors visited the crop)
T6	Control	(No pollination)

3.4 Cultivation practices

3.4.1. Nursery raising:

The varieties Arjun 22 was selected for research purposes and was sown in the seed trays in the month of February of each year *i.e.*, 2022 and 2023. Soil mixture used for filling the nursery pro tray The mixture was prepared by combining soil, farmyard manure (FYM), and sand in a 1:1:1 ratio.

3.4.2. Transplanting:

Three (3) to four (4) weeks old (21-28 days after sowing) pumpkin plants were selected for transplanting on the assigned plots. All pumpkin seedlings were transplanted. Spacing was maintained at 2 meters between rows and 0.8 meters between individual plants. It was done during evening hours followed by irrigation as it provides an adequate supply of moisture for the plants to survive.

3.4.3. Field preparation:

The field was thoroughly ploughed, a tractor-mounted disc plough was used, and the soil was prepared to a fine tilth by subsequent harrowing and levelling by deep ploughing two times, and the stubbles and weeds were removed, and planking was carried out, the field was made free from clods and weeds. Before transplanting the field were levelled and suitable bed size were made on the plot.

3.4.4. Hardening:

Prior to transplanting, watering was stopped for 2-3 days to prevent transplanting shock.

3.4.5. Irrigation:

Light irrigation was given after pumpkin plants were transplanted. The irrigation was done every day when the plants were in its initial stage and afterwards regularly at 3-5 days interval to maintain the desired soil moisture level.

3.4.6. Weeding:

Hand weeding and mechanical weeding were done according to the requirements of treatments. The first weeding was done at 15 days of after transplanting the crop and two more weeding were done subsequently at 25 days interval.

3.4.7. Harvesting:

The crop was harvested plot wise when the fruits attained proper size, colour and before ripening stage.

3.5. Diversity of insect pollinators on pumpkin blooms

Insect collection from pumpkin flowers during the blooming period was carried out using a sweep net with a 30 cm diameter sieve. Sweeping was conducted at weekly intervals throughout March, at two-hour intervals. Specimen collection was carried out throughout the day, and the samples were dry-preserved and identified in the Department of Entomology, Nagaland University.

3.6. Abundance of different insect visitors

To determine the abundance of different insect visitors on pumpkin, the number of individual insects observed was recorded visiting two randomly selected pumpkin flowers per square meter area over a five-minute period. This method, based on the procedure outlined by Free (1993), was employed once 10% of the plants had commenced blooming. The findings of relative abundance were examined in Randomized Block Design.

3.7. Pollination Efficiency Index (PEI) of different pollinators

The comparison of the pollination capabilities of different bee species was evaluated by considering data were recorded on their relative abundance, foraging rate, foraging speed, and the number of loose pollen grains attached to their bodies. The pollination index was computed using the method outlined by Bohart and Nye (1960). The different parameters were given ranks and based on ranks assigned, the PEI was calculated then.

Pollination efficiency = RA(FR+FS+LPG)

were,

RA = Relative abundance

FR = Foraging rate

FS = Foraging speed

LPG = Loosen pollen grains

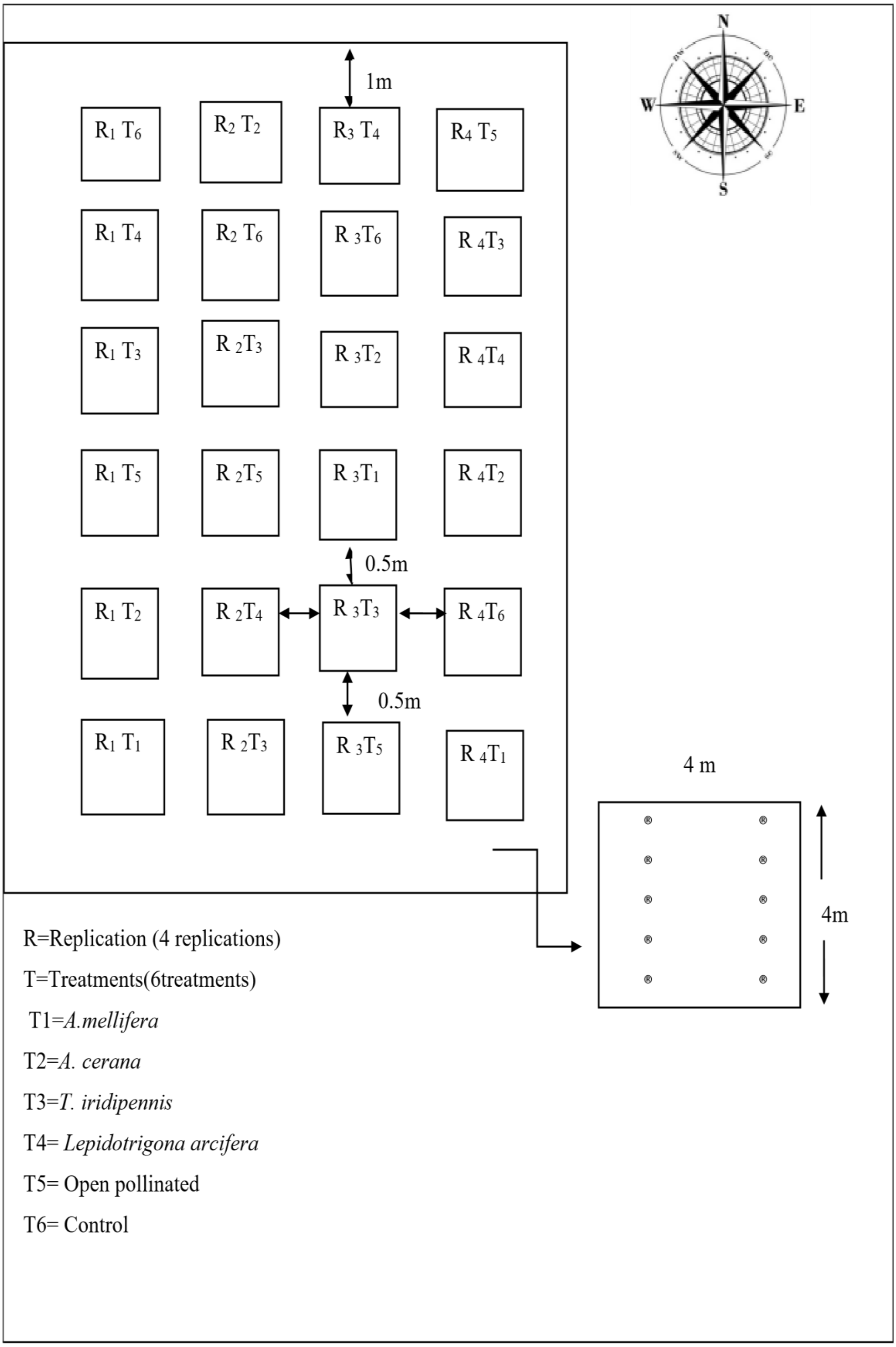


Fig. 3.1. Layout of the experimental field in Randomized Block Design (RBD)

3.8. Introduction of bee colony in the cages

Artificially reared hives of *A. mellifera, A. cerana, T. iridipennis* and *L. arcifera* were introduced in the flowering pumpkin in the cages by placing it in the shade on a tabletop stand. Water pots were installed to submerge the legs of the table to prevent ants and insects. The entry of the boxes was made wide open to permit the foragers to come outdoors. Thereafter, the activities of the foragers were inspected and studied.

3.9. Foraging activity

3.9.1. Foraging rate:

The foraging rate of bees was measured by counting the number of flowers visited per minute. Observations were made at two-hour intervals between 0600 and 1600 hours on a weekly basis during the blooming period, under normal sunny weather conditions.To measure the foraging rate, the number of flowers visited per minute was recorded using a stopwatch.

3.9.2. Foraging speed:

The foraging speed were measured based at the time (in seconds) spent per flower at two-hour interval at 0600-1600h at weekly interval on a fair weathered day during flowering time

3.9.3. Loose Pollen Grains

Loose pollen grains present on the bodies of various bee species were quantified following the method described by Kumar (1990). Bees were gently captured using forceps to prevent dislodging the pollen and their hind legs were carefully amputated. Specimens were collected during peak foraging activity and placed in 70% alcohol in glass vials (9×3 cm) after faintly removing the hind legs. The vials were then shaken vigorously to release the loose pollen grains from the bees' bodies. Using a counting dish placed under a binocular microscope, the dislodged pollen grains were quantified

3.10. Impact of different modes of pollination on pumpkin

Effects on various pollination methods on pumpkin were evaluated using different parameters, as described below.

3.10.1. Per cent fruit set and yield

Flowers on each plant were pre-counted. Random tagging was done on ten selected plants. From each treatment group, *A. cerana, A. mellifera, T. iridipennis, L. arcifera,* control, and open pollination—were observed. Fruit set was recorded, and yield was estimated based on the number of fruits formed.

3.10.2. Per cent healthy fruits and per cent crooked fruits

Ppercentage of well-developed fruits was determined by recording the healthy fruits from the total fruit set for each treatment. Similarly, the percentage of crooked fruits calculation was made by assessing the number of deformed fruits in relation to the total fruit set.

3.10.3. Fruit length, fruit diameter and fruit weight

A total of sixty fruits (10 fruits per treatment) were randomly collected from 24 plots across all six treatments, *A. cerana, A. mellifera, T. iridipennis, L. arcifera,* control, and open pollinated. Fruit length and diameter were measured using a scale, while fruit weight was recorded using a digital weighing balance.

3.10.4. Number of seeds per fruit

Sixty matured fruits were taken (10 representative fruits each from *Apis cerana* pollinated, *Apis mellifera* pollinated, *Tetragonula iridipennis* pollinated, *Lepidotrigona arcifera* pollinated control and open pollinated). Following extraction, seeds from each fruit were individually soaked in water for 24 hours. After rinsing, the seeds were dried in temperature-regulated chambers for 24 hours and subsequently counted.

3.10.5. Weight of 100 seeds

For each treatment, one hundred dried seeds were individually arranged on petri dishes, and their weight was recorded using a weighing balance. Four replications were taken for each treatment.

3.10.6. Per cent increase

The percentage increase in fruit set, healthy fruits, crooked fruits, fruit length, diameter, weight, number of seeds per fruit, and 100-seed weight was calculated in comparison to the open pollinated and control treatments.

3.11. Identification of Pollinators

Pollinator specimens were collected from pumpkin flowers and subsequently identified morphologically and morphometrically in the Department of Entomology, Nagaland University.

3.12. Statistical analysis

Statistical analysis of the collected data across different parameters was performed using the Randomized Block Design (RBD) following the method outlined by Gomez and Gomez (1984).

3.13. Meteorological data

Meteorological parameters, including daily maximum and minimum temperatures, relative humidity, and rainfall, were sourced from the observatory records at ICAR, Jharnapani, Medziphema, Dimapur. Additionally, temperature and humidity were recorded using a digital thermometer and hygrometer, and the data are presented in Table 3.3 and Table 3.4.

Table.3.3. Meteorological data during the period of study for the year 2022

Week no.	Month	Temperature (ºC)		Relative Humidity(%)		Rainfall (mm)
		Max.	Min.	Max.	Min.	
6	February	20.3	10.1	95.3	60.2	5.4
7		22.3	9.0	95.9	48.0	0.0
8		25.6	7.5	94.6	35.1	0.0
9		24.2	11.7	95.6	50.0	3.0
10		28.4	12.3	94.3	39.7	0.1
11	March	31.9	13.3	93.0	37.3	0.0
12		34.4	15.7	91.3	32.9	0.0
13		34.7	18.2	84.9	37.3	0.3
14		29.4	19.5	86.1	64.1	1.0
15		29.4	19.6	91.0	72.0	1.9
16	April	30.7	20.3	94.3	69.3	13.0
17		31.4	19.7	88.9	64.0	4.7
18		33.6	20.1	85.2	66.0	5.3
19		29.5	20.6	91.0	65.5	3.4
20	May	30.7	22.8	92.0	77.4	14.1
21		29.0	21.7	94.0	78.1	12.6
22		32.0	22.4	91.1	68.1	1.4
23		33.5	23.8	94.6	68.1	3.2
24	June	32.8	24.0	93.4	70.0	7.3
25		29.3	22.9	96.3	78.7	10.6
26		32.4	24.1	94.1	69.0	1.1
27		33.3	24.7	93.0	71.4	3.2

Table 3.4. Meteorological data during the period of study for the year 2023

Week no.	Month	Temperature (°C)		Relative Humidity (%)		Rainfall (mm)
		Max	**Min**	**Max**	**Min**	
6	February	27.1	10.4	92.4	51.6	0.0
7		25.5	10.6	93.7	50.0	0.0
8		27.3	11.3	90.4	43.0	0.0
9		29.1	13.8	90.9	48.2	0.0
10	March	29.3	12.1	91.2	39.0	0.0
11		31.4	13.5	89.7	38.0	0.0
12		29.3	15.3	93.3	60.7	3.0
13		26.1	16.3	95.9	60.7	5.5
14		29.0	16.3	91.6	64.6	3.2
15	April	30.3	16.0	89.0	49.6	2.0
16		35.1	16.6	83.4	35.6	0.0
17		34.5	19.7	88.7	57.0	4.8
18		32.5	18.6	84.3	55.4	2.1
19	May	31.9	20.0	86.4	59.0	3.6
20		34.6	19.8	86.6	52.1	0.0
21		30.8	20.9	89.7	57.0	3.5
22		32.7	21.9	81.7	61.0	5.3
23		36.9	22.9	83.6	47.9	0.1
24	June	36.2	24.2	87.4	65.9	18.1
25		29.2	23.4	92.6	80.0	10.4
26		31.3	24.0	91.7	73.6	7.4
27		34.5	25.2	90.6	77.0	3.1

Plate1: General view of the experimental plot for pumpkin pollination

A. Nursery raising

B. Seedling stage

C. Vegetative stage

D. Flowering stage

E. Fruiting stage

Plate 2: Different growth stages of pumpkin

Plate 3: Installation and overview of net in the field

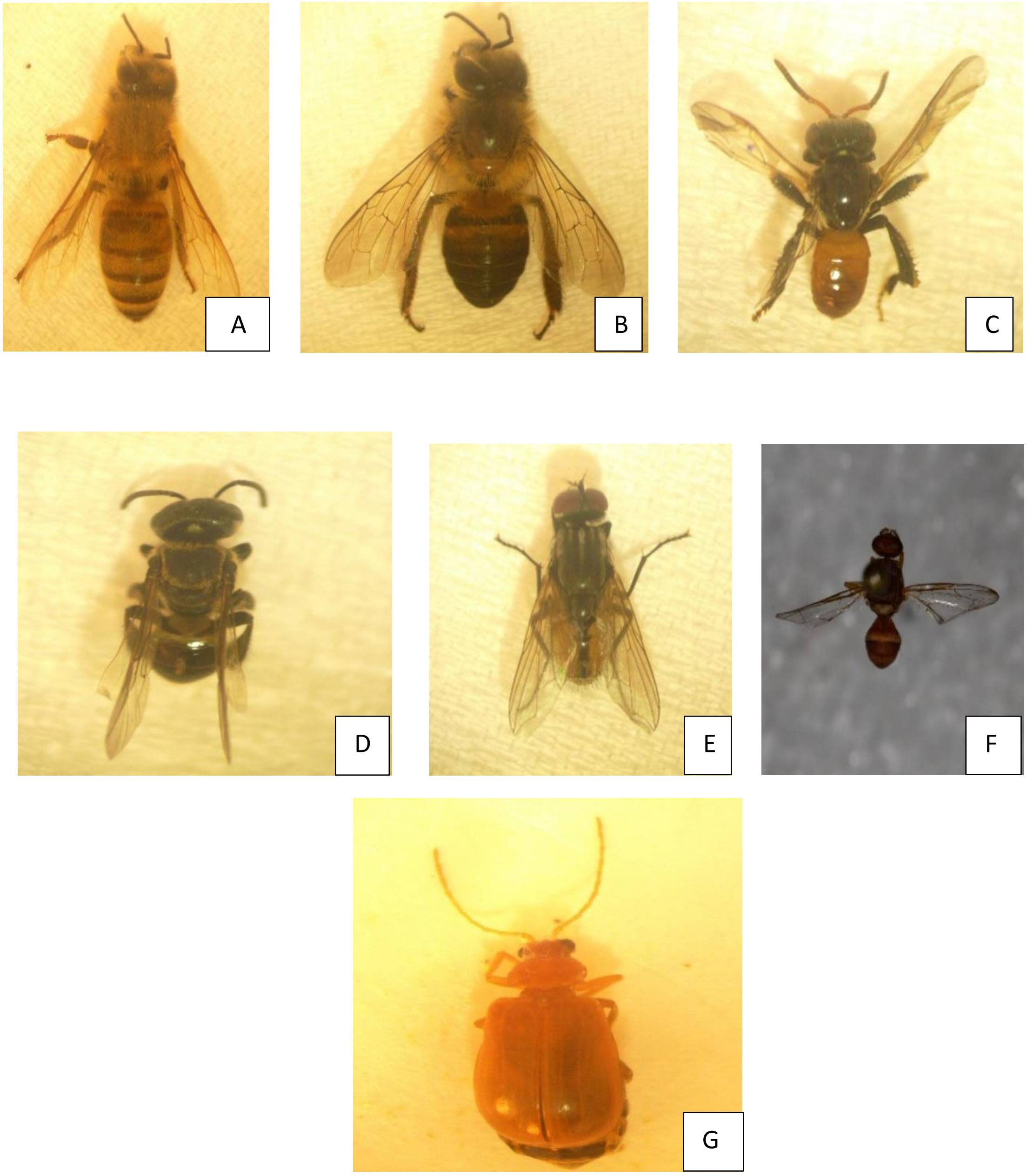


Plate 4: Diversity of insect visitors observed on pumpkin crops: A) *A. mellifera,* B) *A. cerana,* C) *T.iridipennis*, D) *L.arcifera,* E) *Musca* spp., F) *B.dorsalis,* G) *A.foveicollis.*

A. Pumpkin plants in flowering under net house

B. Hive kept for pollination inside net house

C. Pumpkin plants with fruit as a result of pollinators

Plate 5: Applied pollination with insect pollinators under protection

Plate 6: Open pollination

Plate 7: Caged pollination

Plate 8: Fruits harvested from caged and open pollination

CHAPTER IV

RESULTS AND DISCUSSION

RESULTS AND DISCUSSION

The present study entitled, "Diversity of Insect Pollinators and Impact of Bee Pollination on Pumpkin (*Cucurbita moschata* Duch. ex Poir)," was conducted at the Experimental Farm of the Department of Entomology, School of Agricultural Sciences, Nagaland University, Medziphema Campus, during the years 2022 and 2023. The investigation was undertaken with the following objectives viz. (i) to study the diversity of insect pollinators, (ii) pollination efficiency index of different pollinators and (iii) to study the effect of bee pollination on productivity of pumpkin. The results of the study were statistically analyzed, organized into tables, and discussed under the following sections:

4.1 Floral biology of pumpkin

Flowers were fully opened and yellow in colour. It was observed that the Anthesis started early by 0600h and reached its full bloom from 0800h-1000h (Table 4.1).

