

**“Studies on the impact of Bee Pollination on
yield parameters of Mustard (*Brassica juncea*
L.)”**



THESIS

submitted to the

Rajmata Vijayaraje Scindia Krishi Vishwa Vidyalaya

In partial fulfilment of the requirements for the Degree of

MASTER OF SCIENCE

In

AGRICULTURE

ENTOMOLOGY

by

MAHIPAL BIJARNIYA

Department of Entomology

Rajmata Vijayaraje Scindia Krishi Vishwa Vidyalaya

College of Agriculture, Gwalior (M.P.)

2022

CERTIFICATE - I

*This is to certify that the thesis entitled, “**Studies on the impact of Bee Pollination on yield parameters of Mustard (Brassica juncea L.)**” submitted in partial fulfilment of the requirements for the Degree of **MASTER OF SCIENCE** in **Agriculture Entomology** of **Rajmata Vijayaraje Scindia Krishi Vishwa Vidyalaya, Gwalior**, is a record of the bona-fide research work carried out by **Mr. MAHIPAL BIJARNIYA, ID: 20111907** under my guidance and supervision. The subject of the thesis has been approved by the student’s Advisory Committee and the Director of Instruction.*

No part of the thesis has been submitted for any other degree or diploma or has been published. All the assistance and help received during the course of this investigations has been acknowledged by the scholar.

Place: (Dr. Ashok Singh Yadav)
Date: Chairman of the Advisory
Committee

MEMBER OF STUDENT’S ADVISORY COMMITTEE

Chairman	(Dr. Ashok Singh Yadav)
Member	(Dr. M.L. Sharma)
Member	(Dr. Jagendra Singh)
Member	(Dr. V.B. Singh)

CERTIFICATE – II



Aadhar Card No. – 9579 2196 9887

I.D. No.- 20111907

*This is to certify that thesis the entitled “**Studies on the impact of Bee Pollination on yield parameters of Mustard (*Brassica juncea* L.)**” submitted by **Mr. MAHIPAL BIJARNIYA** to the **Rajmata Vijayaraje Scindia Krishi Vishwa Vidyalaya, Gwalior** in partial fulfilment of the requirements for the degree of **MASTER OF SCIENCE in AGRICULTURE** in the department of **Entomology**, College of Agriculture, Gwalior has been accepted after evaluation by the External Examiner and approved by the Student’s Advisory Committee after an oral examination of the same.*

Place: (Dr. Ashok Singh Yadav)
Date: Chairman of the Advisory
Committee

MEMBERS OF STUDENT’S ADVISORY COMMITTEE

Chairman (Dr. Ashok Singh Yadav)

Member (Dr. M.L. Sharma)

Member (Dr. Jagendra Singh)

Member (Dr. V.B. Singh)

Head of the Department

Dean of the College

Director Instruction

ACKNOWLEDGEMENT

It is my great privilege and immense pleasure in availing this golden opportunity to express my deepest sense of gratitude and humble indebtedness towards my respected chairperson **Dr. Ashok Singh Yadav**, Scientist selection grade Entomology, Krishi Vigyan Kendra, Morena (M.P.), for his kind and valuable guidance, intellectual inspiration, constant encouragement, and parental affection with cheerful smiling gestures.

I equally and ineffably cheered to place on record my obligation and gratitude to members of my Advisory Committee **Dr. M.L. Sharma** Professor, Department of Entomology, College of Agriculture, Gwalior, **Dr. V.B. Singh** (Professor and Head) Department of Statistics and Computer Applications, College of Agriculture, Gwalior and **Dr. Jagendra Singh**, Scientist, Zonal Agriculture Research Station, Morena whose keen and continued interest, encouragement-inspiring help in carrying out the work required for my research work.

I feel great pleasure to express my heartfelt thanks to Professor **Dr. S.K. Rao**, Hon'ble V.C. RVSKVV, Gwalior for providing necessary facilities for conducting research work. I would also like to thank **Dr. S.P.S. Tomar**, Director Instructions & SW, RVSKVV, Gwalior, **Dr. S.S. Tomar**, Dean, College of Agriculture, Gwalior, **Dr. U.C. Singh**, Professor & Head of the Department of Entomology, College of Agriculture, Gwalior, **Dr. Bharat Singh**, Associate Director Research, Zonal Agriculture Research Station, Morena and **Dr. R.P.S. Tomar**, Senior scientist and Head, Krishi Vigyan Kendra, Morena for providing necessary facilities during the course of investigation.

I owe my sincere thanks to all my teachers; **Dr. N.S. Bhadauria**, Professor, Department of Entomology, **Dr. S. P. S. Tomar**, Scientist, KVK, Gwalior and **Dr. P.D. Singh**, Scientist, DES, RVSKVV, Gwalior for their infinite favor with which they encouraged me during the period of my work.

I express my sincere and special thanks to **Mr. Deepak Kushwaha**, **Mr. Munesh Parihar** and my seniors **Mr. Ramswaroop Banna**, **Mr. Shankar Lal Yadav**, **Mr. Naveen Jangir**, **Mr. Rakesh Yadav**, **Mr. Ramesh Kantwa**, **Mr. Indra Raj Yadav**, **Mr. Prince**, **Mr. Pawan** and **Mr. Nilesh** for the help rendered during the time of this investigation. My appreciation and thanks goes to my colleagues and friends **Kamlesh Kumawat**, **Rahul Meena**, **Ashok Singh**, **Sri Krishan Yadav**, **Parveen**, **Gauri Saran**, **Ekta**, **Mohit**, **Milan**, **Omprakash**, **Lokendra**, **Babulal**, **Ramawatar** and my juniors **Devesh**, **Dhanraj**, **Naveen**, **Mukesh**, **Deepak**, **Ashish** and **Surendra**.

Words fail me to express my gratitude from the deepest core of my heart to my grandfather **Shri Pusa Ram Bijarniya**, my parents **Shri Bhanwara Ram** and **Smt. Bhanwari Devi** who always inspired me to work hard and my brothers **Mr. Mukesh**, **Mr. Mahendra**, **Mr. Sourabh**, **Mr. Aaditya** and my sisters **Ms. Manju** and **Ms. Sanju** whose selfless love, constant encouragement, sincere prayer, expectation and blessing have made this task a success.

Place : Gwalior

Date : / / 2022

(Mahipal Bijarniya)

Contents

Number	Title	Page range
I	Introduction	1-4
II	Reviews of Literatures	5-25
III	Materials and Methods	26-32
IV	Result	33-67
V	Discussion	68-79
VI	Summary, Conclusion and Suggestions for further work	80-90
	Bibliography	91-100
	Appendices	<i>i-v</i>
	Vita	

List of Tables

Table No.	Title	Page No.
3.1	Skeleton of ANOVA	32
4.1	List of insect pollinators' fauna of mustard crop observed and collected during Rabi 2021-22 flowering season.	35
4.2	Group-wise per cent dominance of insect pollinators' fauna of mustard crop observed during Rabi 2021-22 flowering season.	36
4.3	Abundance of <i>Apis mellifera</i> on the flowers of mustard crop under open pollination during Rabi 2021-22.	38
4.4	Abundance of <i>Apis dorsata</i> on the flowers of mustard crop under open pollination during Rabi 2021-22.	39
4.5	Abundance of <i>Apis cerana indica</i> on the flowers of mustard crop under open pollination during Rabi 2021-22.	40
4.6	Comparative abundance of different honey bee species on the flowers of mustard crop under open pollination during Rabi 2021-22.	41
4.7	Foraging speed of <i>Apis mellifera</i> on the flowers of mustard crop under open pollination during Rabi 2021-22.	42
4.8	Foraging speed of <i>Apis dorsata</i> on the flowers of mustard crop under open pollination during Rabi 2021-22.	43
4.9	Foraging speed of <i>Apis cerana indica</i> on the flowers of mustard crop under open pollination during Rabi 2021-22.	44
4.10	Comparative foraging speed of different honey bee species on the flowers of mustard crop under open pollination during Rabi 2021-22.	45
4.11	Foraging rate of <i>Apis mellifera</i> on the flowers of mustard crop under open pollination during Rabi 2021-22.	46
4.12	Foraging rate of <i>Apis dorsata</i> on the flowers of mustard crop under open pollination during Rabi 2021-22.	47
4.13	Foraging rate of <i>Apis cerana indica</i> on the flowers of mustard crop under open pollination during Rabi 2021-22.	48
4.14	Comparative foraging rate of different honey bee species on the flowers of mustard crop under open pollination during Rabi 2021-22.	49
4.15	Effectiveness of different bee attractants in 1st spray to attract the <i>Apis mellifera</i> L. in mustard crop during Rabi 2021-22.	51
4.16	Effectiveness of different bee attractants in 2nd spray to attract the <i>Apis mellifera</i> L. in mustard crop during Rabi 2021-22.	54
4.17	Effectiveness of different bee attractants in 3rd spray to attract the <i>Apis mellifera</i> L. in mustard crop during Rabi 2021-22.	58
4.18	Effect of bee pollination on quality and quantity parameters of mustard crop during Rabi 2021-22.	66

List of Figures

Figure No.	Title	Between Pages
4.1	Dominance of insect pollinators' fauna of mustard crop observed during Rabi 2021-22 flowering season.	36
4.2	Graph showing the effectiveness of different bee attractants in 1st spray to attract the <i>Apis mellifera</i> L. in mustard crop during Rabi 2021-22.	52
4.3	Graph showing the effectiveness of different bee attractants in 2nd spray to attract the <i>Apis mellifera</i> L. in mustard crop during Rabi 2021-22.	55
4.4	Graph showing the effectiveness of different bee attractants in 3rd spray to attract the <i>Apis mellifera</i> L. in mustard crop during Rabi 2021-22.	59
4.5	Graph showing the effect of bee pollination on quality and quantity parameters of mustard crop during Rabi 2021-22.	67

List of Plates

Plate No.	Title	Between Pages
3.1	(A) Setting of cage net for bee pollination, (B) Spray of bee attractants, (C) Observing the insect pollinators by using sweep net method and (D) Taking observations of foraging activities of bee species.	32-33

List of Abbreviations and Symbols

Symbol	Abbreviation	Stand for
@		At the rate of
%		Per cent
±		Plus or minus
°C		Degree centigrade
	CV	Coefficient of variation
	CD	Critical difference
	d.f.	Degrees of freedom
	<i>et al.</i>	Co- workers
	Fig.	Figure
	RH	Relative Humidity
	NS	Non-significant
	spp.	species
	<i>viz.</i>	For instance
	<i>i.e.</i>	That is
	Etc.	Et Cetera
	kg.	kilogram
	gm	gram
	cm	centimetre
	mg	Milligram
	hrs.	hours
	q	quintal
	r	Correlation coefficient
	m ²	Square meter



*DEDICATED TO MY
LOVABLE PARENTS*

Chapter I

INTRODUCTION

Brassica juncea (L.) Czern & Coss., also known by the name of Indian mustard, commonly referred to as *sarson* or *rai* (Hindi), *mohari* (Marathi) and *sasive* (Kannada) is the oldest cultivated dicotyledonous angiosperm plant belonging to Brassicaceae or Cruciferae family which is generally pollinated by insects (Bhowmik *et al.*, 2014). *B. rapa*, *B. napus*, *B. carinata*, and *Eruca sativa* are four closely related cultivated oilseed species that are frequently referred to as Rapeseed-mustard in the trade related matters. Over the past couple of decades, the mustard crop has become one of the integral parts of the human diet with oil content ranging from 32 to 40% and protein content ranging from 15 to 17% (Dash *et al.* 2019). Continuous improvement in rapeseed mustard has resulted in nutritionally superior edible oil, and meal as an important source of protein in animal feed. Fats and oils, being the sources of essential fatty acids, are used to synthesize phospholipids, which are important components of active tissues *viz.*, brain, nerve, and liver of human beings and other animals. These crops are grown under a wide range of agro-climatic conditions. Indian mustard is the most important member of this group, accounting for more than 70% of the area under rapeseed-mustard, followed by toria, yellow sarson and brown sarson (Bhowmik *et al.*, 2014). The mustard seed contains 8.5 % moisture, 20 g protein, 23.8 g carbohydrates, 39.7g fat, 1.8 g fibre, 490 mg calcium, 700 mg phosphorous, 7.9 mg iron, 541 Kcal energy value per 100 g. edible portion. Mustard is a rich source of Calcium, manganese, copper, iron, selenium and zinc are some of the minerals especially concentrated in these seeds. Saturated fatty acids (SFAs) include palmitic acid, whereas unsaturated fatty acids (MUFAs) include erucic acid and oleic acid, as well as polyunsaturated fatty acids (PUFAs) like omega-3 alpha-linolenic acid and omega-6 linoleic acid, which are both nutritionally significant. The nutritional quality of edible oils is determined by the presence or absence of certain fatty acids (Bhattacharya *et al.*, 2012). Mustard seeds contain flavonoid, and carotenoid antioxidants such as carotenes, zeaxanthin, and lutein.