4.2. Insect visitors on *Cucurbita moschata*

A variety of insects visiting the flowers were collected from pumpkin flowers are listed in Table 4.2. The flowers of *Cucurbita moschata* were visited by a total of fourteen insect species, representing five families across three orders. Among them, Hymenoptera emerged as the dominant group of floral visitors on floral comprises of nine species viz., *Apis cerana, Apis mellifera, Tetragonula iridipennis, Lepidotrigona arcifera, Apis florae, Apis dorsata, Xylocopa tenuiscapa, Xylocopa fenestrate* and *Lasius niger.* It was followed by coleoptera (three species) *viz., Aulacophora foveicollis, Aulacophora atripennis, Aulacophora nigripennis* and dipteran (two species) *viz., Bactrocera dorsalis and Musca sp.* Among them, the most frequent visitors were *A. cerana, A. mellifera, T. iridipennis, L. arcifera, A. florae* and *A. dorsata*, *Xylocopa tenuiscapa, Xylocopa fenestrate, Aulacophora*

Table 4.1: Floral biology of pumpkin

Flower structure	***Flower type***	***Time (hours)***	***Floral biology of pumpkin***				***Mean***	***Pollen shape and size (µm) L x D***
			Anthesis (%)	***Stigma receptivity (%)***	***Anther dehiscence (%)***	***Pollen viability (%)***		
Inflorescence Solitary, funnel shape	Fully open	0600 - 0700	30.80	35.00	32.40	38.80	*34.25*	Shape: Round
		0700 - 0800	42.00	45.60	42.80	46.40	*44.20*	
Androecium Large and erect	Actinomorphic	0800 - 0900	35.60	40.00	38.20	40.80	*38.65*	
		0900 - 1000	20.40	26.20	25.20	22.60	*23.60*	
Calyx Bulbous, green colour		1000 - 1100	14.20	16.00	18.40	17.20	*16.45*	
	Heterostyle	1100 - 1200	10.00	10.20	12.00	12.20	*11.10*	

Corolla Gamopetalous, lobed, yellow colour ***Gynoecium*** Ovary ovoid, style short, stigma two-lipped								

Table.4.2. Insect visitor on pumpkin during 2022 and 2023

Sl.no	Insect visitors/ pollinators	Family	Order	N/ P/ N & P/ EFE	Frequency of occurring*
1	*Apis cerana*	Apidae	Hymenoptera	Nectar and pollen	MFV
2	*Apis mellifera*	Apidae	Hymenoptera	Nectar and pollen	*MFV
3	*Tetragonula iridipennis*	Apidae	Hymenoptera	Nectar and pollen	MFV
4	*Lepidotrigona arcifera*	Apidae	Hymenoptera	Nectar and pollen	MFV
5	*Apis florea*	Apidae	Hymenoptera	Pollen	MFV
6	*Apis dorsata*	Apidae	Hymenoptera	Pollen	MFV
7	*Xylocopa tenuiscapa*	Apidae	Hymenoptera	Pollen	FV
8	*Xylocopa fenestrata*	Apidae	Hymenoptera	Pollen	FV
9	*Aulacophora foveicollis*	Chrysomelidae	Coleoptera	Foliage/ floral parts	FV
10	*Aulacophora atripennis*	Chrysomelidae	Coleoptera	Foliage/floral parts	LFV
11	*Aulacophora nigripennis*	Chrysomelidae	Coleoptera	Foliage/ floral parts	LFV
12	*Lasius niger*	Formicidae	Hymenoptera	Nectar	FV
13	*Bactrocera dorsalis*	Tephritidae	Diptera	Nectar	*FV
14	*Musca sp.*	Muscidae	Diptera	Nectar	*LFV

*Frequency of occurring-M.F.V=Most Frequent Visitor, F.V =Frequent Visitor, L.F.V=Least Frequent Visitor.

foveicollis, Lasius niger, Bactrocera dorsalis were found to be the frequent visitors. Besides these, *Aulacophora atripennis, Aulacophora nigripennis* and *Musca* sp. were found to be least visited in pumpkin flowers. Similar results were observed by several other researchers. According to Grewal and Sidhu (1978), the primary insect visitors of cucurbit crops included *Apis florea*, *Apis mellifera*, *Apis dorsata*, *Halictus* species, and *Bombus* species. Sajjanar *et al*. (2004) recorded 24 insects visiting cucumber crops where hymenopterans were predominant visitors. Anooj (2012) documented 29 insect species visiting smooth gourd flowers, which included 12 hymenopterans, 8 lepidopterans, 5 dipterans, 1 hemipteran, and 4 coleopterans. Similarly, Deyto and Cervancia (2009) grouped the insect visitors of *Cucurbita moschata* flowers into four primary orders: Hymenoptera (including *Apis dorsata*, *A. mellifera*, *Trigona* spp., *Halictus* spp., *Xylocopa* spp., and members of Formicidae), Lepidoptera (butterflies), Coleoptera (Chrysomelidae), and Diptera (such as *Calliphora* spp., Sarcophagidae, and Syrphidae). Among these groups, *Trigona* spp., *Halictus* spp., and Lepidoptera were reported as the most frequent flower visitors.

4.3. Relative abundance of different insect pollinators on pumpkin under open conditions

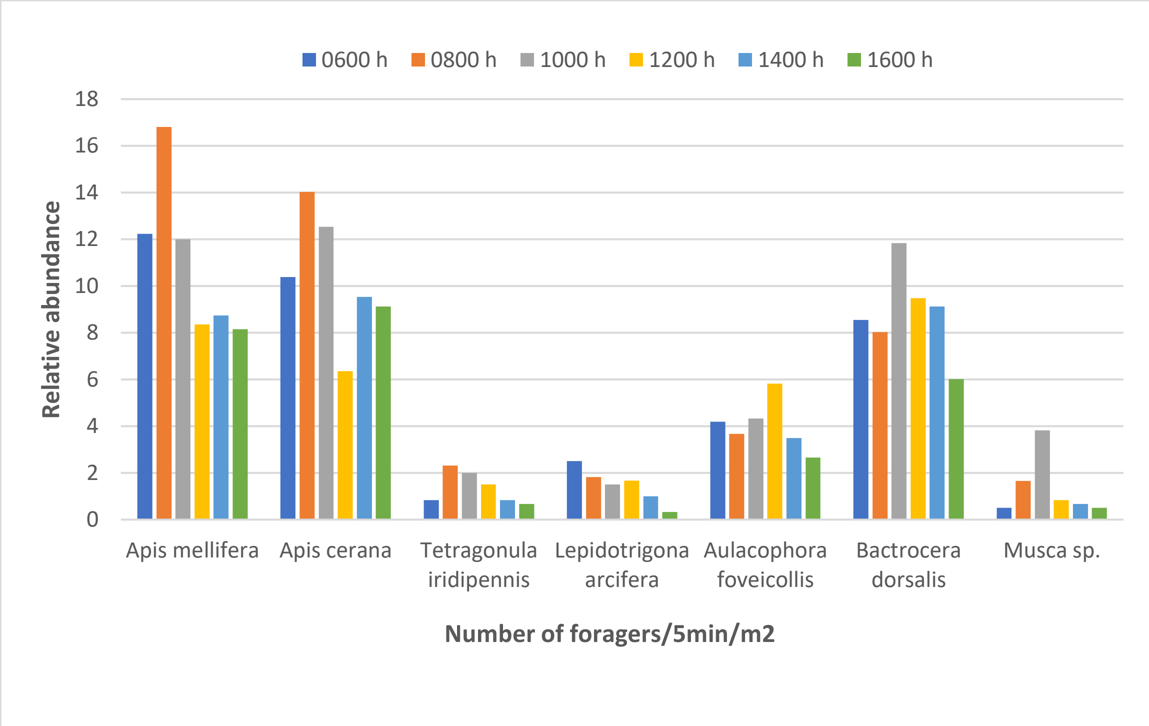
Information on the abundance of insect visitors to the *Cucurbita moschata* cultivar is provided in Tables 4.3 and 4.4 and depicted in Figure 4.1. During the first year of the experiment (2022), *Apis mellifera* emerged as the most prevalent insect visitor on pumpkin under open condition with 11.05 followed by *A. cerana* (10.33), *B. dorsalis* (8.84), *A. foveicollis* (4.03), *L. arcifera* (1.47), *T. iridipennis* (1.36) and *Musca* sp. (1.33). The highest count of *A. mellifera* was recorded observed at 0800 h with 16.81 bees/m^2/5min followed by 0600 h at 12.23 bees/m^2/5min and start decreasing gradually at 1600 h with 8.15 bees/ m^2/5min. During 2023, *A. cerana* recorded the highest mean abundance with 7.73 followed by *A. mellifera* (7.32*), B. dorsalis* (5.79), *T. iridipennis* (1.29), *A. foveicollis* (1.28), *L. arcifera* (1.17) and *Musca* sp. (0.79). The maximum abundance of *A. cerana* was at 0800 h (12.82 bees/ m^2/5min) and the minimum at 1400 h (3.17 bees/ m^2/5min). Pateel and Sattagi (2007) also It was observed that the most common insect pollinators visiting Rabi-season cucumber.

Table 4.3: Relative abundance of insect visitors on pumpkin in open conditions during 2022

Sl. No.	Time (hours)	Number of foragers /5 mins /m^2							
		Apis mellifera	***Apis cerana***	***Tetragonula iridipennis***	***Lepidotrigona arcifera***	***Aulacophora foveicollis***	***Bactrocera dorsalis***	***Musca* sp.**	**Mean**
1.	0600	12.23	10.39	0.83	2.50	4.19	8.55	0.50	*5.60*
2.	0800	16.81	14.03	2.32	1.82	3.67	8.03	1.66	*6.91*
3.	1000	12.00	12.54	2.00	1.50	4.33	11.83	3.82	*6.86*
4.	1200	8.35	6.35	1.50	1.67	5.82	9.48	0.83	*4.86*
5.	1300	8.74	9.53	0.83	1.00	3.49	9.12	0.67	*4.77*
6.	1400	8.15	9.12	0.67	0.33	2.66	6.02	0.50	*3.92*
	Mean	*11.05*	*10.33*	*1.36*	*1.47*	*4.03*	*8.84*	*1.33*	-
		Forager	*Time*	*Forager x Time*		-	-	-	-
	SEm±	*0.02*	*0.03*	*0.09*		-	-	-	-
	CD (p = 0.05)	*0.06*	*0.10*	*0.26*		-	-	-	-

Table 4.4: Relative abundance of insect visitors on pumpkin in open conditions during 2023

Sl. No.	Time (hours)	Number of foragers /5 mins /m^2							
		Apis mellifera	***Apis cerana***	***Tetragonula iridipennis***	***Lepidotrigona arcifera***	***Aulacophora foveicollis***	***Bactrocera dorsalis***	***Musca* sp.**	**Mean**
1.	0600	10.79	9.10	0.67	0.67	0.66	7.71	0.17	*4.25*
2.	0800	11.98	12.82	1.67	1.67	1.66	8.05	0.67	*5.50*
3.	1000	8.31	8.66	3.05	2.33	1.67	8.40	1.17	*4.80*
4.	1200	6.99	7.61	1.33	1.33	1.34	5.70	1.00	*3.61*
5.	1300	4.33	4.99	1.00	1.00	1.33	4.18	1.00	*2.55*
6.	1400	1.50	3.17	0.00	0.00	1.00	0.67	0.70	*1.01*
	Mean	*7.32*	*7.73*	*1.29*	*1.17*	*1.28*	*5.79*	*0.79*	-
		Forager	*Time*	*Forager x Time*		-	-	-	-
	SEm±	*0.03*	*0.03*	*0.07*		-	-	-	-
	CD (p = 0.05)	*0.08*	*0.08*	*0.21*		-	-	-	-



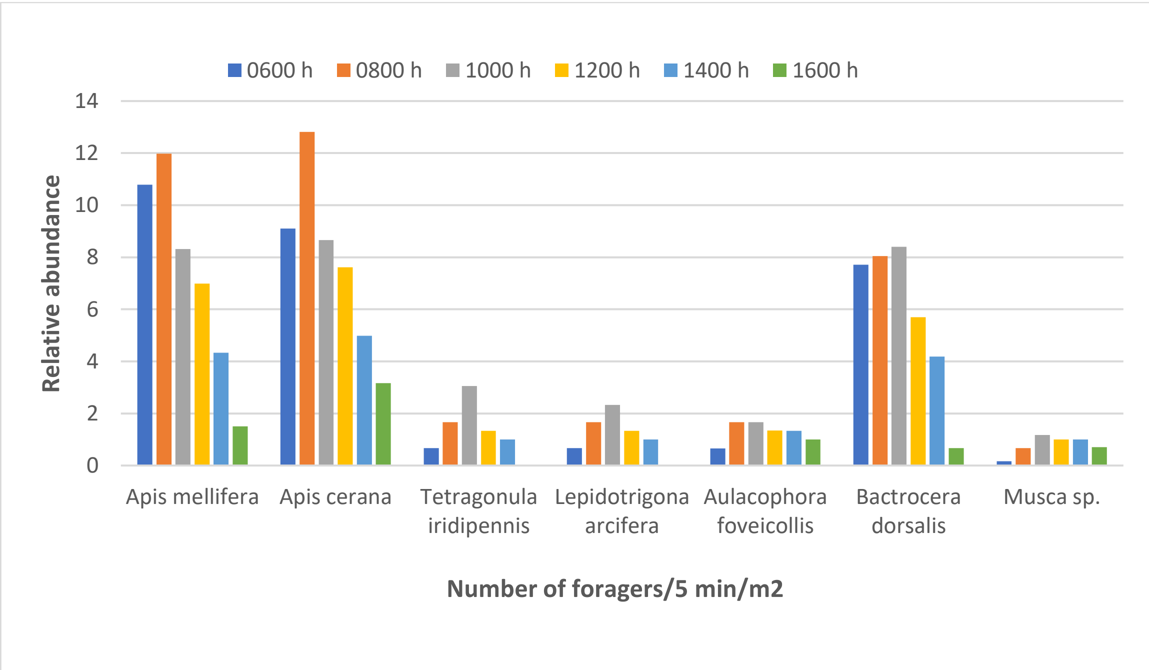


Fig.4.1. Relative abundance of insect pollinators on pumpkin in open condition during 2022 and 2023.

flowers were *A. florea*, *A. cerana* and *A. dorsata* abundant of 8.03, 6.03 and 3.43 bees/m²/5 minutes, respectively, .In contrast to present study, Pinkus-Rendon *et al*. (2005) reported that the dominant bee species observed on the staminate flowers of *Cucurbita moschata* were *Peponapis limitaris* (80.0%), *Augochlora nigrocyana* (11.0%), *Apis mellifera* (7.0%), and *Partamona biteanata* (2.0%). In the case of pistillate flowers, *Peponapis limitaris* was again the most dominant (70.0%), followed by *P. biteanata* (17.3%), *A. nigrocyana* (8.7%), and *A. mellifera* (4.0%).