Mustard has taken on a significant role in the national economy, ranking second in terms of acreage behind groundnut. With a volume of 68.87 million tonnes, it is the world's second-largest oilseed crop (Anonymous, 2021). Mustard crops are commercially cultivated in more than 60 countries and major producers include China, Canada, India, Australia, France, Germany, United Kingdom, Poland, Ukraine, Russia, the USA and the Czech Republic (Anonymous 2018). In India mustard is grown at an area of 66.99 Mha, with an output of 102.10 million tonnes and productivity of 1524 kg/ha. In India, it is cultivated predominantly in Rajasthan, Haryana, Madhya Pradesh, Uttar Pradesh, West Bengal, Gujarat, Assam, Punjab and Maharashtra (Anonymous, 2021). Rajasthan is the leading producer of mustard contributing 27.16 mha area and 45.50 million tonnes production. Haryana holds the second position (13.13 million tonnes) in mustard production and Madhya Pradesh at the third position (13.07 million tonnes). (Anonymous 2021).

In several cross-pollinated crops, external bioagents are required to accomplish this process and pollination in these crops. Honeybees is considered one of the effective, cheapest and eco-friendly input methods for triggering the crop yield both qualitatively and quantitatively. It has been reported that there are more than 25000 described species of bees in the world and account for 65% of the pollination of various flowering crops. Mustard is an often-cross-pollinated and in fact self pollinated crop, adequate pollination is vital for the significant increase in seed production. *Brassica* plants are considered to be very attractive to insect pollinators, and they primarily serve as a source of nectar and pollen. Because of its bilateral, bright yellow flowers, the mustard flower attracts a wide range of insect species, especially pollen and nectar-feeders. The mustard flower's bowl shape makes it an ideal landing spot for insect pollinators, especially honey bees (Roubik, 1989). Bee pollination not only results in increasing the yield but also improves the quality. It ensures uniform maturity and early harvest of the crop (Anil, 2015).

A total of 19 insect visitors belonging to the order Hymenoptera (15) and Diptera (4) were found to visit the mustard blossoms. Hymenopterans were the most abundant, followed by Dipterans and other insects. Goswami

and Khan (2014) reported that honeybees were the most reliable pollinators among Hymenopterans, followed by non-*Apis* bees and scolid wasps. The mustard bloom was visited by 88 insects from 63 species belonging to 31 families and 9 orders. Order Hymenoptera formed a higher percentage of the insect visitors in scan sampling. *Apis cerana* and *A. mellifera* abundance were higher by scan sampling methods (Devi *et al.*, 2017). A total of 30 species belonging to four orders, Hymenoptera (23), Diptera (5), Lepidoptera (1) and Coleoptera (1) visited mustard flowers (Kunjwal *et al.*, 2014). However, there have been few research in India on the usage of bee attractants. (Patil *et al.* 2010). Local bee attractants, such as pomegranate juice, sugar solution, honey solution, sugarcane juice, jaggery solution, and onion solution, are commonly utilised in India to boost crop output. The low average yield of mustard is due to the cultivation of traditional varieties, non-availability of seeds of high yielding varieties and delayed sowing (Alam *et al.*, 2014). Although such decline could be attributed to insect pests, disease damage, poor soil fertility or water stress, also there is evidence that insufficient pollination can also significantly minimize the crop yield (Free, 1999). Sushil *et al.* (2013) reported that low seed yield due to inadequate pollination is often faced as a major problem in *Brassica* seed production. Inadequate pollination is caused by several factors and the most important of which include the lack of adequate number and diversity of pollinators. Mahadik, (2019) studied various indigenous food attractants and revealed that honey solution at 5 per cent attracted the maximum number of bees followed by jaggery solution at 10 per cent and molasses at 10 per cent.

Besides contributing to the conservation of natural ecosystems, bee pollination is one of the main alternatives for the improvement of crop productivity (Westcott and Nelson, 2001; D'Avila and Marchini, 2005). The yield of rapeseed and canola can be increased by several per cent through pollination by insects (Manning and Wallis 2005; Sabbahi *et al.*, 2005, 2006). Insect pollinations increased the number of pods, seeds per pod, seed weights per plant, and seed germination (Atmowidi *et al.*, 2007). Goswami and Khan, (2014) the influence of diverse pollination modes revealed that open-pollinated plots had the highest percent pod set (83.42%) and bee-pollinated plots (75.41%), and caged pollinated plots (62.80%). The highest

yield (994.3 kg/ha) was obtained from insect managed pollination treatment followed by open (759.7 kg/ha) and caged conditions (272.3 kg/ha). Insect pollination revealed a higher percentage of germination, 100-seed weight, per cent oil and protein content (Mandal *et al.*, 2018).

Thus, there is a need to ensure pollination by conserving the pollinators and attracting them to the cropland. Pollination by insects is inevitable for *Brassica* since they are generally incompatible (Sihag, 2001) and the pollen is heavier and sticky, which is unable to be easily windborne. So, going through all the facts and information discussed above, this study was aimed to determine the diversity of insect pollinators, pollination behaviour of *Apis mellifera* L. and also to infer the effect of pollination on the yield parameters of seed production, hence the study was undertaken with the following objectives:-

1. To study the pollinators fauna of mustard.
2. To study the foraging behaviour of honey bees in mustard crop.
3. To study the different bee attractant for attract the *Apis mellifera* in mustard.
4. Impact of bee pollination on quality and quantity parameters of mustard.

Chapter II

REVIEW OF LITERATURE

A successful crop production greatly depends on the efficient pollination in the flowers. This results in the higher economic and biological yield. An efficient pollination in different crops, vegetables and fruits by different pollinators plays role in increasing nutrition and aids in fruit setting. Several studies have been conducted earlier related to all these aspects of role of pollination in crops due to insects, i.e. entomophily. The available literature on the pollinators' fauna, foraging behaviour of honey bees, effect of bee attractants to attract the bees and the effect of bee pollination on quality and quantity of mustard is reviewed in this chapter under the following heads:

2.1 To study the pollinators fauna of mustard.

2.2 To study the foraging behaviour of honey bees in mustard crop.

2.3 To study the different bee attractant for attract the *Apis mellifera* in mustard.

2.4 Impact of bee pollination on quality and quantity parameters of mustard.

2.1 To study the pollinators fauna of mustard.

Sinha *et al.* (1994) recorded that mustard flowers were visited by many insect pollinators. Of these, honey bees namely *A. dorsata*, *A. cerana indica* and *A. florea* together constituted 49 per cent and Dipteran constituted 49.5 per cent and other pollinators such as solitary bees and Lepidopterans were less than 1 per cent.

Abrol and Kapil (1996) reported that oilseed crops were visited by 13 species of bees belonging to 5 families. Among the various pollinating insects, *A. florea* and *A. dorsata* were the most efficient pollinators of all the crops. They constituted more than 80 per cent and 98 per cent cruciferous crops and more than 70 per cent in case of sun flower. Other bee pollinators were present few in number at interrupted hours.

Mahindru *et al.* (1998) reported that *A. dorsata*, *A. mellifera*, *A. florea* and *Andrena* sp. constituted 51.43, 23.77, 20.00 and 4.80 per cent, respectively of total bees on *B. juncea* at Ludhiana.

Chaudhary (2001) reported insects belonging to Apidae (98.50% of total insects) as the major visitors of *B. juncea*. Among Apidae, the social honey bees constituted 59.50 per cent. The little bee, *A. florea* was the most abundant (42.80%) followed by rock bee, *A. dorsata* (16.60%). Solitary bees constituted 39 per cent of total visitors.

Virakamath *et al.* (2002) observed 29 species on oilseed crop out of which 15 species belonged to hymenoptera, 8 to diptera and 6 to Lepidoptera constituting 51.7, 27.59 and 20.69 per cent, respectively. However, when individual oilseed crop was considered, hymenoptera constituted more than 80 per cent. Honey bee collectively formed the most predominant group of pollinators as high as 97.87, 96.70, 97.58 and 88.21 per cent on sun flower, sesamum, mustard and niger, respectively. *A. mellifera* was the next predominant pollinator on sunflower, sesamum and niger, respectively. Other pollinators remained 2.13, 3.30 and 11.25 per cent on these crop respectively.

Pandey and Tripathi (2003) reported that *A. cerana indica* had the highest foraging intensity followed by *A. dorsata*, *A. mellifera* and *A. florea* (3.2, 3.1, 2.4 and 2.0 bees/bunch of mustard flowers/5 min. respectively) on *B. juncea*.

Ahmad (2005) reported 22 and 16 Hymenopterans and 7 and 5 Dipteran species visiting mustard flowers in Diriyah and Derab (Saudi Arabia), respectively. They observed honey bees as the dominant Hymenopteran pollinators followed by other bees such as *Andrena*, *Hexachysis*, *Halictus*, *Osmia*, *Pompilus* and *Dieles* and wasps.

Atmowidi *et al.* (2007) reported that a total number of 5,955 pollinator insects associated with *B. rapa* were observed. They were belonged to 19 species and 4 orders (Hymenoptera, Lepidoptera, Coleoptera, and Diptera, for 95, 2.17, 2.07, and 1%, respectively). Three species of flower-visiting insects showed a high abundance i.e. *A. cerana* (43.1%), *Ceratina* sp. (37%), and *A. dorsata* (8.4%). Additionally, six species of Lepidoptera (*Nyctemera* sp., *Parnara guttata*, *Eurema hecabe*, *Potanthus* sp., *Jamides virgulatus*, and *Neptis hylas*), and one species of Coleoptera (*Papilia biguttata*) and Diptera (*Shyrphus balteatus*) visited mustard flowers, but they all accounted for less than 3% of the total number of observed pollinators.

Kumar and Jaiswal (2012) reported that, over all the insect visitors followed by *Apis florea* (6.11, 5.42), *Apis dorsata* (5.72, 5.21), *Apis cerana indica* (5.10, 4.70) and the lowest (3.13, 3.00) in other insects during 2005-06 and 2006-07.

Bendifallah *et al.* (2013) reported that, the insect fauna visiting crop flowers includes Diptera (Syrphidae), Coleoptera, and Hymenoptera such as Chrysididae, Vespoidea, and Apoidea (Bees). The latter super-family comprises the majority of insect pollinator. *Andrena cinerea elliptica* having 100% pollinating visits while *Apis mellifera* has only 63%.

Goswami and Khan (2014) concluded that a total of 19 insect visitors belonging to order Hymenoptera (15) and Diptera (4), were found to visit the mustard blossoms at Pantnagar. Hymenopteran visitors belonged to six families namely Apidae (6), Scollidae (3), Xylocopidae (1), Halictidae (2), Magachilidae (1), Anthophoridae (1) and Sphecidae (1). Lepidopteran visitors belonged to families Pieridae (1). Besides this some Dipteran visitor belonged to families these were Syrphidae (3) and Muscidae (1) were observed on mustard flowers.

Bhowmik *et al.* (2014) observed 19 insect species belonging to 13 families under 4 orders *viz.* Hymenoptera, Coleoptera, Diptera and Lepidoptera on *B. juncea* among which 4 species (*A. dorsata*, *A. cerana*, *A. mellifera* and *Vespa* sp.) were both pollen and nectar collectors, 14 species were only nectar collectors and rest of them were just, visitors. Abundance of Hymenoptera was observed to be maximum (52.74%) followed by Coleoptera (25.45%), Diptera (11.66%) and Lepidoptera (10.13%). Out of the three honey bee species the abundance of *A. mellifera* was maximum (18%) followed by *A. dorsata* (16%) and *A. cerana indica* (14%) whereas with *Vespa* sp. the abundance percentage was reported to be only 5 per cent.

Kunjwal *et al.* (2014) reported at Pantnagar, Uttarakhand, India on the flower visiting insects pollinators of brown mustard, *Brassica juncea* L. found that honey bees are the primary pollinators. A total of 30 species belonging to four orders, Hymenoptera (23), Diptera (5), Lepidoptera (1) and Coleoptera (1) visited mustard flowers. Hymenopteran visitors belonged to six families namely Apidae (5), Andrenidae (1), Anthophoridae (3), Megachilidae (4), Halictidae (4) and Xylocopidae (6).

Roy *et al.* (2014) reported that 24 insect species belonging to 14 families under six orders were found at the day time in mustard blooms among which four species (*Apis dorsata*, *Apis cerana*, *Apis florea*, *Vespa sp.*) are pollen and nectar collectors (Pollinators), 13 insects were only nectar collector and rest species were only visitors. Number of species of order Lepidoptera and Hymenoptera were high at day time. But the abundance of Hymenoptera was observed maximum followed by Coleoptera and Lepidoptera during this study.

Maity *et al.* (2014) reported that the *Apis* spp. were the dominant pollinators and the maximum abundance of pollinator recorded in the forenoon in male line and in the afternoon in female line. Abundance decrease in row distantly positioned from the male parent row. The temperature was positively correlated and with honeybee foraging warmer weather condition during flowering period showed higher number of honeybee visiting the hybrid seed production plot.

Meena *et al.* (2015) reported that, a large population of insect visits several seed spices and other crops right from initiation of flowering to harvesting of crops for foraging in seed spices. Coriander and fennel normally received 25 and 24 floral visitors, respectively in semi-arid and arid conditions of Rajasthan and honeybees are considered as primary pollinators of all seed spice crops. Among honeybee species, *Apis florea* contributed greatest percentage followed by *A. mellifera* and *A. dorsata* for pollination.