4.4. Relative abundance of different insect pollinators on pumpkin under closed conditions

Data on abundance of insect visitors on *C. moschata* cultivar details are provided in Tables 4.5 and 4.6 and visually represented in Figure 4.2.During 2022, *A. mellifera* had the highest mean (20.91) under closed condition followed by *A. cerana* (19.39), *T. iridipennis* (14.21) and *L. arcifera* (11.20). The abundance of *A. mellifera* was observed to be maximum (27.13 number of foragers/ 5min/m²) at 1000 h followed by 26.79 number of foragers/ 5min/m² at 0800 h, it started decreasing during noon time and recorded minimum 15.36 number of foragers/ 5min/m² at 1400 h. The same trend continued in 2023, the second year of the study in *A. mellifera* (20.32), the maximum mean recorded followed by *A. cerana* (17.81), *T. iridipennis* (13.92), *L. arcifera* (11.91). The highest mean abundance was at 1000 h (28.29 number of foragers/ 5min/m²) followed by at 1200 h with 25.29 number of foragers/ 5min/m² and at lowest at 1400 h 10.45 number of foragers/ 5min/m².The findings are in agreement with those of Gahlawat *et al*. (2002), who reported *Apis mellifera* as the dominant pollinator of cucumber flowers, with. bee visitation rates of 0.08, 2.58, 1.75, and 0.83 bees/m²/5 minutes at 0600, 0800, 1000, and 1200 hours, respectively. Similarly, Nicodemo et al. (2009) reported that the primary insect visitors to pumpkin flowers were *A. mellifera*, *Diabrotica speciosa* (Germ.), and *Trigona spinipes* (Fab.), with *A. mellifera* constituting 73.4% and *T. spinipes* 26.6% of the total bee visitors.

4.5. Diversity index of pollinators

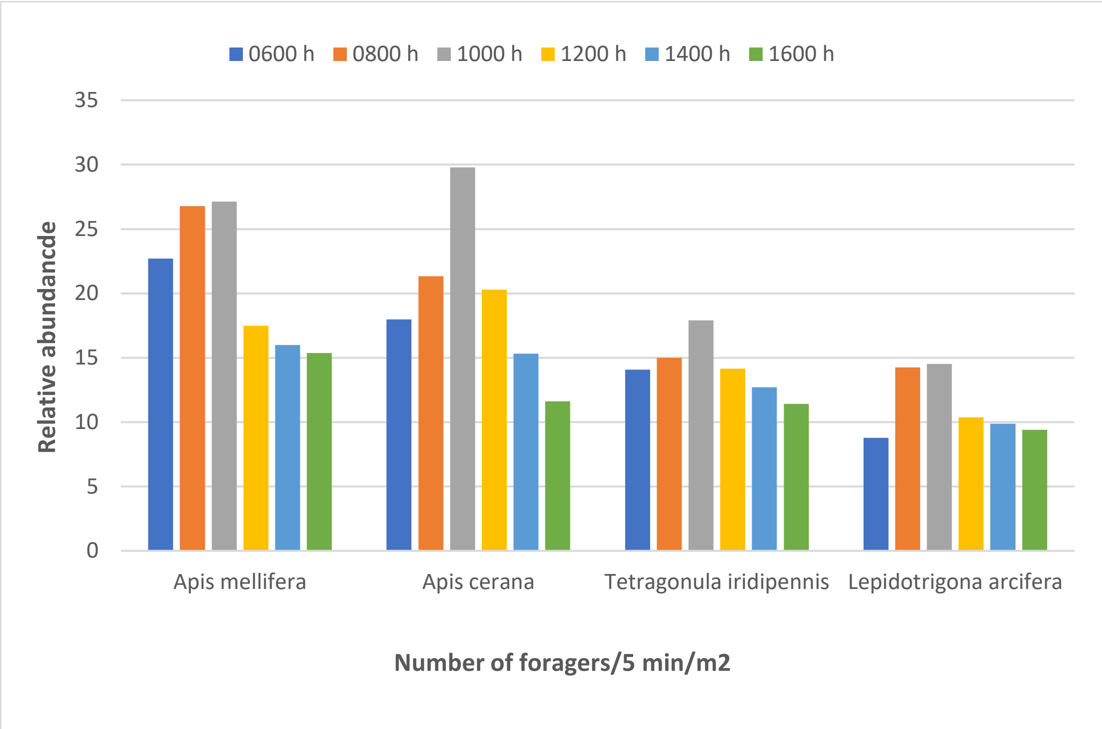
Diversity index of different pollinators was calculated using Shannon diversity index formula represented in Table.4.7 and Table. 4.8. The Shannon's diversity index

Table 4.5: Relative abundance of insect pollinators on pumpkin under closed conditions during 2022

Sl. No.	Time (hours)	Number of foragers /5 mins /m^2				
		Apis mellifera	***Apis cerana***	***Tetragonula iridipennis***	***Lepidotrigona arcifera***	**Mean**
1.	0600	22.69	17.97	14.07	8.77	*15.88*
2.	0800	26.79	21.34	15.00	14.26	*19.35*
3.	1000	27.13	29.79	17.91	14.53	*22.34*
4.	1200	17.49	20.3	14.16	10.38	*15.58*
5.	1300	15.98	15.32	12.71	9.88	*13.47*
6.	1400	15.36	11.61	11.42	9.40	*11.95*
	Mean	*20.91*	*19.39*	*14.21*	*11.20*	-
		Forager	*Time*	*Forager x Time*		-
	SEm±	*0.08*	*0.10*	*0.23*		-
	CD (p = 0.05)	*0.23*	*0.29*	*0.66*		-

Table 4.6: Relative abundance of insect pollinators on pumpkin under closed conditions during 2023

Sl. No.	Time (hours)	Number of foragers /5 mins /m²				
		Apis mellifera	*Apis cerana*	*Tetragonula iridipennis*	*Lepidotrigona arcifera*	Mean
1.	0600	16.54	16.83	11.57	11.3	*14.06*
2.	0800	22.77	21.95	16.61	13.57	*18.73*
3.	1000	28.29	22.79	16.81	17.89	*21.45*
4.	1200	25.29	20.34	16.33	11.88	*18.46*
5.	1300	18.56	15.86	12.17	8.45	*13.76*
6.	1400	10.45	9.06	10.03	8.36	*9.48*
	Mean	*20.32*	*17.81*	*13.92*	*11.91*	-
		Forager	*Time*	*Forager x Time*		-
	SEm±	*0.10*	*0.09*	*0.20*		-
	CD (p = 0.05)	*0.29*	*0.24*	*0.56*		-



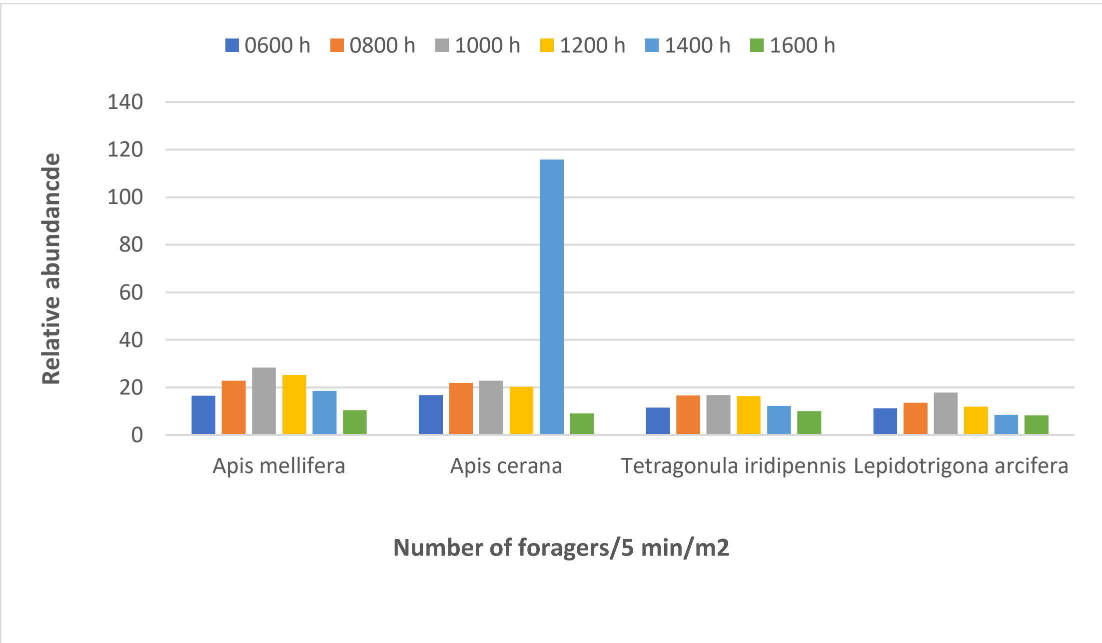


Fig.4.2. Relative abundance of insect pollinators on pumpkin in closed condition during 2022 and 2023.

of insect pollinators of pumpkin was documented as 1.64 and 1.61 respectively, during 2022 and 2023 under open conditions. The result of the present study is more or less in close agreement with the work reported by Jamir (2021). She also recorded Shannons-Wiener diversity index of stingless bee (H) of 1.77. Chirag *et al*. (2023) also conducted a study on insect pollinators and recorded Shannon's diversity index (H) of 1.75 and evenness (EH) of 0.93 on insect pollinators of cucumber crops.

4.6. Foraging activity of different insect pollinators on pumpkin during the year 2022 and 2023 under open condition

The study in the first experimental trial (2022) as shown in Table 4.9, foraging activities of *A. mellifera* were initiated at 0620 h, their peak activity was observed between 0800 and 1000 hours, with activity ceasing by 1600 hours**.** The study also revealed that the foraging activities of *A. cerana* were initiated at 0800 h. Its peak activities were observed between 0800 and 1000 hours, with cessation occurring around 1600 hours. In the case of *T. iridipennis*, activity began at 0600 h, peaked between 0800 and 1000 h, and ended by 1630 h.The foraging activity of *L. arcifera* was initiated at 0800 h, peak activities were recorded at 0800-1000 h and cessation time were recorded at 1600 h. The foraging activity of *Musca* sp. was found high during the late morning hours and was initiated at 1000 h. Its peak activity was recorded at 0800 h and cessation time was recorded at 1600. Similarly, in the second trail experiment (2023), foraging activities of *A. mellifera* were initiated at 0630 h, their peak activities were recorded at 0800-1000 h and cessation time were recorded at 1600 h. The study also revealed that foraging activities of *A. cerana* were initiated at 0600 h. Its peak activities were recorded at 0800-1000 h and cessation time were recorded at 1630 h. The foraging activities of *T. iridipennis* were initiated at 0620h, its peak activity was recorded at 0800-1000 h and cessation time was recorded at 1630 h. The foraging activity of *L. arcifera* was initiated at 0800 h, peak activities were recorded at 0800-1000 h and cessation time were recorded at 1600 h.

Table 4.7: Shannon diversity index of different insect visitors on pumpkin in open conditions during 2022.

Sl. No.	Scientific Name	N_i	P_i=Ni/∑Ni	ln P_i	- (P_i * ln P_i)
1.	*Apis mellifera*	11.05	0.288	-1.25	-0.358
2.	*Apis cerana*	10.33	0.269	-1.31	-0.353
3.	*Tetragonula iridipennis*	1.36	0.035	-3.34	-0.118
4.	*Lepidotrigona arcifera*	1.47	0.038	-3.26	-0.125
5.	*Aulacophora foveicollis*	4.03	0.105	-2.25	-0.236
6.	*Bactrocera dorsalis*	8.84	0.230	-1.47	-0.338
7.	*Musca* sp.	1.33	0.035	-3.36	-0.116
	Total density (∑N_i)	38.41	-	-	-

Shannon diversity index (H) = 1.64

Table 4.8: Shannon diversity index of different insect pollinators on pumpkin in open conditions during 2023

Sl. No.	Scientific Name	N_i	P_i=Ni/∑Ni	ln P_i	- (P_i * ln P_i)
1.	*Apis mellifera*	7.32	0.289	-1.24	-0.358
2.	*Apis cerana*	7.73	0.305	-1.19	-0.362
3.	*Tetragonula iridipennis*	1.29	0.051	-2.98	-0.151
4.	*Lepidotrigona arcifera*	1.17	0.046	-3.07	-0.142
5.	*Aulacophora foveicollis*	1.28	0.050	-2.98	-0.151
6.	*Bactrocera dorsalis*	5.79	0.228	-1.48	-0.337
7.	*Musca* sp.	0.79	0.031	-3.47	-0.108
	Total density (∑N_i)	25.37	-	-	-

Shannon diversity index (H) = 1.61

Table 4.9: Foraging activity of different insect pollinators on pumpkin in open conditions during 2022 and 2023

Sl. No.	Scientific Name	Foraging activity of different insect pollinators on pumpkin in open conditions					
		2022			2023		
		Initiation time (hours)	Peak activity time (hours)	Cessation time (hours)	Initiation time (hours)	Peak activity time (hours)	Cessation time (hours)
1.	*Apis mellifera*	0620	0800 - 1000	1600	0630	0800 - 1000	1600
2.	*Apis cerana*	0800	0800 - 1000	1600	0600	0800 - 1000	1630
3.	*Tetragonula iridipennis*	0600	0800 - 1000	1630	0620	0800 - 1000	1630
4.	*Lepidotrigona arcifera*	0800	0800 - 1000	1600	0800	0800 - 1000	1600
5.	*Musca* sp.	1000	0800 - 1000	1600	1030	0800 - 1000	1800

The foraging activity of *Tetragonula iridipennis* began at 0620 hours, peaked between 1000 and 1200 hours, and ceased by 1630 hours. In the case of *Lepidotrigona arcifera*, foraging started at 0800 hours, reached its peak between 1000 and 1200 hours, and ended around 1600 hours. Kedswing et al. (2023) also observed that foraging activity peaked between 0700 and 0900 hours (30.06) and gradually declined throughout the day, reaching its lowest between 1600 and 1800 hours (21.33). Similarly, Thakur and Rana (2008) reported that *Apis mellifera* initiated peak foraging between 0900 and 1000 hours, with activity declining and ending between 1300 and 1600 hours. Chauhan and Singh (2021) noted that pollinator activity on watermelon began at 0600 hours, peaked at 1000 hours, declined after 1600 hours, and was minimal by 1800 hours.

4.7. Foraging activity of different insect pollinators on pumpkin during the year 2022 and 2023 under closed condition

From Table 4.10, the study in the first experimental trial (2022) revealed that foraging activities of *A. mellifera* were initiated at 0620 h, their peak activities were recorded at 1000-1200 h and cessation time were recorded at 1600 h. While the foraging activities of *A. cerana* were initiated at 0800 h reaching its peak activity at 1000-1200 h and cessation time were recorded at 1600 h.

The foraging activities of *T. iridipennis* were initiated at 0600h, its peak activity was documented at 1000-1200 h and cessation time was recorded at 1630 h. The foraging activity of *L. arcifera* was initiated at 0800 h, peak activities were recorded at 1000-1200 h and cessation time were documented at 1600 h. Similarly, in the second trail experiment (2023), foraging activities of *A. mellifera* were initiated at 0630 h, their peak activities were documented at 1000-1200 h and cessation time were recorded at 1600 h. The study also revealed that foraging activities of *A. cerana* were initiated at 0600 h. Its peak activities were recorded at 1000-1200 h and cessation time were recorded at 1630 h.

The foraging activities of *T. iridipennis* were initiated at 0620h, its peak activity was documented at 1000-1200 h and cessation time was recorded at 1630 h. The foraging activity of *L. arcifera* was initiated at 0800 h, peak activities were recorded at

1000-1200 h and cessation time were documented at 1600 h. Kedswing *et al*. (2023) also reported that the foraging activity was maximum between 0700h and 0900h (30.06) and as the day proceeds it decreases the foraging activity with minimum result between 1600h and 1800h (21.33). Thakur and Rana (2008) observed that *A. mellifera* the peak initiation time was recorded at 0900–1000 h and cessation time was observed at 1300-1600 h. Chauhan and Singh (2021) also recorded the different pollinators activity that foraging activity in the watermelon crop commenced at 0600 h, attained its peak at 1000 h, began to diminish by 1600 h, and was minimal by 1800 h.

4.8. Foraging rate of different insect pollinators on pumpkin

The foraging rate of different insect pollinators on pumpkin under open condition are presented in Tables 4.11-4.12 and illustrated in figure.4.3.

Experimental trials from the two-year analysis of data revealed significant on the foraging rate. In 2022, the data on the number of flowers visited 5 minutes by forager among the different pollinators *i.e.,* the mean foraging rate observed was maximum in *Apis mellifera* (4.83) followed by *A. cerana* (3.04), *T. iridipennis* (2.47), L. *arcifera* (2.02) and *Musca* sp. (0.87). The foraging rate of *Apis mellifera* was highest at 0800 h (8.23) followed by 0600 h (6.54) and the lowest was observed at 1600 h (1.49). The longest duration was at 0800 h (5.94) for *A. cerana* followed by 0600 h (4.31) and the shortest duration was recorded at 1300 h (1.40) and 1400 h (1.34). The foraging rate of *Musca* sp. was longest at 0800 h (1.43) followed by at 0600 h (1.03) and the lowest was observed at 1400 h (2.02).