Bajija and Abrol (2017) reported that the mustard bloom was visited by 15 insect species belonging to 4 orders and 7 families. The hymenopterans were the most dominant visitors. Among the hymenopterans species, *A. mellifera* L. was highest in visitors followed by *A. cerana*, *A. dorsata*, *A. florea* and *Xylocopa fenestrata*.

Devi *et al.* (2017) reported that a total of 88 insects belonging to 63 genera under 31 families and 9 orders were found to visit the mustard bloom. Order Hymenoptera formed higher percentage of the insect visitors in scan sampling. *Apis cerana* and *A. mellifera* abundance were higher by scan sampling methods. Relative abundance (by scan sampling) and diversity (by sweep net method), in general, was statistically more at full bloom than at onset and end of bloom. Other dipterans were the dominant insect trapped in

mustard crop by fluorescent pan trap. All the three methods namely fluorescent pan traps, scan sampling and sweep net method are essential for determining pollinator diversity as no single method is fully reliable.

Mandal *et al.* (2018) reported that 8 species of insects were observed in mustard crop at Gazipur, Bangladesh which belonged to 8 different families in 3 orders namely Lepidoptera, Diptera and Hymenoptera were found as pollinator.

Akhtar *et al.* (2018) reported that the 35 insect species belonging to 20 families under 5 orders were recorded on canola (*Brassica napus* L. Var. Chakwal Sarsoon). Among the hymenopterans, abundance of managed *A. mellifera* was maximum (87.76%) followed by *A. florea* (1.11%) and *A. dorsata* (0.98%). Peak activity of the insect visitors was observed at the mid of the day.

Das and Jha (2018) reported that 13 insect visitors belong to order Hymenoptera (comprising of 6 species viz., *A. dorsata*, *A. mellifera*, *A. cerana indica*, *A. florea*, *Ceratina* sp. and *Halictus* sp.), Diptera (comprising of 5 species viz., *Episyrphus* sp., *Eristalinus talabanooides*, *Musca domestica*, *Chrysomya* sp. and *Sarcophaga* sp.) and Lepidoptera (comprising of 2 species viz., *Amata bicincta* and *Pieris* sp.) were visited on the bloom of mustard. The abundance of Hymenopterans was maximum followed by the Dipterans and Lepidoptera. Among the Hymenopterans, the honeybees (*Apis* spp.) were observed maximum. Among the honeybees, the *A. mellifera* was dominant sequentially followed by the *A. cerana indica*, *A. dorsata* and *A. florea*.

Giri *et al.* (2018) reported that the insects of order-Hymenoptera namely; *Apis dorsata*, *Apis mellifera*, *T. iridipennis* were the major floral visitors belonging to family Apidae. The insects among this apidae family, *Apis dorsata* and *A. mellifera* were the most frequent visitors.

Singh *et al.* (2018) found that total of eight insect visitors belonging to three different orders viz., Hymenoptera, Diptera and Coleoptera were visiting on mustard flower. The highest contribution of per cent relative abundance and average insect population were observed in the order Hymenoptera as 84.64% with 22.15 insect visitors/m²/min.

Subedi and Subedi (2019) reported that altogether 16 species of pollinator insects belonging to five orders and nine families were recorded. Hymenoptera (36 %) was the most abundant order visiting mustard flowers followed by Diptera (34 %), Coleoptera (17 %), Lepidoptera (12 %) and Heteroptera (1 %). The most abundant family was Apidae (35.64 %), followed by Syrphidae (31.84 %). *Apis cerana* and *Eristalis* sp. were the most important pollinator insects of mustard.

Shakeel *et al.* (2019) reported that the insect pollinators belong to four orders *i.e.* Hymenoptera, Diptera, Lepidoptera, and Coleoptera. A total of 20 major species of insect pollinators were recorded, the abundant pollinator species belonged to Hymenoptera. The most prominent insect pollinator species were *A. mellifera* followed by *A. cerana*, *A. florea*, and *A. dorsata*, respectively. Among these honeybee species, some species of solitary bees, four species of Syrphid fly and one species of Muscidae family of diptera were also recorded.

Singh and Mall (2020) found that a variety of pollinators frequent the *Brassica campestris* blossoms. Hymenopterans were the most common floral travellers to the Mustard crop. *Apis dorsata* had a mean foraging pace (time spent/flower) of 8.64 to 11.42 seconds during various day periods of the day, whereas *Apis cerana*, *Apis mellifera*, and *Apis florea* had values of 8.57- 9.42, 9.85-13.08 and 11.42-14.64 seconds. *Halictus ligatus* expended the most time (average 20.35 seconds) per flower.

2.2 To study the foraging behaviour of honey bees in mustard crop.

Glibert (1980) reported that foraging speed (time in second spent per flower) and foraging rate (number of flower visited per minute) depends upon the foraging behaviour of insects and the floral structure of the crop concerned.

Tanda (1984) observed that *A. florea* started foraging later and spent more time (5.9-6.4 sec) on *B. juncea* flower as compared to *A. mellifera* (3.0-3.2 sec) and *A. dorsata* (2.2-3.0 sec).

Deshmukh *et al.* (1985) found that on safflowers the time of foraging varied slightly among honey bee species. During collection of pollen 17, 24, and 32 seconds and while foraging for nectar 13, 21 and 33 seconds were

spent on an individual flower head by *A. dorsata*, *A. cerana*, and *A. florea*, respectively *A. dorsata* was an efficient forager and visited a greater number of florets and heads per unit time than the others.

Mishra *et al.* (1988) observed the peak foraging activity of *A. mellifera*, *Eristalis* sp. and other dipterans between 1200 to 1300 h, whereas of *A. cerana indica* and syrphid fly between 1300 to 1400 h on mustard flower at Solan, India.

Arya *et al.* (1994) observed 20 insect species visiting the floral heads of the sunflower of the species observed, *Apis mellifera* (22.8 /30heads) were the most frequent visitors, foraging both for nectar and pollen.

Khatkar (1996) observed that the abundance of *A. dorsata*, *A. mellifera* and *A. florea* was 2.63, 3.20 and 6.50 bees/m²/min on RH-8812 and 1.93, 2.47 and 5.1 bees/m²/min on RH-30 at Hisar, respectively.

Bernard and Vaissiera Frossart (1996) reported that three major pollinators are recorded in bitter gourd and proved that *A. florea* spent less time on flowers. The maximum time spent by *A. florea* was 14.26 second with average foraging time of 9.28 second per flower. This was recorded during the peak foraging hour of all three-bee species. These findings are near with the earlier reports.

Priti (1996) observed that the abundance of *A. mellifera*, *A. dorsata* and *A. florea* on *B. rapa* was 8.89, 3.24 and 1.86 bees/m²/5 min respectively, at Hisar and they comprised 51.78, 18.87 and 10.83 per cent of the total insect population, respectively.