Table 4.10: Foraging activity of different insect pollinators on pumpkin under closed conditions during 2022 and 2023

Sl. No.	Scientific Name	Foraging activity of different insect pollinators on pumpkin under closed conditions					
		2022			2023		
		Initiation time (hours)	Peak activity time (hours)	Cessation time (hours)	Initiation time (hours)	Peak activity time (hours)	Cessation time (hours)
1.	*Apis mellifera*	0620	1000 - 1200	1600	0630	1000 - 1200	1600
2.	*Apis mellifera*	0800	1000 - 1200	1600	0600	1000 - 1200	1630
3.	*Tetragonula iridipennis*	0600	1000 - 1200	1630	0620	1000 - 1200	1630
4.	*Lepidotrigona arcifera*	0800	1000 - 1200	1600	0800	1000 - 1200	1600

In 2023, the same trend was also observed with the maximum rate in *A. mellifera* (9.15) followed by *A. cerana* (7.02), *T. iridipennis* (5.90), *L. arcifera* (4.29) and similarly, the least in *Musca* sp. (1.70). The foraging rate of *Apis mellifera* was 13.26 at 0800 h followed by 11.46 at 0600 h and the least was documented at 1600 h with 5.43. The maximum foraging rate in *A. cerana* at 0800 h (10.06) and minimum during 1400h (7.02). *Musca* Sp. was reported maximum at 0800 h (3.80) and decrease at 1400h (0.49). From the data analysed, a similar pattern was observed in both years, with *A. mellifera* as the highest mean foraging rate. Lalita and Kumar (2017) also observed that the mean foraging rate was maximum (3.63 flowers/min) during 0730-0830 h while the lowest (3.15 flowers/min) was during 0930-1030 h of the day. Carillo *et al*. (2018) observed that collection of pollen by *A. mellifera* was highest in the morning and showed a declining trend as the day progressed into the afternoon. On the contrary, according to Pernal and Currie (2010), the average foraging rate in the afternoon (36.02 foragers/min) was higher than in the morning (17.66 foragers/min). This difference may be attributed to varying climatic conditions at the two locations

4.9. Foraging speed of different insect pollinators on pumpkin

The findings on foraging speed *i.e*., the time spent per flower in seconds in *C. moschata* cultivar are presented in Tables 4.13-4.14 and illustrated in figure.4.4.

During 2022, the foraging speed was observed to begin around 0600 h and cease around 1400 h. The maximum mean foraging speed of *A. mellifera* (19.93 sec) was as comparable to *T. iridipennis* (16.36 sec) and it was followed by *A. cerana* (16.04 sec), *L. arcifera* (11.19 sec) and *Musca* sp. (4.64 sec) in descending order. The maximum time spent per flower (23.36 sec) was documented at 0800 h in *A. mellifera* followed by 1000 h (20.61 sec) and was found to decrease after 1400 h (19.99 sec) and 1400 h (14.04 sec). Whereas the minimum time spent/flower was observed in *Musca* sp. from 0800 h (2.73 sec) and gradually started to decline from 1400 h onwards

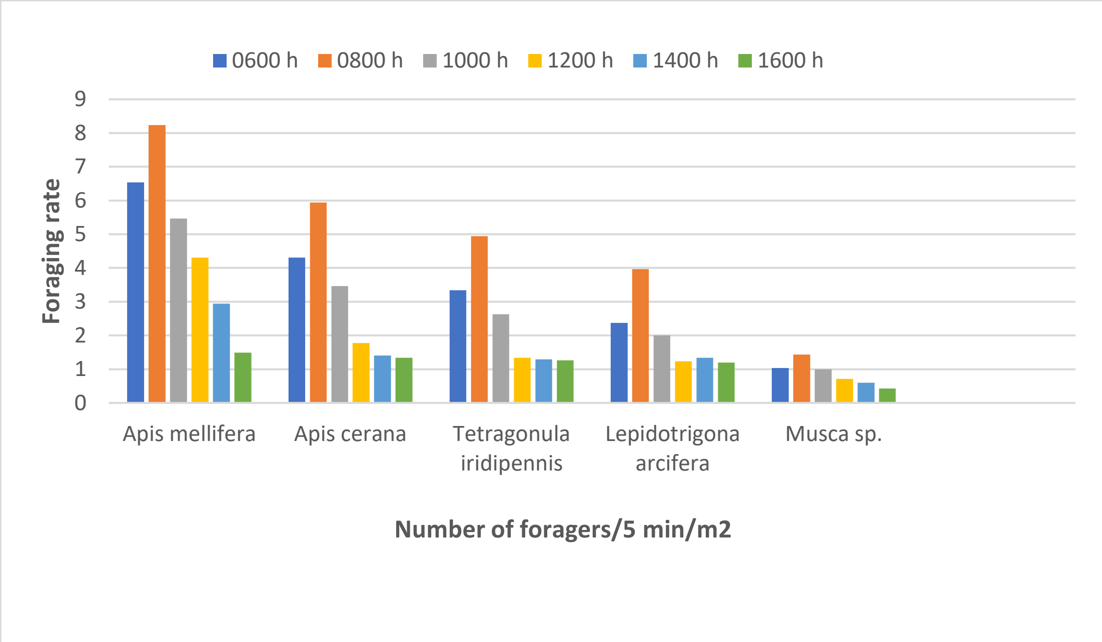
During 2023, the study revealed that *A. mellifera* recorded the longest time spent of 20.83 sec. While in the case of *A. cerana*, it was 19.29 sec followed by *T. iridipennis* (14.19 sec) and *L. arcifera* (11. 19 sec). The lowest foraging speed was observed in *Musca* sp. with 4.64 sec.

vTable 4.11: Foraging rate of different insect pollinators on pumpkin in open conditions during 2022

Sl. No.	Time (hours)	Number of flowers visited by foragers per 5 minutes					
		Apis mellifera	***Apis cerana***	***Tetragonula iridipennis***	***Lepidotrigona arcifera***	***Musca* sp.**	**Mean**
1.	0600	6.54	4.31	3.34	2.37	1.03	*3.52*
2.	0800	8.23	5.94	4.94	3.97	1.43	*4.90*
3.	1000	5.46	3.46	2.63	2.00	1.00	*2.91*
4.	1200	4.31	1.77	1.34	1.23	0.71	*1.87*
5.	1300	2.94	1.40	1.29	1.34	0.60	*1.51*
6.	1400	1.49	1.34	1.26	1.20	0.43	*1.14*
	Mean	*4.83*	*3.04*	*2.47*	*2.02*	*0.87*	-
		Forager	*Time*	*Forager x Time*		-	-
	SEm±	*0.02*	*0.03*	*0.09*		-	-
	CD (p = 0.05)	*0.05*	*0.10*	*0.25*		-	-

Table 4.12: Foraging rate of different insect pollinators on pumpkin in open conditions during 2023

Sl. No.	Time (hours)	Number of flowers visited by foragers per 5 minutes					
		Apis mellifera	***Apis cerana***	***Tetragonula iridipennis***	***Lepidotrigona arcifera***	***Musca* sp.**	**Mean**
1.	0600	11.46	8.49	7.40	6.37	2.20	*7.18*
2.	0800	13.26	10.06	9.29	8.14	3.80	*8.91*
3.	1000	9.57	7.74	6.63	5.97	1.57	*6.30*
4.	1200	8.11	5.77	4.77	1.86	1.17	*4.34*
5.	1300	7.09	5.34	4.54	1.83	0.97	*3.95*
6.	1400	5.43	4.71	2.77	1.54	0.49	*2.99*
	Mean	*9.15*	*7.02*	*5.90*	*4.29*	*1.70*	-
		Forager	*Time*	*Forager x Time*		-	-
	SEm±	*0.03*	*0.03*	*0.07*		-	-
	CD (p = 0.05)	*0.08*	*0.07*	*0.19*		-	-



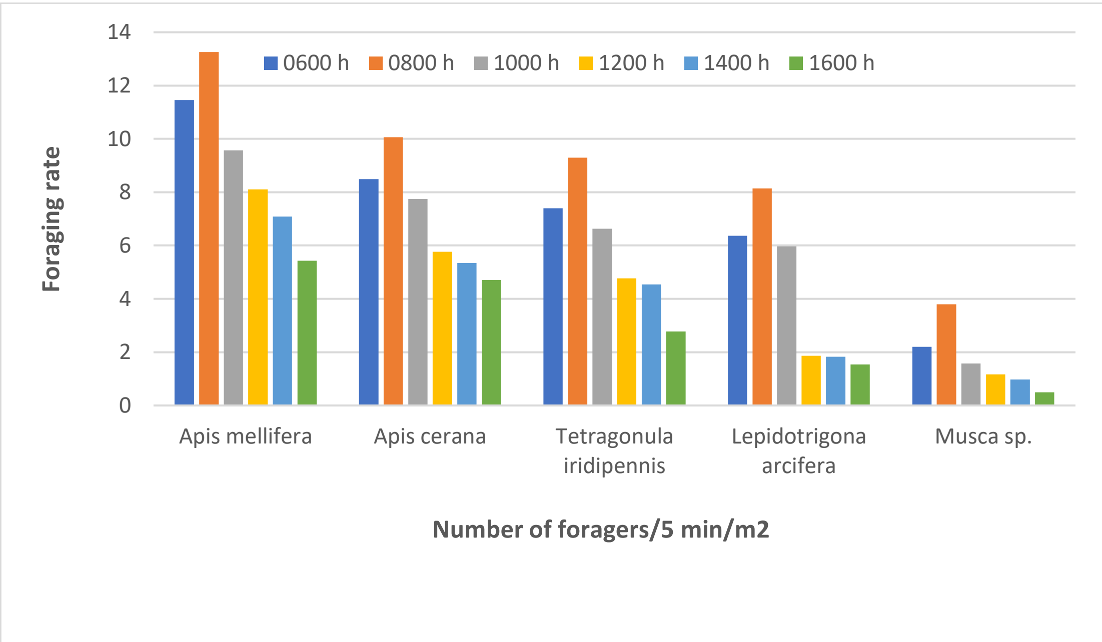


Fig. 4.3. Foraging rate of different insect pollinators on pumpkin in open conditions during 2022 and 2023

The time spent/flower by *A. mellifera* was 27.00 sec per flower at 0800 h and 14.04 seconds per flower at 1400 h and it was followed by *A. cerana* which spent the highest time during 0800 h (29.57sec) and the lowest at 1400 h (11.57 sec). Nicodemo *et al*. (2009) reported *Apis mellifera* spent an average of 34.5 seconds per flower for pollen collection, 43.9 seconds on female flowers and 29.3 seconds on male flowers for nectar collection in pumpkin, which contradicts This variation from the present findings could be due to differences in climatic conditions and the pumpkin varieties used at the respective study sites. However, current results align with those of Ahmad et al. (2017), who recorded that *A. mellifera* spent 8.44 seconds per apple flower at 0900 hours and 10.05 seconds at 1200 hours. According to Girish (1981), the foraging duration per flower on *Cucurbita pepo* L. was 34 seconds for *A. cerana* and 38 seconds for *A. dorsata.*

4.10. Loose Pollen Grains (LPGs)

Information on the number of loose pollen grains adhering to the bodies of four honey bee species is presented in Table 4.15 and depicted in Figure 4.5

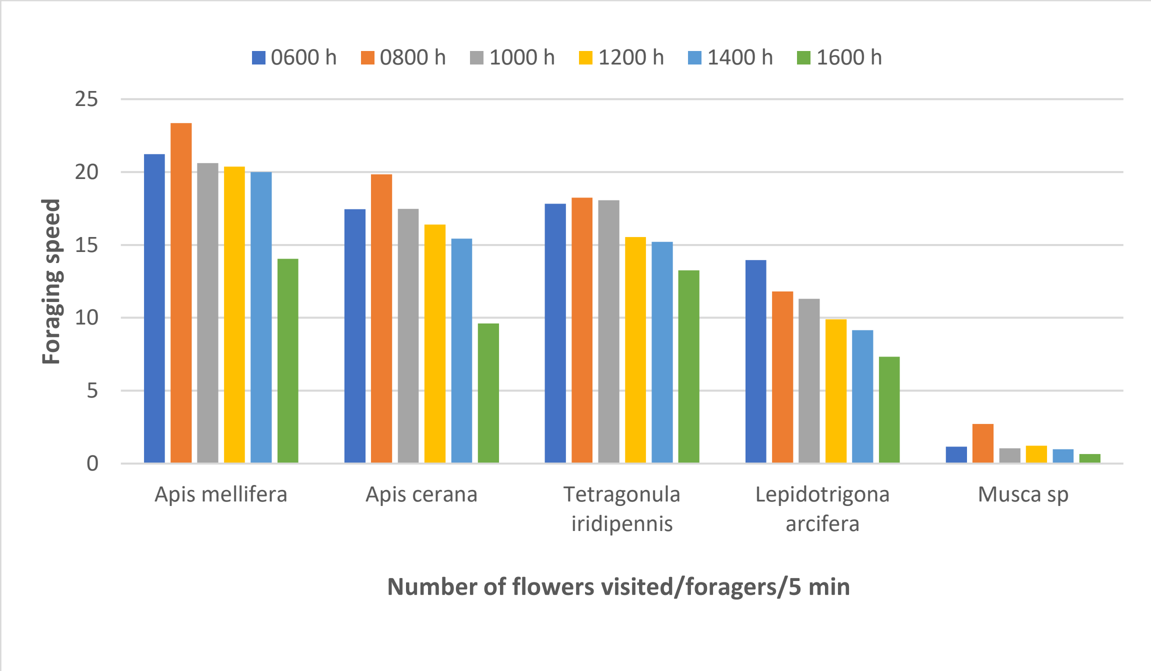
The overall total mean of loose pollen grains were observed to be highest in *A. cerana* with 1861.67 and 1745.00 while the lowest was recorded in *L. arcifera* with 1705.67 and 1687.67 in 2022 and 2023, respectively. Analysis of pooled data demonstrated that the number of loose pollen grains was recorded at its maximum in *A. cerana* (1804.83) followed by *T. iridipennis* (1736.00), *A. mellifera* (1734.00) and the lowest loose pollen grains were recorded in case of *L. arcifera* (1696.67). These results align with Jamir (2021), also recorded *T. iridipennis*, *A. mellifera* and *T. laeviceps* could carry a mean pollen grain of 1618,2015 and 1405 respectively. Similar observations were also recorded by Rani (2017), in a study on summer squash (*Cucurbita pepo* L.), It was reported that *Apis cerana* had the highest number of loose pollen grains adhering to its body (1977 grains), followed by *A. mellifera* (1650), *A. dorsata* (1600), and *A. florea* (1480).

Table 4.13: Foraging speed of different insect pollinators on pumpkin in open conditions during 2022

Sl. No.	Time (hours)	Time spent per flower (in sec.)					
		Apis mellifera	***Apis cerana***	***Tetragonula iridipennis***	***Lepidotrigona arcifera***	***Musca* sp.**	**Mean**
1.	0600	21.22	17.46	17.82	13.96	1.17	*14.33*
2.	0800	23.36	19.85	18.25	11.81	2.73	*15.20*
3.	1000	20.61	17.48	18.06	11.3	1.06	*13.70*
4.	1200	20.36	16.39	15.55	9.89	1.22	*12.68*
5.	1300	19.99	15.44	15.22	9.16	0.98	*12.16*
6.	1400	14.04	9.62	13.25	7.33	0.65	*8.98*
	Mean	*19.93*	*16.04*	*16.36*	*10.58*	*1.30*	-
		Forager	*Time*	*Forager x Time*		-	-
	SEm±	*0.06*	*0.11*	*0.29*		-	-
	CD (p = 0.05)	*0.18*	*0.30*	*0.80*		-	-

Table 4.14: Foraging speed of different insect pollinators on pumpkin in open conditions during 2023

Sl. No.	**Time (hours)**	**Time spent per flower (in sec.)**					
		Apis mellifera	***Apis cerana***	***Tetragonula iridipennis***	***Lepidotrigona arcifera***	***Musca* sp.**	**Mean**
1.	0600	22.57	17.86	14.00	8.71	3.43	*13.31*
2.	0800	27.00	29.57	17.86	14.57	8.57	*19.51*
3.	1000	26.71	21.29	15.00	14.14	5.71	*16.57*
4.	1200	17.43	20.14	14.14	10.43	3.86	*13.20*
5.	1300	16.00	15.29	12.71	9.43	3.57	*11.40*
6.	1400	15.29	11.57	11.43	9.86	2.71	*10.17*
	Mean	*20.83*	*19.29*	*14.19*	*11.19*	*4.64*	-
		Forager	*Time*	*Forager x Time*			-
	SEm±	*0.06*	*0.07*	*0.18*			-
	CD (p = 0.05)	*0.17*	*0.19*	*0.50*			-



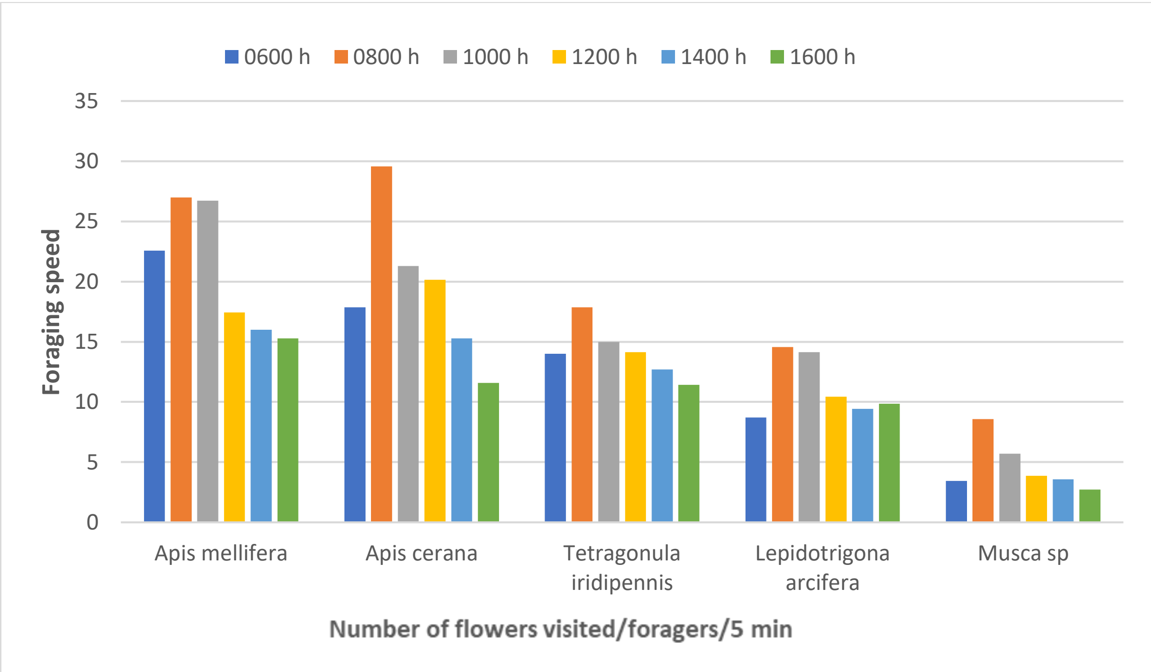


Fig.4.4. Foraging speed of different insect pollinators on pumpkin in open conditions during 2022 and 2023.

Canto-Aguilar and Parra-Tabla (2000) found that *Apis mellifera* carried an average of 1282.9 pollen grains and deposited about 253.4 grains onto the stigma of female flowers. In contrast, Anooj (2012) recorded significantly higher numbers of loose pollen grains adhering to the bodies of *A. mellifera* (97,600), *A. florea* (48,750), and *Ceratina* sp. (44,620) in smooth gourd. The reason could be due to variation in crops and environmental conditions.

4.11. Pollination Efficiency Index

Pollination efficiency index for various bee species visiting pumpkin cultivars was calculated based on relative abundance (RA), foraging rate (FR), foraging speed (FS), and loose pollen grains (LPG). The results are summarized in Tables 4.16 and 4.17 and illustrated in Figure 4.6

From the result it was observed that the pollination efficiency index of *A. cerana* were found to be maximum (30) followed by *A. mellifera* (24), *L. arcifera* (14), and the least pollination efficiency was found in *T. iridipennis* (7) during the year 2022. Similarly, during 2023, the pollination efficiency index of *A. cerana* was maximum (32) followed by *A. mellifera* (27), *T. iridipennis* (14) and the least pollination efficiency was observed in *L. arcifera* (6). In contrast to present findings, Singh and Mall (2020) also documented the maximum pollination index in *A. mellifera* on cucumber. Rao and Suryanarayana (1988) reported that *Apis cerana*, comprising 87% of the bee population, was the primary pollinator of watermelon and proved to be more efficient than *A. florea* and *Trigona irridipennis* which is in agreement with the present findings.

4.12. Impact of bee pollination in pumpkin

4.12.1 Fruit set, healthy fruit % and crooked fruit %

The influence of insect pollinators on fruit set, normal fruit development, and occurrence of crooked fruits is summarized in Table 4.18 and depicted in Figure 4.7

Table 4.15: Number of loose pollen grains collected by insect pollinators on pumpkin during 2022 and 2023

Sl. No.	Number of loose pollen grains per forager											
	Apis mellifera			*Apis cerana*			*Tetragonula iridipennis*			*Lepidotrigona arcifera*		
	2022	***2023***	***Pooled***	***2022***	***2023***	***Pooled***	***2022***	***2023***	***Pooled***	***2022***	***2023***	***Pooled***
1.	1864.00	1982.00	1923.00	2403.00	1896.00	2149.50	1921.00	2146.00	2033.50	2062.00	2008.00	2035.00
2.	1743.00	2014.00	1878.50	1862.00	1927.00	1894.50	2106.00	1906.00	2006.00	1903.00	1903.00	1903.00
3.	964.00	1837.00	1400.50	1320.00	1421.00	1370.50	1173.00	1164.00	1168.50	1152.00	1152.00	1152.00
Mean	*1523.67*	*1944.33*	*1734.00*	*1861.67*	*1748.00*	*1804.83*	*1733.33*	*1738.67*	*1736.00*	*1705.67*	*1687.67*	*1696.67*
SD	*488.45*	*94.32*	*289.68*	*541.50*	*283.61*	*397.17*	*494.00*	*511.94*	*491.66*	*486.04*	*466.86*	*476.29*
SEm±	*282.00*	*54.46*	*167.24*	*312.64*	*163.74*	*229.30*	*285.21*	*295.57*	*283.86*	*280.61*	*269.54*	*274.99*

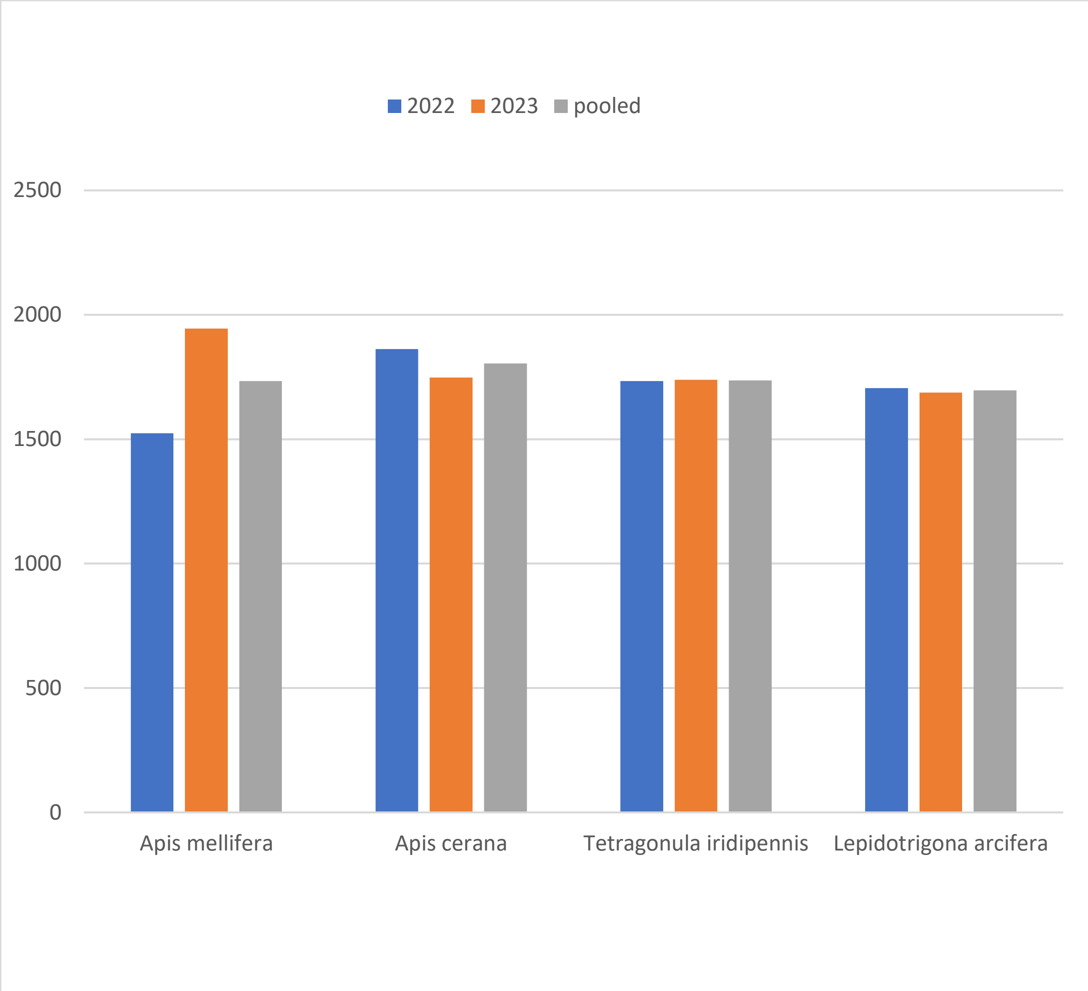


Fig.4.5. Pooled data on number of loose pollen grains collected by pollinators on pumpkin

The findings indicated that the highest fruit set of 75.00 % in 2022 and 80.00 % in 2023 was observed in plots caged with *A. cerana* while the lowest fruit set was recorded in control plot with 48.00% and 52.00% during 2022 and 2023, respectively. Combined data indicated that the maximum percentage on fruit setting was significantly higher in plot caged with *A. cerana* (77.50%) followed by *A. mellifera* (64.00%), *L. arcifera* (62.50%), open pollination (60.00%), *T. iridipennis* (56.00%) and control (50.00%). Dorjay *et al*. (2017) recorded the highest fruit set of 87.14% under bee pollination, compared to 65.21% under open pollination, which closely aligns with the present study. Similarly, Sarwar *et al*. (2008) found that in cucumber, the highest fruit set (85.40%) was recorded in open-pollinated plants with bee activity, followed by 81.28% in bee-caged plants, whereas the lowest fruit set (16.4%) was observed in plants caged without bees. Girish (1981) also observed that plots of *C. pepo* caged without bees failed to set any fruit, compared to 46.00 per cent fruit set in plants caged with *A. cerana* and 57.00 per cent fruit set in plots which were not caged which is contradictory to the present finding. The variation may be due to different environmental conditions.

Similarly, the highest per cent maximum fruit was recorded at plots caged with *A. cerana* 88.65 % in 2022 and 90.82 % in 2023 while the lowest was observed in control plot with 75.37 % and 82.55% during 2022 and 2023, respectively. Pooled results indicated that the maximum proportion of healthy fruits occurred in plots caged with *A. cerana* (89.73%) followed by *A. mellifera* (87.24%), *L. arcifera* (85.54%) open pollination (84.36%), *T. iridipennis* (82.54%) and control (78.96%). In 2022, the crooked fruit was recorded maximum (24.63%) in open pollination and minimum in *A. cerana* (11.35%). Whereas, during 2023, the maximum number was recorded in open pollination with (17.45%) and the least in *A. cerana* (9.18%). Pooled findings demonstrated that the lowest % of crooked fruit were recorded at *A. cerana* with 10.26% followed by *A. mellifera* (12.76%), *L. arcifera* (14.46%), control (15.64%), *T. iridipennis* (17.46%) and open pollination (21.04%).

Table 4.16: Pollination efficiency index of insect pollinators on pumpkin during 2022

Sl. No.	Pollinator	Relative abundance (RA)	Foraging rate (FR)	Foraging speed (FS)	Loose pollen grains (LPG)	Pollination efficiency index (PEI)
1.	*Apis mellifera*	11.05 (4)	4.83 (4)	19.93 (1)	1523.67 (1)	24.00
2.	*Apis cerana*	10.33 (3)	3.04 (3)	16.04 (3)	1861.67 (4)	30.00
3.	*Tetragonula iridipennis*	1.36 (1)	2.47 (2)	16.36 (2)	1733.33 (3)	7.00
4.	*Lepidotrigona arcifera*	1.47 (2)	2.02 (1)	10.58 (4)	1705.67 (2)	14.00

*Value in parenthesis are ranked

Table 4.17: Pollination efficiency index of insect pollinators on pumpkin during 2023

Sl. No.	Pollinator	Relative abundance (RA)	Foraging rate (FR)	Foraging speed (FS)	Loose pollen grains (LPG)	Pollination efficiency index (PEI)
1.	*Apis mellifera*	7.32(3)	9.15 (4)	20.83(1)	1944.33 (4)	27.00
2.	*Apis cerana*	7.73(4)	7.02 (3)	19.29(2)	1748.00 (3)	32.00
3.	*Tetragonula iridipennis*	1.29(2)	5.90 (2)	14.19(3)	1738.67 (2)	14.00
4.	*Lepidotrigona arcifera*	1.17(1)	4.29 (1)	11.19(4)	1687.67 (1)	6.00

*Value in parenthesis are ranked

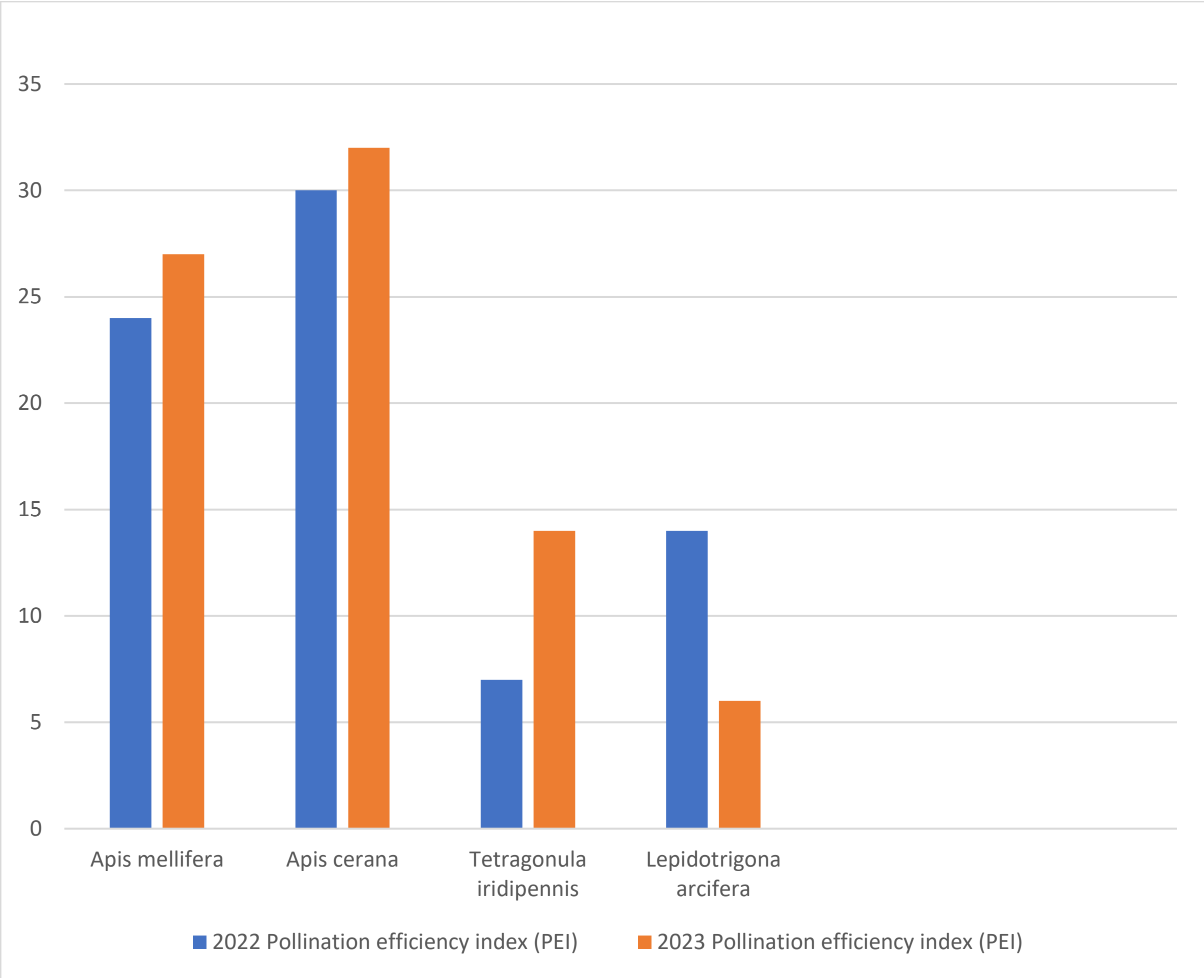


Fig.4.6. Pollination efficiency index of insect pollinators on pumpkin during 2022 and 2023.