Rana *et al.* (1997) observed that *A. cerana* and *A. mellifera* were found on rapeseed bloom in equal proportion from 1200 to 1500 h. The mean numbers of *A. cerana* foragers were significantly higher than the *A. mellifera* foragers. Peak abundance of all the insect pollinators was observed during mid flowering period at 1200 to 1400 h.

Rana and Kumar (1999) observed that the *A. cerana indica* spent 22.1 per cent more time per day in pollinating cauliflower bloom than *A. mellifera*. Mean number of *A. cerana indica* and *A. mellifera* per inflorescence per hour were 4.75 and 2.06 respectively. Mean duration on each blossom visited by pollen forager, nectar forager and nectar robber of *A. cerana indica* were 5.14,

6.34 and 6.05 seconds, respectively while it was 6.62, 7.37 and 5.26 seconds of *A. mellifera*.

Chandel *et al.* (2000) reported that *A. cerana* started its foraging activity on toria earlier in the morning (at 06:25 h) than *A. mellifera* (at 07:20 h). In the evening *A. mellifera* ceased foraging earlier (at 17:30 h) than *A. cerana* (at 17:40 h). Thus the average duration of foraging in *A. cerana* was 11:18 hours compared to 10:12 hours by *A. mellifera*. The highest number of incoming foragers (90.7 and 247.3 bees/minute of *A. mellifera* and *A. cerana*, respectively) was recorded between 10:00 to 10:30 h at a temperature of 25°C.

Chakravarty (2000) observed that *A. mellifera* initiated work an hour later than *A. cerana indica* in *Brassica napus*. The time of commencement of foraging varied from 08:24 to 09:40 h. The cessation time of foraging of *A. mellifera* was found an hour earlier than *A. cerana indica* in *Brassica napus*. He also observed that the foraging activity of honeybees was highest during 13:00-14:00h (14.89/m/row/5min) followed by 12:00-13:00h, 14:00-15:00h and 11:00-12:00h during which 13.36, 8.75 and 5.83 bees visited the flowers per meter row per five minutes. Peak activity of *A. dorsata* was observed at 12:00 and 16:00 hr. *A. cerana indica* and *A. florea* were active at 10:00 hr, while *A. mellifera* and other pollinators at 12:00 hr.

Kumar *et al.* (2003) reported that the foraging rate in sunflower (number of capitulum visited by bees /minutes) revealed a greater number of capitulum (12.85) were visited by *Apis mellifera* L. (10.98). The foraging rate was maximum at 01:00 pm and minimum at 10:00 am for both the species. The foraging speed (time in seconds spent by a bee per capitulum) revealed that *A. mellifera* spent more time (6.69 seconds / capitulum) revealed that *A. mellifera* spent more time (6.69 seconds /capitulum) compared to *Apis cerana* recorded highest at 2:00 pm and lowest at 10:00 am.

Kumar (2004) reported that foraging rate (no. of flowers visited / 3 min) of *Apis* spp. on different cultivars of *Brassica* revealed that time spent by *Apis* spp was maximum on cultivars of juncea followed by Toria and sarson during both the years. Among the *Apis* spp. *A. dorsata*, spent maximum time on flower followed by *A. mellifera*, *A. cerana indica* and minimum time spent by *A. florea*.

Choudhary and Kumar (2007) who reported that *Apis mellifera* started foraging early at 09:05 hrs, reached the peak from 11:00 to 16:00 hrs and declined drastically thereafter.

Choudhary and Singh (2007) observed that mean foraging rate was higher in *A. mellifera* (5.0) than *A. dorsata* (3.92) and *A. florea*, (2.91). Initially, *A. mellifera* was not observed on coriander flowers till 07:00 h because of low temperature and fog water deposited on the floral parts but its population increased latterly. The maximum foraging rate of *A. mellifera* was recorded at 14:00 h (13.6 umbels visited min⁻¹). Similarly, the average 1 plant and maximum 3.10 plants were visited by this species in each five minutes.

Chambo *et al.* (2011) reported that the foraging behaviour of Africanized *Apis mellifera* L. (Hymenoptera, Apidae) and its efficiency of pollination on seed yield of sunflower genotypes (open pollination and restricted pollination) were evaluated. There were peaks of visits by *A. mellifera* for nectar collection on the 2nd and 3rd flowering days between 7:00h and 8:30h. The average density of *A. mellifera* during increased visitation ranged from 2.27 to 2.94 bees per capitulum. Nectar collecting bees were more frequent (2.28 bees per capitulum) than pollen collecting (0.40 bees per capitulum). On the 3rd flowering day, Helio 360 and Aguará hybrids had higher ($p \leq 0.05$) number of bee visits per flower head than the other genotypes.

Dalio (2012) *Cannabis sativa* is an important source of pollen for *Apis mellifera* during the period of floral scarcity (May and June) when major flora is absent. Foraging of bees on the herb under experiment took place during morning and evening hours, while during rest of the day activity remained totally ceased. All the Foraging bees were pollen gatherers as the plant provides pollen only. Maximum foraging took place during morning, however pollen was also collected thoroughly by specific sweeping activity and scrabbling behaviour during evening hours. Foraging frequency of bees was more during morning as compared to that at evening. Average pollen load observed was 4mg/bee. Abundance, Foraging behaviour and pollen loads indicated that this annual herb is good source of pollen during dearth period in summer.

Silva *et al.* (2013) reported that honeybee (*Apis mellifera*) workers spend more time on the flower during foraging, visit a greater number of flowers, and travel greater distances within patches.

Kunjwal *et al.* (2014) observed that in open pollination, *Trigonala viceps* had maximum average abundance (4.51 bees / m² / 2 minute) and foraging speed (18.55 sec) in Vardhan and EC 399313, respectively whereas *Apis mellifera* showed highest foraging rate (10.68 flowers / min) in EC 399313 as compared to other bees in different varieties. Under caged Pollination, Line EC 399313 was most preferred by *A. mellifera* with maximum abundance (6.24 bees /m² / min), foraging speed (2.33 s) and foraging rate (7.69 flowers / min). It indicated that *A. mellifera* visited all varieties / lines in both open and caged plots. Overall average abundance (4.09 bees / m²/2min) and foraging speed (1.97S) of *A. mellifera* was found maximum under caged pollination while highest foraging rate (8.52 flowers / min) was recorded in open pollination per day.