Table 4.18: Impact of insect pollinators on fruit setting, healthy fruit and crooked fruit of pumpkin during 2022 and 2023

Sl. No.	Treatments	Fruit setting (%)			Healthy fruit (%)			Crooked fruit (%)		
		2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
1.	*Apis mellifera*	60.00	68.00	64.00	84.90	89.58	87.24	15.10	10.42	12.76
2.	*Apis cerana*	75.00	80.00	77.50	88.65	90.82	89.73	11.35	9.18	10.26
3.	*Tetragonula iridipennis*	52.00	60.00	56.00	79.50	85.58	82.54	20.50	14.42	17.46
4.	*Lepidotrigona arcifera*	60.00	65.00	62.50	83.50	87.58	85.54	16.50	12.42	14.46
5.	Open pollination	58.00	62.00	60.00	75.37	82.55	78.96	24.63	17.45	21.04
6.	Control	48.00	52.00	50.00	82.06	86.66	84.36	17.94	13.34	15.64
	SEm±	*0.78*	*0.50*	*0.46*	*0.87*	*0.85*	*0.61*	*0.20*	*0.16*	*0.13*
	CD (p = 0.05)	*2.35*	*1.50*	*1.34*	*2.63*	*2.56*	*1.76*	*0.60*	*0.47*	*0.36*

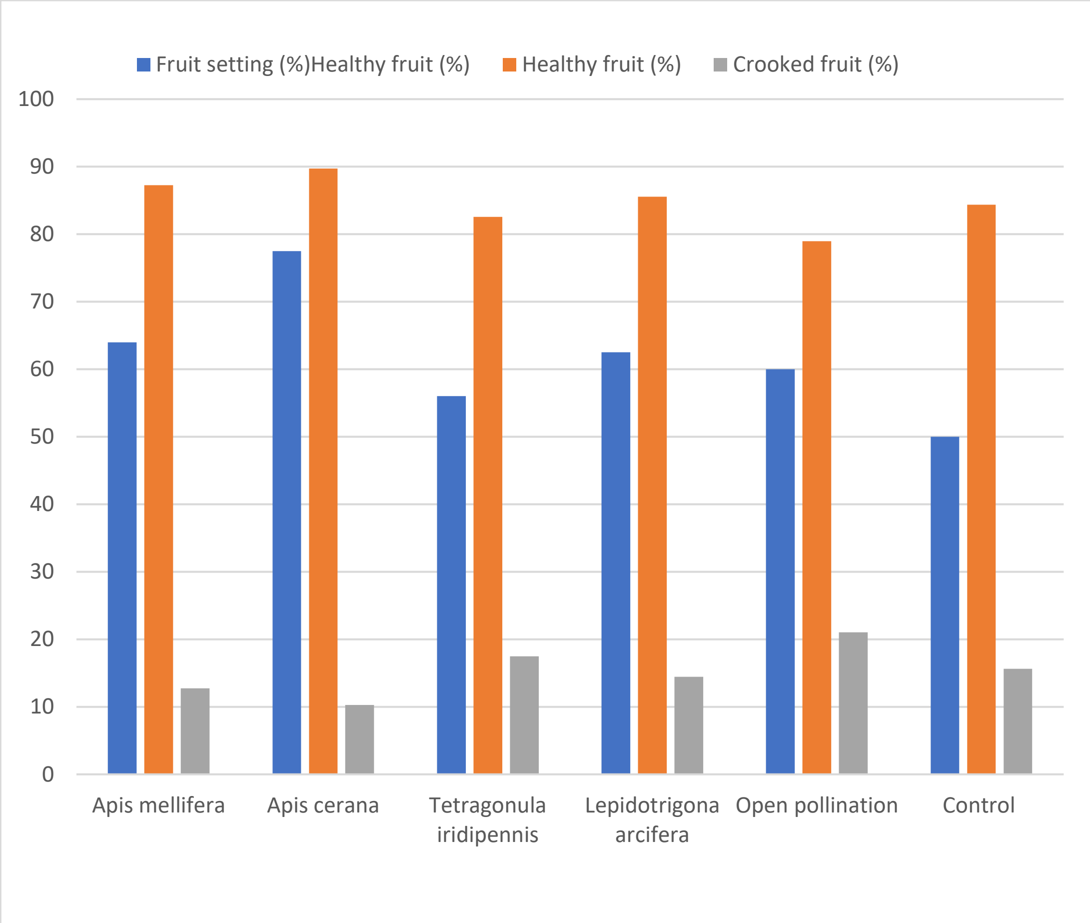


Fig .4.7. Pooled data on the impact of different bee pollination modes on fruit set, healthy fruit and crooked fruit in pumpkin

Lowest per cent healthy fruit and maximum crooked fruits observed in open pollination conditions this could be attributed to less pollinators have visited the flowers resulting in the adequate pollination leading to the formation of malformed fruits (Hodges and Baxendale, 1995). Anderson (1941) also opined that malformed fruits in cucumbers were due to few bee visits per flower resulting in poor pollination.

14.12.2. Fruit length (cm), diameter (cm) and fruit weight (kg) in pumpkin.

The findings on the effects of various pollination methods on yield and quality attributes of *C. moschata* recorded during the year 2022 and 2023 are presented in Table 4.19 and figure 4.8.

During 2022, the longest fruit length (cm) was observed in *A. cerana* pollinated plots with 19.10 cm and the shortest was in control plot (13.35 cm). Similarly, during 2023, the longest fruit length was observed in *A. cerana* pollinated plots with (21.35 cm) and the shortest was recorded in control plot (15.66 cm). The representation of pooled data showed significant effect on fruit length (cm) was recorded maximum in *A*. *cerana* pollinated plots (20.17 cm) followed by *A. mellifera* (19.10 cm), *L. arcifera* (18.76 cm), *T. iridipennis* (18.76 cm), open pollination (17.11 cm). The least fruit length 14.50 cm was observed in control plot.

A. cerana pollinated plots recorded maximum fruit diameter with 45.25 cm and 47.56 cm during 2022 and 2023 respectively. The pooled results indicated notable differences between the treatment groups and the largest mean fruit diameter (cm) was recorded in *A*. *cerana* (46.41) followed by *A. mellifera* (43.90*), L. arcifera* (42.17*), T. iridipennis* (40.88), open pollination (39.40) and control (37.16).

The maximum fruit weight was observed. in *A. cerana* pollinated plots with 1.56 kg and 1.85 kg during 2022 and 2023, respectively. While the lowest was observed in control plot with 1.02 kg and 1.22 kg during 2022 and 2023, respectively. The pooled data during both the year showed significant effect. The data recorded was highest in plot caged with *A*. *cerana* (1.71 kg) followed by *A.*

Table 4.19: Impact of insect pollinators on yield attributes of pumpkin during 2022 and 2023

Sl. No.	Treatments	Fruit length (cm)			Fruit diameter (cm)			Fruit weight (kg)		
		2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
1.	*Apis mellifera*	17.96	20.25	19.10	42.25	45.55	43.90	1.34	1.74	1.54
2.	*Apis cerana*	19.10	21.25	20.17	45.25	47.56	46.41	1.56	1.85	1.71
3.	*Tetragonula iridipennis*	15.36	17.77	16.56	38.05	40.75	39.40	1.08	1.42	1.25
4.	*Lepidotrigona arcifera*	17.96	19.56	18.76	40.95	43.40	42.17	1.36	1.81	1.59
5.	Open pollination	15.55	18.67	17.11	39.56	42.20	40.88	1.27	1.66	1.46
6.	Control	13.35	15.66	14.50	35.98	38.35	37.16	1.02	1.22	1.12
	SEm±	*0.32*	*0.22*	*0.19*	*0.49*	*0.28*	*0.28*	*0.016*	*0.025*	*0.015*
	CD (P = 0.05)	*0.95*	*0.67*	*0.56*	*1.47*	*0.85*	*0.81*	*0.048*	*0.076*	*0.043*

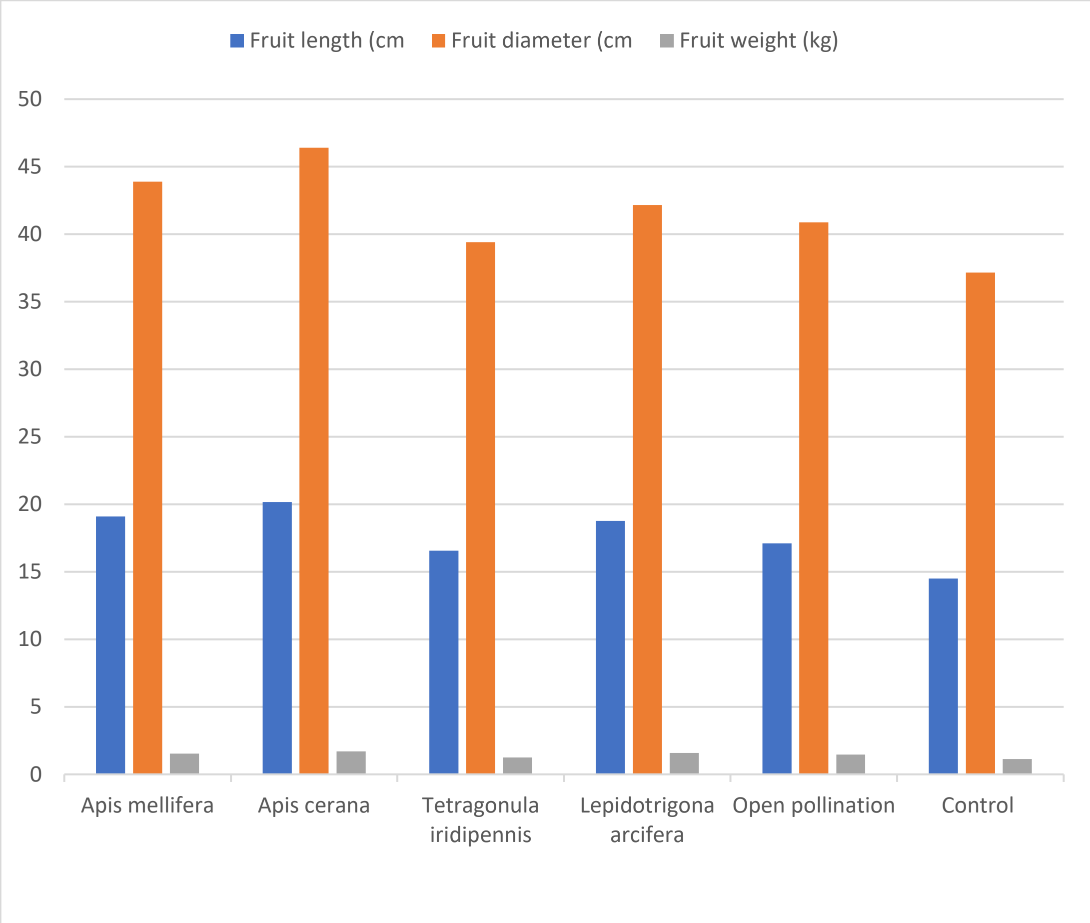


Fig .4.8. Pooled data on impact of different bee pollination modes on fruit length, fruit diameter and fruit weight in pumpkin.

mellifera (1.54 kg)*, L. arcifera* (1.59 kg), *T. iridipennis* (1.46 kg), open pollination (1.25 kg) and the least was in control plot (1.12 kg). The data indicated that, regardless of the treatment applied, fruit length, diameter, and weight were significantly higher with plot caged with bees than the other treatments. The maximum fruit length (cm), fruit diameter (cm) and fruit weight (kg) of *A. cerana* pollinated plots were recorded as 20.17 cm, 46.41 cm and 1.71 kg, respectively. While the minimum fruit length (cm), fruit diameter (cm) and fruit weight (kg) were observed in control plot with 14.50 cm, 37.16 cm and 1.12 kg, respectively. The results are in conformity with Mattu and Nirala (2013) also reported that honeybee-pollinated flowers produced fruits with significantly greater weight, length, breadth, volume, and seed count. Similarly, findings from Prakash et al. (2004), Santos and Dos (2008), and Thakur and Rana (2008) demonstrated that bee-pollinated plots yielded larger and heavier fruits than those resulting from open or hand pollination. Furthermore, research by Nogueira and Calmona (1993) and Walters and Taylor (2006) showed that plots netted with bees yielded a greater number of fruits per square meter and produced healthier and better-quality fruits than other treatments.

14.12.3. Number of seeds per fruit and weight of 100 seeds.

The data on the impact of insect pollinators on number of seeds/fruit and weight of 100 seeds are tabulated in Table 4.20 and illustrated in Figure. 4.9.

The highest number of seeds of 142.80 was observed in *A. cerana* pollinated plots (142.80) followed by *A. mellifera* (128.20) during 2022. Similarly, in 2023 similar trend was observed, number of seeds was highest in plots caged *A. cerana* (182.00) followed by *A. mellifera* (163.10) and *L. arcifera* (142.60) and the least was recorded in control plot with 117.40. The pooled data depicted that the maximum number of seeds per fruit was observed in *A. cerana* as (162.40) followed by *A. mellifera* (145.65), *L. arcifera* (124.35), open

Table 4.20: Impact of insect pollinators on number of seeds per fruit and 100 seed weight of pumpkin during 2022 and 2023

Sl. No.	Treatments	Number of seeds per fruit			100 seed weight (g)		
		2022	**2023**	**Pooled**	**2022**	**2023**	**Pooled**
1.	*Apis mellifera*	128.20	163.10	145.65	13.93	14.58	14.25
2.	*Apis cerana*	142.80	182.00	162.40	15.73	14.54	15.14
3.	*Tetragonula iridipennis*	100.30	131.70	116.00	15.51	15.74	15.63
4.	*Lepidotrigona arcifera*	106.10	142.60	124.35	13.71	15.34	14.53
5.	Open pollination	100.80	134.20	117.50	15.07	14.10	14.59
6.	Control	99.60	117.40	108.50	13.08	13.70	13.39
	SEm±	*1.75*	*1.75*	*1.24*	*0.15*	*0.16*	*0.11*
	CD (p = 0.05)	*5.28*	*5.27*	*3.57*	*0.44*	*0.48*	*0.31*

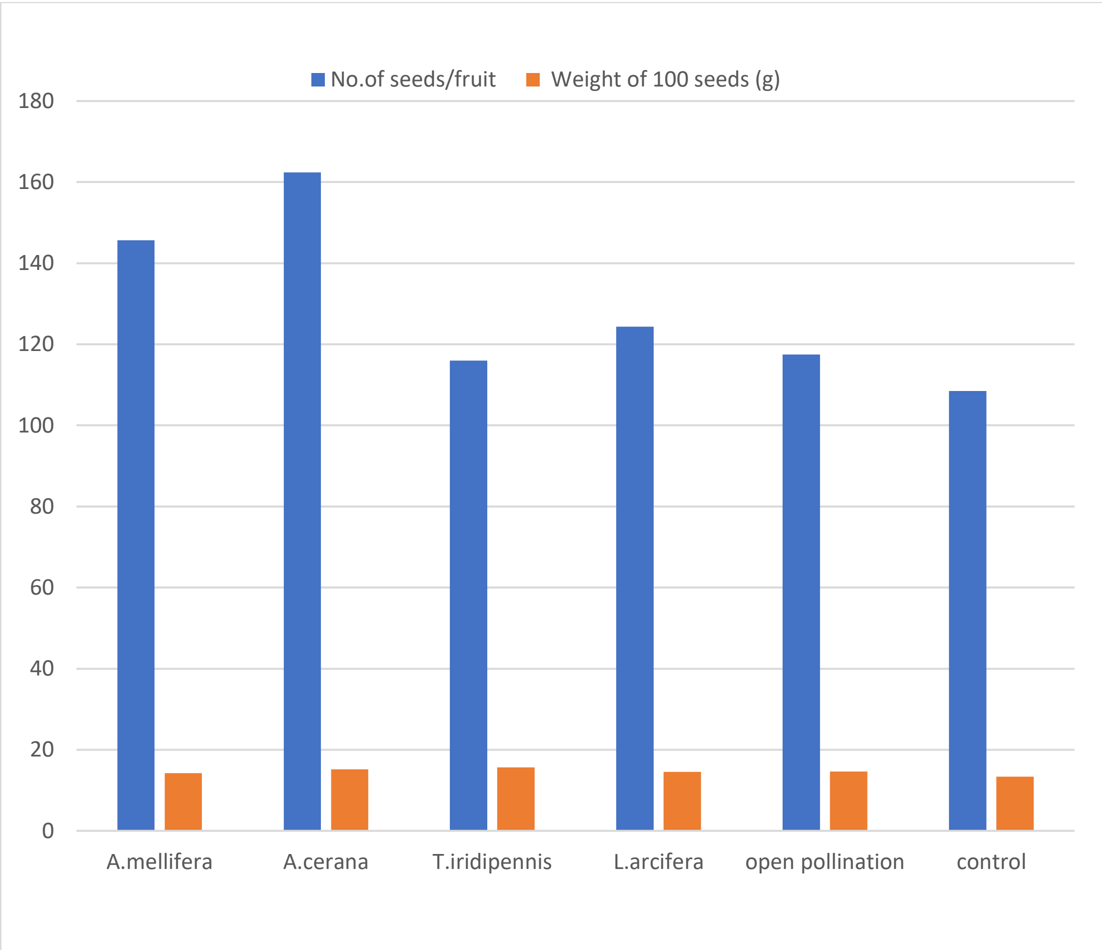


Fig .4.9. Pooled data on the impact of different bee pollination on the number of seeds/fruit and weight of 100 seeds in pumpkin during.

pollination (117.50), *T. iridipennis* (116.00) and the least was found in (108.50) control plot (108.50 seeds/fruit). The higher increased seed count per fruit associated with *Apis cerana* pollination is likely due to the effective transfer of an adequate amount of pollen grains by honeybees under caged conditions, leading to more effective pollination compared to open pollination (Prakash *et al*., 2004).The most important pollinators of *Cucurbita* spp. are honeybees and as the number of bee visits to *Cucurbita* flowers increases, the fruit set and seed number generally increased (Delaplane and Mayer, 2000). Bee visitation rates strongly influenced fruit set and seed production (Mayfeld *et al*., 2001, Karron *et al*., 2009). Mattu and Nirala (2013) also observed that honeybee pollinated flowers significantly influenced the number of seeds per fruit.

During 2022, 100 seeds weight (g) was recorded maximum in plots caged in *A. cerana* (15.73). Whereas, in 2023, it was recorded in plots caged with *T. iridipennis* (15.74). The pooled data revealed that significantly higher seed weight was recorded plots caged in *T. iridipennis* (15.63g) followed by *A. cerana* (15.14g), open pollination (14.59g), *L. arcifera* (14.53g), *A. mellifera* (14.25g) and in control (13.39g). Results showed that plots caged with *A. cerana* produced fruits with a greater number of seeds (162.40 seeds/fruit) as compared to other pollinated plants and the least observed in control plot with (108.50 seeds/fruit). However, the test weight of the seeds was more in *T. iridipennis* 15.63 g and the least seed test weight was in control plot with 13.39g.

4.12.4 Impact of bee pollination on different parameters in pumpkin

The findings are summarized in Table 4.21 and illustrated in Figure 4.10. The 2022 study revealed that an increase in fruit set (26.99 %), healthy fruit (6.59%), reduction in crooked fruit was (6.59%), fruit length (5.75 %), fruit diameter (9.27%), fruit weight (0.53%), seed number (43.20%), and weight of 100 seeds (2.65 %) in *A. cerana* was observed over control. Similarly, during 2023, the use *A. cerana* led to an increase in fruit set (28.00%), healthy

Table 4.21: Impact of bee pollination in pumpkin over control during 2022 and 2023

Sl. No.	*Quality*	*Pollinator*	*% increase over control*	
			2022	***2023***
1.	Fruit setting (%)	*Apis mellifera*	12.00	16.00
		Apis cerana	26.99	28.00
		Tetragonula iridipennis	4.00	8.00
		Lepidotrigona arcifera	12.00	13.00
		Open pollination	9.99	10.00
2.	Healthy fruits (%)	*Apis mellifera*	2.84	2.92
		Apis cerana	6.59	4.16
		Tetragonula iridipennis	-2.56	-1.08
		Lepidotrigona arcifera	1.44	0.92
		Open pollination	-6.69	-4.11
3.	*Crooked fruits (%)	*Apis mellifera*	2.84	2.92
		Apis cerana	6.59	4.16
		Tetragonula iridipennis	-2.56	-1.08
		Lepidotrigona arcifera	1.44	0.92
		Open pollination	-6.69	-4.11
4.	Fruit length (cm)	*Apis mellifera*	4.61	4.59
		Apis cerana	5.75	5.59
		Tetragonula iridipennis	2.01	2.11
		Lepidotrigona arcifera	4.61	3.90
		Open pollination	2.20	3.01
5.		*Apis mellifera*	6.26	7.20

	Fruit diameter (cm)	*Apis cerana*	9.27	9.21
		Tetragonula iridipennis	2.07	2.40
		Lepidotrigona arcifera	4.97	5.05
		Open pollination	3.58	3.86
6.	Fruit weight (g)	*Apis mellifera*	0.31	0.52
		Apis cerana	0.53	0.63
		Tetragonula iridipennis	0.05	0.20
		Lepidotrigona arcifera	0.34	0.59
		Open pollination	0.24	0.44
7.	Number of seeds per fruit	*Apis mellifera*	28.60	45.70
		Apis cerana	43.20	64.60
		Tetragonula iridipennis	0.70	14.30
		Lepidotrigona arcifera	6.50	25.20
		Open pollination	1.20	16.80
8.	100 seeds weight (g)	*Apis mellifera*	0.85	0.88
		Apis cerana	2.65	0.84
		Tetragonula iridipennis	2.43	2.04
		Lepidotrigona arcifera	0.63	1.64
		Open pollination	1.99	0.40

Note:*Crooked fruit (%) signifies the percent decrease of treatments over control

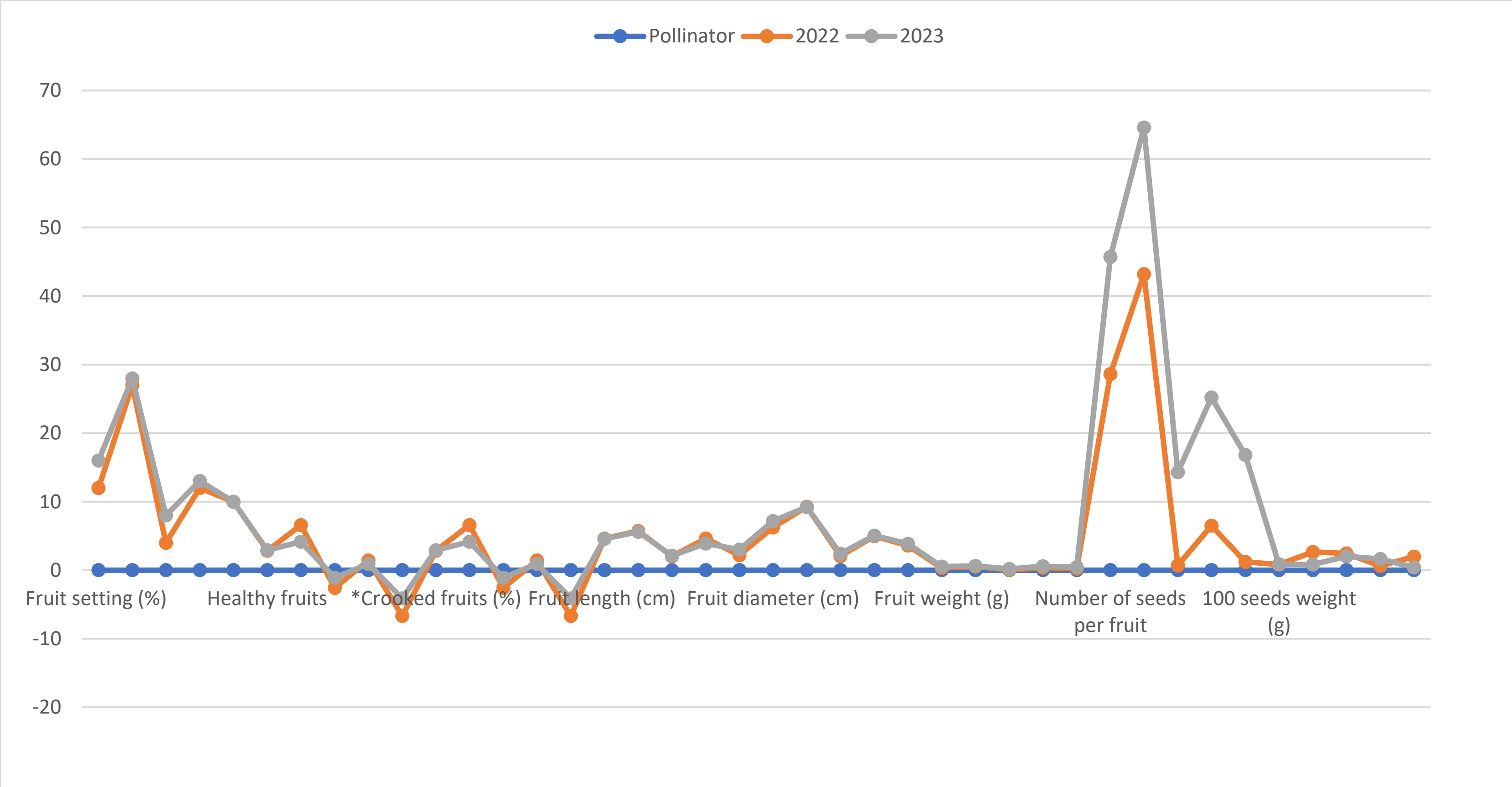


Fig .4.10. Impact in % increase in pumpkin over control during 2022 and 2023

fruit (4.16 %), reduction in crooked fruit (4.16 %), fruit length (5.59%), fruit diameter (9.21%), fruit weight (0.63%), seed number (64.60%), and weighs of 100 seeds (2.04 %) in *T. iridipennis* were observed over control. Kedswin *et al.* (2023) observed an enlargement in fruit weight (kg) of 3.85% and yield (t/ha) of 14.74 % with *A. cerena* in pumpkin. Hosamani *et al.* (2020) also observed that bee pollinated plots recorded a higher per cent increase in seed weight and yield over control. Mitta *et al.* (2017) observed that stingless bee pollinated crops resulted in higher per cent increase improvement in fruit length, fruit weight, fruit count, and overall yield compared to the control in cucumber.

CHAPTER V

SUMMARY AND CONCLUSION

SUMMARY AND CONCLUSION

The present research investigations entitled "Diversity of insect pollinators and impact of bee pollination on pumpkin (*Cucurbita moschata* Duch. ex Poir)" were undertaken with three objectives viz. (i) to study the diversity of insect visitor on pumpkin, (ii) to find out the Pollination Efficiency Index (PEI) of different pollinators and (iii) to determine the effect of bee pollination on productivity pumpkin. The salient findings are summarized here below.

- During the blooming period of pumpkin, a total of fourteen insect pollinator species were recorded, of which nine the identified species comprised members from the order Hymenoptera, with three species from Coleoptera and two from Diptera

- Major floral visitors comprise of hymenopteran such as *Apis cerana, Apis mellifera, Tetragonula iridipennis, Lepidotrigona arcifera, Apis florae, Apis dorsata, Xylocopa tenuiscapa, Xylocopa fenestrate* and *Lasius niger,* and it was followed by coleoptera's viz. *Aulacophora foveicollis, Aulacophora atripennis, Aulacophora nigripennis,* and dipterans*, Bactrocera dorsalis, Musca* sp.

- The experimental result under open condition obtained during the investigation period (2022 and 2023) revealed that the highest mean relative abundance of insect pollinator was recorded in *A. mellifera* with (11.05 foragers/5 min/m^2) followed by *A. cerana* with (7.73 foragers/5 min/m^2) Whereas the least mean relative abundance of insect pollinator was recorded in *Musca* sp. with 1.33 and 0.79 during 2022 and 2023, respectively.

- The highest relative abundance of insect visitor on pumpkin under closed condition was observed with *A. mellifera* on all days of observations for both years of experiment (2022 and 2023). The overall mean data was observed maximum in *A. mellifera* with 20.91 foragers/5 min/m² in 2022 and 20.32 foragers/5 min/m² in 2023 and the minimum was recorded in *L. arcifera* with 11.20 and 11.91 during 2022 and 2023, respectively.

- From the data recorded during both the experimental year 2022 and 2023, the foraging activity under open conditions was initiated at 0600-0800 h, reaching its peak at 1000-1200 h and cessation of activity at 1400-1600 h for most of the insect pollinators.

- According to the data from foraging activity under closed conditions in both experimental years, the highest number of pollinators visited pumpkin flowers was at 0600-0800 h. The initiation time of different pollinators was recorded at Activity began at 0600–0800 h, reached its peak between 0800–1000 h, and declined thereafter was recorded during 1400-1600 h.

- Under open conditions, the highest foraging rate was observed in *A. mellifera* with 4.83 flowers/minute during 2022 and 9.15 flowers/minute during 2023. Whereas the lowest rate was recorded in *Musca* sp. with 0.87 flowers/minute and 1.70 flowers/minute during 2022 and 2023 respectively.

- The mean foraging speed under open conditions revealed that the maximum time spent/flower in sec was in *A. mellifera* with a foraging speed of 19.93 secs and 20.83 secs during 2022 and 2023, respectively. On the contrary, the minimum time spent/flower in sec was in *Musca* sp. with 1.30 sec in 2022 and 4.64 sec in 2023.

- The quantity of loose pollen grains adhering to the body was more or less same for the honeybees. The pooled data revealed that highest loose pollen grains were recorded in *A. cerana* (1804.83) on their body followed by *T. iridipennis* (1736.00), *A. mellifera* (1734.00) and *L. arcifera* carried about 1696.67 the count of pollen grains present on their bodies.

- During both years of the experiment trials during 2022 and 2023 the study on pollination efficiency index of the pollinators showed that *A. cerana* had the highest pollination efficiency of 30.00 PEI and 32.00 PEI respectively, which characterized them as true pollinators of pumpkin and the least efficiency was observed in *T. iridipennis* with 7 PEI during 2022 and *L. arcifera* with 6 PEI during 2023.

- From the study of per cent fruit set and per cent healthy fruits, for both the years. The pooled data indicated that fruit set was highest in recorded in plots caged *A. cerana* with 77.50% in 2022 and 89.73% in 2023 whereas, the minimum was recorded in control condition with 50.00% and 78.96 % during 2022 and 2023, respectively. The highest percentage on crooked fruit was recorded in open pollination 21.04% in 2022, while the lowest in *A. cerana* 10.26% during 2023.

- Findings on the influence of various pollination methods on yield traits indicated that the greatest fruit length was recorded in *A. cerana* pollinated plants with 19.10 cm in 2022 and 21.25 cm in 2023. Whereas the shortest fruit length was noted in control condition with 13.35 cm and 15.66 cm, respectively. The pooled data recorded highest fruit length in *A. cerana* 20.17 cm followed by *A. mellifera* 19.10 cm, *L. arcifera* 18.76 cm, open pollinated 17.11 cm, *T. iridipennis* 16.56 cm and control 17.11 cm.

- The diameter of the fruit was found to be 42.25 cm for both *A. cerana* and *A. mellifera* during the first year of experimental period (2022). Whereas, for the second research period 2023, largest fruit length of 47.56 cm was observed in plots caged with *A. cerana.* The shortest fruit length was observed in control conditions with 35.98 cm and 38.35 cm during 2022 and 2023 respectively. The combined data revealed a significant impact of pollinators on yield attributes.

The largest fruit diameter was recorded in plots caged with *A. cerana* with 46.41 cm followed by *A. mellifera* (43.90 cm), *L. arcifera* (42.17 cm), open pollinated (40.88 cm), *T. iridipennis* (39.40 cm) and control plots (37.16 cm).

- The data analysis on fruit weight (kg) was more in plots of pollinated with *A. cerana* with 1.56 kg and 1.85 kg as compared to that of control condition with 1.02 kg and 1.22 kg during 2022 and 2023, respectively. According to the pooled data, the maximum fruit weight (kg) was observed in *A. cerana* pollinated plots (1.71 kg) followed by *L. arcifera* (1.59 kg), *A. mellifera* (1.54 kg), open pollinated (1.46 kg), *T. iridipennis* (1.25 kg) and control plots (1.12 kg) in descending order.

- A higher number of seeds per fruit was observed in plots caged with *A. cerana* with 142.80 seeds/fruit (2022) and 182.00 seeds/fruit (2023). However, the number of the seeds was less in control condition with 99.60 seeds/fruit and 117.40 seeds/fruit during 2022 and 2023, respectively. The pooled data revealed that the maximum number of seeds per fruit was observed in plots caged with *A. cerana* with 162.40 seeds/fruit followed by *A. mellifera* 145.65 seeds/fruit, *L. arcifera* 124.35 seeds/fruit, open pollinated 117.50 seeds/fruit, *T. iridipennis* 116.00 seeds/fruit and control 108.50 seeds/fruit.

- The 100 seeds weight (g) was recorded highest in plots caged with *A. cerana* 15.73 g in the first research trial but for the second trial period, it was *T. iridipennis* with 15.74 g. Whereas the lowest was recorded in control condition with 13.08 g (2022) and 13.70 g (2023).According to the pooled data analysis, the highest 100-seed weight (in grams) was observed in in *T. iridipennis* (15.63 g) followed by *A. cerana* (15.14 g), open pollinated (14.59 g), *L. arcifera* (14.53 g), *A. mellifera* (14.25 g) and control plots (13.39 g).

- The highest increase of 26.99% and 28.00% in the fruit set, 6.59% and 4.16% of healthy fruits, reduction in crooked fruits 6.59% and 4.16%, increased in fruit length (cm) of 5.75% and 5.59%, diameter (cm) of 9.27 % and 9.21%, fruit weight (kg) of 0.53 % and 0.63%, number of seeds per fruits of 43.20% and 64.60% and weight of 100 seeds (g) of 2.65 % and 0.84 % was observed in plots caged with *A. cerana* over control, during the experimental trial 2022 and 2023, respectively.

Conclusion

The results of the present studies entitled, "Diversity of insect pollinators and impact of bee pollination on pumpkin (*Cucurbita moschata* Duch.ex Poir)" under protected conditions revealed that insect pollinators play a major role in pollinating the pumpkin crop. The experimental data indicate that relative abundance (under both open and caged conditions), Increased foraging rate, faster foraging speed, and more loose pollen grains were observed in *A. cerana* over *A. mellifera, T. iridipennis*, *L. arcifera* and other pollinators in pumpkin. Pollination efficiency index was also found more in *A. cerana followed* by *A. mellifera*, *T. iridipennis* and *L. arcifera* under open conditions. The fruit set and healthy fruits were higher in *A. cerana* with 77.50% and 89.73% respectively. The crooked fruits were recorded higher from *T. iridipennis* (17.46%) outperformed by other treatments. The maximum fruit weight (kg) was observed in the plots treated with caged *A. cerana* (1.71 kg) and lowest in *T. iridipennis* (1.25 kg). Likewise, The greatest number of seeds per fruit was noted in *A. cerana* (162.40 seeds/fruit) followed by *A. mellifera* (145.65 seeds/fruit), *L. arcifera* (124.35 seeds/fruit), open pollinated (117.50 seeds/fruit) and *T. iridipennis* (116.00 seeds/fruit). The lowest seed count per fruit was observed in control of 108.50 seeds/fruit. All pollinator species significantly influenced fruit set, fruit weight, fruit size, and seed count per fruit. Among them, *Apis cerana*-pollinated plots recorded the highest fruit set, along with healthier fruits, greater fruit weight, larger size, and increased number of seeds in each fruit. Resulting the highest quantity and best quality fruits. Therefore, to obtain quality produce in pumpkin crops, pollination with *A. cerana* should be encouraged and practiced in Nagaland conditions. A comprehensive study of the potential of *A. cerana* for pollination of other crops is still required.