Goswami and Khan (2014) observed that the diversity and abundance of different insect visitors on mustard (*Brassica juncea*) were studied at Pantnagar. A total of 19 insect visitors belonging to order Hymenoptera and Diptera were found to visit the mustard blossom the abundance (percentage of insect / m²/ 2 min) of Hymenopterans were maximum followed by the dipterans and others. In Hymenopterans, the honeybee (*Apis* bees) were observed maximum followed by non - *Apis* bees and the scolid wasp.

Roy *et al.* (2014) reported that peak activity of the insect visitors was mainly observed at the middle of the day i.e., from 12 noon to 2 P.M. Among the three honey bee species the abundance of *A. dorsata* was maximum (18%) followed by *A. cerana* (15%) and *A. florea* (4%). It was observed that the different weather conditions effect the abundance of honeybees.

Meena *et al.* (2015) reported that the large population of insects visits several seed spices and other crops right from initiation of flowering to harvesting of crops. Among honeybee species, *Apis florea* contributed greatest percentage followed by *A. mellifera* and *A. dorsata* for pollination.

Taha *et al.* (2016) insect pollinators and the foraging behaviour of Carniolan honey bees (*Apis mellifera carnica* Pollmann) and dwarf honey bees (*A. florea* F.) on alfalfa flowers was conducted in May of 2013 and 2014.

In comparison to the *Carniolan bees*, the dwarf bees were more active on alfalfa flowers. Two peaks of foraging activity for the two species were recorded; the first one was at 0800–0900 hrs, while the second and the highest peak was at 17:00–18:00 hrs. Carniolan bees were more active in gathering pollen at 0800–0900 hrs. It is concluded that Carniolan and dwarf honey bees were found to be the most abundant pollinators on alfalfa flowers in Saudi Arabia.

Painkra and Shaw (2016) observed maximum visitation of *Apis cerana* at 1100hrs (66.06 bees/5min/m²). The maximum foraging activity of *Apis dorsata* was observed at 1100 hrs. (11.75 bees/5min/m²) whereas, the lowest was observed at 1700 hrs. (0.50 bee/5min/m²). The higher foraging activity of *Apis florea* was noticed at 1300 hrs. (4.00 bees/5min/m²) and was found least at 0900hrs (0.56 bee/5min/m²).

Manhare *et al.* (2017) reported that the activity of *Apis cerana indica* was found higher in third week of December 2016 (69.71 bees/5min/m²). Its maximum visitation was found at 1200 hrs (98.62 bees/5min/m²). The maximum foraging activity of *Apis dorsata* was found at 1200 hrs (61.12 bees/5min/m²). Whereas, the lowest was observed at 1700hrs (1.25 bees/5 min/m²) in *Apis cerana indica* and *Apis dorsata* the lowest was observed at 1700hrs (0.75 bees/5 min/m²). The foraging activity of *Apis florea* was noticed at 1400hrs (3.25 bees/5min/m²) and was found least at 0800hrs (0.57 bees/5min/m²).

Singh and Thakur (2017) reported that the foraging initiation, foraging cessation and foraging duration in a day of the pollinators accomplished to determine the arduous pollinators. The longest foraging duration/ day and latest foraging cessation of *Haematobia irritans* Linnaeus was observed while *Apis cerana* Fab. initiated earliest foraging. Among pollinators of guava, *Apis* spp., *H. irritans* and *Lucilia sericata* Meigen were the most arduous pollinators.

Giri *et al.* (2018) reported that abundance of insect pollinators was found maximum in afternoon (3.00-4.00 PM) with 31.56 pollinators /plant/5 min. The higher number of floral visitors in the evening can be attributed of favourable meteorological parameters of afternoon. However, *A. dorsata*

showed its maximum visit on flowers in afternoon with respect to other pollinators.

Singh (2018) studied that the foraging initiation, cessation and duration/day of the pollinators were studied. The longest foraging duration/day and latest foraging cessation was of *Megachile lanata* Fabricius, and the least values for these were observed with *Xylocopa tenuiscapa* Westwood. Among pollinators of pigeon pea, *M. lanata* was the most arduous one.

Singh *et al.* (2018) reported highest contribution of per cent relative abundance and average insect population in the order Hymenoptera and higher activities of honeybees were recorded during 1200h and 1500h, respectively.

Subedi and Subedi (2019) reported that seven species were found foraging both on pollen and nectar, four species foraging only on nectar and remaining five as casual visitors and peak foraging activities of majority of the insects between 1200 h to 1400 h.

Nagpal *et al.* (2020) revealed that *Apis florea* had the longest average time spent per flower (6.08 sec), followed by *Apis dorsata* (3.41 sec), *Apis mellifera* (2.60 sec), and *Apis cerana indica* (2.33 sec). The average time spent per flower of various *Apis* spp. over various day periods varied from 3.25 to 4.20 seconds. *Apis mellifera*, *Apis dorsata*, and *Apis cerana indica* spent the least amount of time per flower (2.02 seconds, 2.38 seconds and 2.97 seconds, respectively) at 1200-1400 h, but *Apis florea* lowest amount of time spent per flower was (4.23 sec) at 0800- 1000 h on *Brassica juncea*.

2.3 To study the different bee attractant for attract the *Apis mellifera* in mustard.

Allsop and Cherry (1991) reported that study on attraction of *A. mellifera* to volatile compounds proved that anetholes and commercial trace Japanese beetle lure (10:22:11, 2-phenyl ethyl propionate : eugenol : geraniol) exposed in trace traps which attracted *A. mellifera*, but other floral lures and fatty acids did not attract the bees.

Ahmad (1992) recorded that the best results from with European bees (*A. mellifera*) in sealed polyethylene tunnels which yielded 0.97 kg export

grade fruits per plants compared to sealed polyethylene tunnels open at one end which gave 0.56 kg/plant.

Patil *et al.* (2000) reported that spraying of Bee here and Bee-Q on sesamum shows increase in foraging activities of bees and yield parameters significantly increased on sprayed crop up to fifth day in Dharwad.

Viraktamath and Anagoudar (2002) reported the research on bee attractants on *Cucumis sativa* proved that two applications of Bee-Q (12.5 gm/lit), Bee-here (4 ml/lit) and sugar solution (10%) on staminate or female flowers of *Cucumis sativa* attracted a greater number of bees (4.01 to 4.97 bees/flower in 5 min.) up to five days after first and second sprays compared to unsprayed crop (3.25 to 3.59 bees). Similarly, higher visits were recorded on pistillate or male flowers on the sprayed crop.

Jayaramappa *et al.* (2011) reported that the studies on Bee-Q @ 10, 12.5 and 15 gm/lit, Fruit boost @ 0.50, 0.75 and 1 ml/lit, Cinnamon leaf extract @ 5%, Tuberose floral scented water, 10% sugar solution on ridge gourd, which is open pollinated observed that spraying of Fruit boost @ 0.50 ml/lit and Bee-Q @ 12.5 gm/lit enhanced foraging activities of Indian bees and yield by increasing yield parameters like number of fruits per plant to 19.00 and 17.00 fruits, when compared to 10.66 fruits per plant in open pollinated plot. Number of fruits was 21.83 and 20.83 fruits per plot, when compared to 15.68 fruits per plot in open pollinated plots.