Future thrust:

The research on the diversity of insect pollinators and the impact of bee pollination on pumpkin holds immense potential for application in sustainable agriculture, biodiversity conservation, and pollination ecology. Given the increasing concern over pollinator decline and its effects on crop yields, this study provides a foundation for various future directions, innovations, and policy interventions.

1. Enhancing crop productivity through pollinator management

One of the most direct future prospects of this study lies in improving pumpkin yield and quality through effective pollinator management. By identifying the most efficient and frequent pollinators of pumpkin crops, such as specific bee species, the findings can be used to:

- Promote the use of managed pollinators (e.g., Apis mellifera or Apis cerana) in pumpkin farms.
- Design pollinator-friendly agricultural practices that improve visitation rates and pollen transfer efficiency.
- Reduce dependency on chemical inputs by harnessing ecosystem services offered by natural pollinators.

This can contribute to more economically and environmentally sustainable pumpkin production systems, especially for small and medium-scale farmers.

2. Conservation of native pollinator diversity

The documentation and analysis of diverse insect pollinators visiting pumpkin flowers also open pathways to biodiversity conservation, particularly of native and wild bee populations. Many such pollinators are often overlooked in conventional agriculture.

- Help identify species at risk due to habitat loss or pesticide exposure.
- Provide baseline data for establishing pollinator conservation zones or corridors.
- Aid in creating local pollinator inventories for biodiversity monitoring programs.

Such efforts support ecological resilience and can help offset the decline of globally important pollinators like honey bees, which are vulnerable to disease and climate change.

3. Further Academic Research and Cross-Crop Comparisons

Future researchers may:

- Extend this work to compare pollinator efficiency and diversity across different cucurbit crops (e.g., cucumber, bottle gourd, watermelon).
- Study genetic and morphological traits of pumpkins that influence pollinator preference.
- Conduct economic valuations of pollination services to estimate their contribution to pumpkin farming profitability.

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APPENDICES

APPENDICES

1. Relative abundance of different insect pollinators on pumpkin in open conditions during 2022 and 2023

Source of Variance	***Degree of Freedom***	***Sum of Square***	***Mean Sum of Square***	***F ratio***	***F table***	***Logic***
Replication	3.00	0.07	0.02	2.06	3.16	***NS***
Forager	6.00	166.18	27.70	2510.90	2.66	***Significant***
Error a	18.00	0.20	0.01			
Time	5.00	2835.73	567.15	17061.45	2.30	***Significant***
Forager x Time	30.00	354.93	11.83	355.91	1.57	***Significant***
Error b	105.00	3.49	0.03			
Total	167.00	3360.60	20.12			

Source of Variance	***Degree of Freedom***	***Sum of Square***	***Mean Sum of Square***	***F ratio***	***F table***	***Logic***
Replication	3.00	0.06	0.02	1.25	3.16	***NS***
Forager	6.00	357.01	59.50	3629.60	2.66	***Significant***
Error a	18.00	0.30	0.02			
Time	5.00	1501.92	300.38	13730.09	2.30	***Significant***
Forager x Time	30.00	411.25	13.71	626.58	1.57	***Significant***
Error b	105.00	2.30	0.02			
Total	167.00	2272.84	13.61			

2. Relative abundance of different insect pollinators on pumpkin in closed conditions during 2022 and 2023

Source of Variance	***Degree of Freedom***	***Sum of Square***	***Mean Sum of Square***	***F ratio***	***F table***	***Logic***
Replication	3.00	0.04	0.01	0.10	3.29	***NS***
Forager	3.00	1126.65	375.55	2724.66	3.29	***Significant***
Error a	15.00	2.07	0.14			
Time	5.00	1465.09	293.02	1797.91	2.39	***Significant***
Forager x Time	15.00	439.07	29.27	179.60	1.86	***Significant***
Error b	54.00	8.80	0.16			
Total	95.00	3041.72	32.02			

Source of Variance	***Degree of Freedom***	***Sum of Square***	***Mean Sum of Square***	***F ratio***	***F table***	***Logic***
Replication	3.00	0.32	0.11	0.47	3.29	***NS***
Forager	3.00	1503.70	501.23	2234.68	3.29	***Significant***
Error a	15.00	3.36	0.22			
Time	5.00	1030.66	206.13	1776.10	2.39	***Significant***
Forager x Time	15.00	284.61	18.97	163.49	1.86	***Significant***
Error b	54.00	6.27	0.12			
Total	95.00	2828.92	29.78			

3.Foraging rate of different insect pollinators on pumpkin during 2022 and 2023

Source of Variance	***Degree of Freedom***	***Sum of Square***	***Mean Sum of Square***	***F ratio***	***F table***	***Logic***
Replication	3.00	0.01	0.00	0.53	3.16	***NS***
Forager	6.00	219.32	36.55	4998.85	2.66	***Significant***
Error a	18.00	0.13	0.01			
Time	5.00	220.53	44.11	1341.02	2.30	***Significant***
Forager x Time	30.00	72.17	2.41	73.14	1.57	***Significant***
Error b	105.00	3.45	0.03			
Total	167.00	515.62	3.09			

Source of Variance	***Degree of Freedom***	***Sum of Square***	***Mean Sum of Square***	***F ratio***	***F table***	***Logic***
Replication	3.00	0.02	0.01	0.48	3.16	***NS***
Forager	6.00	665.28	110.88	6976.47	2.66	***Significant***
Error a	18.00	0.29	0.02			
Time	5.00	881.87	176.37	9471.68	2.30	***Significant***
Forager x Time	30.00	65.10	2.17	116.54	1.57	***Significant***
Error b	105.00	1.96	0.02			
Total	167.00	1614.51	9.67			

4. Foraging speed of different pollinators on pumpkin during 2022 and 2023

Source of Variance	***Degree of Freedom***	***Sum of Square***	***Mean Sum of Square***	***F ratio***	***F table***	***Logic***
Replication	3.00	0.13	0.04	0.48	3.16	***NS***
Forager	6.00	822.47	137.08	1542.26	2.66	***Significant***
Error a	18.00	1.60	0.09			
Time	5.00	7008.91	1401.78	4267.74	2.30	***Significant***
Forager x Time	30.00	972.46	32.42	98.69	1.57	***Significant***
Error b	105.00	34.49	0.33			
Total	167.00	8840.06	52.93			

Source of Variance	***Degree of Freedom***	***Sum of Square***	***Mean Sum of Square***	***F ratio***	***F table***	***Logic***
Replication	3.00	0.28	0.09	1.15	3.16	***NS***
Forager	6.00	637.60	106.27	1335.07	2.66	***Significant***
Error a	18.00	1.43	0.08			
Time	5.00	9046.97	1809.39	14480.30	2.30	***Significant***
Forager x Time	30.00	1003.27	33.44	267.63	1.57	***Significant***
Error b	105.00	13.12	0.12			
Total	167.00	10702.67	64.09			

5.Qualitative parameters

Fruit set (%)

ANOVA Table of first year						
Source of Variance	***Degree of Freedom***	***Sum of Square***	***Mean Sum of Square***	***F Cal***	***F Tab at 5%***	***S/NS***
Replication	3	1.89	0.63	0.64	3.29	***NS***
Treatment	5	1714.41	342.88	346.20	2.90	***Significant***
Error	15	14.86	0.99			
Total	23	1731.16				

ANOVA Table of second year						
Source of Variance	***Degree of Freedom***	***Sum of Square***	***Mean Sum of Square***	***F Cal***	***F Tab at 5%***	***S/NS***
Replication	3	2.14	0.71	0.29	3.29	***NS***
Treatment	5	1741.45	348.29	143.17	2.90	***Significant***
Error	15	36.49	2.43			
Total	23	1780.09				

ANOVA Table of Pooled						
Source of Variance	***Degree of Freedom***	***Sum of Square***	***Mean Sum of Square***	***F Cal***	***F Tab at 5%***	***S/NS***
Years	1	385.56	385.56	225.27	4.17	***Significant***
Replication	6	4.03	0.67	0.39	2.42	***NS***
Treatment	10	3455.86	345.59	201.91	2.16	***Significant***
Error	30	51.35	1.71			
Total	47	3896.81				

Healthy fruit %

ANOVA Table of first year						
Source of Variance	***Degree of Freedom***	***Sum of Square***	***Mean Sum of Square***	***F Cal***	***F Tab at 5%***	***S/NS***
Replication	3	14.30	4.77	1.57	3.29	***NS***
Treatment	5	417.40	83.48	27.49	2.90	***Significant***
Error	15	45.54	3.04			
Total	23	477.24				

ANOVA Table of second year						
Source of Variance	***Degree of Freedom***	***Sum of Square***	***Mean Sum of Square***	***F Cal***	***F Tab at 5%***	***S/NS***
Replication	3	30.89	10.30	3.57	3.29	***Significant***
Treatment	5	173.58	34.72	12.04	2.90	***Significant***
Error	15	43.26	2.88			
Total	23	247.73				

ANOVA Table of Pooled						
Source of Variance	***Degree of Freedom***	***Sum of Square***	***Mean Sum of Square***	***F Cal***	***F Tab at 5%***	***S/NS***
Years	1	276.11	276.11	93.27	4.17	***Significant***
Replication	6	45.18	7.53	2.54	2.42	***Significant***
Treatment	10	590.98	59.10	19.96	2.16	***Significant***
Error	30	88.81	2.96			
Total	47	1001.07				

Crooked fruit (%)

ANOVA Table of first year						
Source of Variance	***Degree of Freedom***	***Sum of Square***	***Mean Sum of Square***	***F Cal***	***F Tab at 5%***	***S/NS***
Replication	3	0.28	0.09	0.60	3.29	***NS***
Treatment	5	417.97	83.59	533.64	2.90	***Significant***
Error	15	2.35	0.16			
Total	23	420.61				

ANOVA Table of second year						
Source of Variance	***Degree of Freedom***	***Sum of Square***	***Mean Sum of Square***	***F Cal***	***F Tab at 5%***	***S/NS***
Replication	3	0.08	0.03	0.28	3.29	***NS***
Treatment	5	173.52	34.70	351.99	2.90	***Significant***
Error	15	1.48	0.10			
Total	23	175.09				

ANOVA Table of Pooled						
Source of Variance	***Degree of Freedom***	***Sum of Square***	***Mean Sum of Square***	***F Cal***	***F Tab at 5%***	***S/NS***
Years	1	276.37	276.37	2165.50	4.17	***Significant***
Replication	6	0.36	0.06	0.47	2.42	***NS***
Treatment	10	591.50	59.15	463.47	2.16	***Significant***
Error	30	3.83	0.13			
Total	47	872.06				

Fruit length (cm)

ANOVA Table of first year						
Source of Variance	***Degree of Freedom***	***Sum of Square***	***Mean Sum of Square***	***F Cal***	***F Tab at 5%***	***S/NS***
Replication	3	1.00	0.33	0.84	3.29	***NS***
Treatment	5	92.59	18.52	46.47	2.90	***Significant***
Error	15	5.98	0.40			
Total	23	99.57				

ANOVA Table of second year						
Source of Variance	***Degree of Freedom***	***Sum of Square***	***Mean Sum of Square***	***F Cal***	***F Tab at 5%***	***S/NS***
Replication	3	0.25	0.08	0.42	3.29	***NS***
Treatment	5	78.23	15.65	79.39	2.90	***Significant***
Error	15	2.96	0.20			
Total	23	81.44				

ANOVA Table of Pooled						
Source of Variance	***Degree of Freedom***	***Sum of Square***	***Mean Sum of Square***	***F Cal***	***F Tab at 5%***	***S/NS***
Years	1	64.30	64.30	215.94	4.17	***Significant***
Replication	6	1.25	0.21	0.70	2.42	***NS***
Treatment	10	170.83	17.08	57.37	2.16	***Significant***
Error	30	8.93	0.30			
Total	47	245.31				

Fruit diameter (cm)

ANOVA Table of first year						
Source of Variance	***Degree of Freedom***	***Sum of Square***	***Mean Sum of Square***	***F Cal***	***F Tab at 5%***	***S/NS***
Replication	3	3.74	1.25	1.30	3.29	***NS***
Treatment	5	211.97	42.39	44.34	2.90	***Significan t***
Error	15	14.34	0.96			
Total	23	230.06				

ANOVA Table of second year						
Source of Variance	***Degree of Freedom***	***Sum of Square***	***Mean Sum of Square***	***F Cal***	***F Tab at 5%***	***S/NS***
Replication	3	1.14	0.38	1.19	3.29	***NS***
Treatment	5	219.07	43.81	137.84	2.90	***Significant***
Error	15	4.77	0.32			
Total	23	224.98				

ANOVA Table of Pooled						
Source of Variance	***Degree of Freedom***	***Sum of Square***	***Mean Sum of Square***	***F Cal***	***F Tab at 5%***	***S/NS***
Years	1	82.91	82.91	130.15	4.17	***Significant***
Replication	6	4.88	0.81	1.28	2.42	***NS***
Treatment	10	431.04	43.10	67.67	2.16	***Significant***
Error	30	19.11	0.64			
Total	47	537.94				

Fruit weight (Kg)

ANOVA Table of first year						
Source of Variance	***Degree of Freedom***	***Sum of Square***	***Mean Sum of Square***	***F Cal***	***F Tab at 5%***	***S/NS***
Replication	3	0.00	0.00	0.53	3.29	***NS***
Treatment	5	0.78	0.16	151.20	2.90	***Significan t***
Error	15	0.02	0.00			
Total	23	0.79				

ANOVA Table of second year						
Source of Variance	***Degree of Freedom***	***Sum of Square***	***Mean Sum of Square***	***F Cal***	***F Tab at 5%***	***S/NS***
Replication	3	0.00	0.00	0.10	3.29	***NS***
Treatment	5	1.22	0.24	97.30	2.90	***Significant***
Error	15	0.04	0.00			
Total	23	1.26				

ANOVA Table of Pooled						
Source of Variance	***Degree of Freedom***	***Sum of Square***	***Mean Sum of Square***	***F Cal***	***F Tab at 5%***	***S/NS***
Years	1	1.43	1.43	809.92	4.17	***Significant***
Replication	6	0.00	0.00	0.22	2.42	***NS***
Treatment	10	2.00	0.20	112.92	2.16	***Significant***
Error	30	0.05	0.00			
Total	47	3.49				

Number of seeds / fruits

ANOVA Table of first year						
Source of Variance	***Degree of Freedom***	***Sum of Square***	***Mean Sum of Square***	***F Cal***	***F Tab at 5%***	***S/NS***
Replication	3	40.09	13.36	1.09	3.29	***NS***
Treatment	5	6625.15	1325.03	108.14	2.90	***Significant***
Error	15	183.80	12.25			
Total	23	6849.04				

ANOVA Table of second year						
Source of Variance	***Degree of Freedom***	***Sum of Square***	***Mean Sum of Square***	***F Cal***	***F Tab at 5%***	***S/NS***
Replication	3	11.33	3.78	0.31	3.29	***NS***
Treatment	5	11030.19	2206.04	180.67	2.90	***Significant***
Error	15	183.15	12.21			
Total	23	11224.67				

ANOVA Table of Pooled						
Source of Variance	***Degree of Freedom***	***Sum of Square***	***Mean Sum of Square***	***F Cal***	***F Tab at 5%***	***S/NS***
Years	1	12443.47	12443.47	1017.31	4.17	***Significant***
Replication	6	51.42	8.57	0.70	2.42	***NS***
Treatment	10	17655.34	1765.53	144.34	2.16	***Significant***
Error	30	366.95	12.23			
Total	47	30517.18				

Weight of 100 seeds (g)

ANOVA Table of first year						
Source of Variance	***Degree of Freedom***	***Sum of Square***	***Mean Sum of Square***	***F Cal***	***F Tab at 5%***	***S/NS***
Replication	3	0.29	0.10	1.15	3.29	***NS***
Treatment	5	23.34	4.67	54.61	2.90	***Significant***
Error	15	1.28	0.09			
Total	23	24.91				

ANOVA Table of second year						
Source of Variance	***Degree of Freedom***	***Sum of Square***	***Mean Sum of Square***	***F Cal***	***F Tab at 5%***	***S/NS***
Replication	3	0.13	0.04	0.43	3.29	***NS***
Treatment	5	11.51	2.30	22.52	2.90	***Significant***
Error	15	1.53	0.10			
Total	23	13.17				

ANOVA Table of Pooled						
Source of Variance	***Degree of Freedom***	***Sum of Square***	***Mean Sum of Square***	***F Cal***	***F Tab at 5%***	***S/NS***
Years	1	0.31	0.31	3.36	4.17	***NS***
Replication	6	0.43	0.07	0.76	2.42	***NS***
Treatment	10	34.85	3.48	37.14	2.16	***Significant***
Error	30	2.81	0.09			
Total	47	38.40				