Ventaramegowda *et al.* (2013) reported that studies on use of bee attractants like Bee-Q and Fruit Boost in the pollination of Niger. Bee visits to Niger flowers were observed for two weeks and seed yield was determined. Results indicate that applications of Bee-Q at 12.5 gm/lit and Fruit boost at 0.75 ml/lit on Niger significantly increased in the bee foraging activities over control plots. In addition, plots sprayed with these bee attractants significantly enhanced the seed set, seed weight and germination of Niger.

Naik *et al.* (2014) reported that bee attractant plays a significant and beneficial role in enhancing pollination and yield of crops especially when target crop is not so attractive to the bees naturally or when the weather conditions are not conducive for foraging by the bees on target crop and evaluated that Citral E, Citral Z, *F. budrunga*, *S. densifolia* attracted significantly a greater number of bees with 2.13 to 2.96 bees /10 m²/5 min.

Which were on par with each other and were as good as Fruit boost showed 2.00 to 2.17 bees /10 m²/5 min.

Jayaramappa and Bhargava (2015) reported that the usage of bee attractants, Bee-Q and Fruit Boost in the pollination of watermelon at different concentrations and showed that, Bee-Q at 12.5 gm/lit and Fruit boost at 0.5 ml/lit of watermelon plots attracted several bee foragers than the control plots.

Singh *et al.* (2015a) reported that the abundance and foraging activities of different bee visitors to pigeon pea (*Cajanus cajan* L.) cultivar ICPL-151 and Bahar. The four species of bees were observed that visiting the flowers viz. *Megachile sp.*, *Apis florea*, *A. cerana indica* and *A. mellifera* and five species of bees namely *A. florea*, *A. dorsata*, *A. cerana indica*, *A. mellifera* and *Megachile spp.* of both cultivars respectively.

Singh *et al.* (2015b) reported that the mean number of *Apis mellifera* collecting both nectar and pollens were found to be 14.71 + 2.47 and 3.71 + 0.65 per hour, respectively. The pollen collecting activity reached its peak at 13:00 hrs after that it began to decline.

Subhakar and Sreedevi (2015) reported that the pollinators were composed of 15 insect species in 3 orders and 10 families in bitter gourd. Bees were the most dominant (435 individuals) floral visitors. *Parnara guttata*, *A. florea* and *A. dorsata* were the most abundant pollinators. *A. florea* and *A. dorsata* also exhibited the highest visitation rates and frequencies. Five major pollinators were tested for their single-visit efficacy, showing that *A. dorsata* was the most effective pollinator, along with *A. florea* and *Eristalinus laetus*. Conserving and enhancing these pollinators may enhance *M. charantia* production in Pakistan.

Rojeet *et al.* (2016) reported that *A. cerana indica*, *A. florea*, *Apis dorsata*, *Xylocopa fenestrata*, *Andrena sp.*, *Eristalinus arvorum*, *Nomia sp.*, *E. taeniops*, *E. punctulatus*, *Erisyrphus balteatus* and *Pieris napi* as pollinators in rapeseed. Out of these, six species of pollinators viz., *X. fenestrata*, *Andrena sp.*, *Nomia sp.*, *E. taeniops*, *E. punctulatus* and *P. napi* were abundant.

Manchare *et al.* (2019) reported that the bee attractants were sprayed two times, first at 10 percent flowering and second at 50 percent flowering. The results from the foraging activity of bees noted that the intensity of *Apis cerana indica* was increased on 1st day after spraying and it reduced as gone

towards 7th days after spray. Spraying of bee attractants i.e. honey solution 10 percent, jaggery solution 10 percent and molasses 10 percent attracted the maximum number of *Apis cerana indica* up to 5th day after first spray and 7th day after second spray.

More *et al.* (2020) reported that the peak foraging activity of *A. mellifera* (7.50 bees/m²/5 minute) were found during fourth week of flowering period and maximum at 12:00 hrs of day with an average of 12.00 bees/m²/5 minute. The foraging activity of *A. mellifera* initiated at early in morning at 8:00 hrs and continues till evening up to 18:00 hrs. On 1st, 3rd and 5th day after first spray of bee attractants, the treatment with Jaggery solution (10%) was found significantly superior in attracting a greater number of bees with an average of 12.68, 15.18 and 13.75 bees/m²/5 minute, respectively. The bee visits on one, three and five days after second spray of bee attractants was 13.57, 15.89 and 15.89 bees/m²/5 minute, respectively and for third spray it was 14.11, 16.25 and 14.82 bees/m²/5 minute, respectively.

2.4 Impact of bee pollination on quality and quantity parameters of mustard.

Bisht *et al.* (1983) reported that the rape plants visited by insect pollinators yielded 472 pods per plant and 14 seeds per pod as compared to plants caged to exclude insects that yielded 37 pods per plant and 3 seeds per pod.

Mishra *et al.* (1988) reported that per cent pod setting, seeds per pod and proportion of healthy seeds were significantly higher in open-pollinated flowers of *B. campestris* L. var. sarson cv. 'BSH-1' than in net-caged and muslin-bagged ones. The average weight of 100 seeds and oil content of seeds were significantly greater from muslin-bagged than from net caged and open-pollinated flowers. Oil yield was 9.76 and 1.55 times higher under open pollination and net caging, respectively, than under muslin-bagging.

Chand and Singh (1995) observed that the plots which remained without access to pollinators (caged without any pollinator) had the lowest yield (966 kg /ha). Plots having free access to all the pollinators showed the maximum yield (1620 kg /ha), followed by plots having honeybees (1160 kg

/ha). Thus, honeybee alone contributed 20 per cent towards increasing the yield of the crop.

Panda *et al.* (1996) observed that the open pollinated sunflower yielded highest (70.3%) seeds / capitulum followed by the crop subjected to bee pollination (61.2%) and crop without insect pollination (57.46 %). They also mentioned that seed obtained from sunflower grown under open pollination gave the highest seed weight (70.8 gm /1000 seed) followed by crop subjected to bee pollination (60.8 gm) and without insect pollination (34 gm). They further reported that sunflower crop yielded 22.4 Q/ ha in open pollinated as a against a significant lower yield of 16.2 q /ha and 12.2 q/ha under bee pollination and without insect pollination, respectively. They also found highest oil per cent (38.42) in open pollinated, in bee pollinated (36.67) and without insect pollinated (32.57).

Ahmed and Rehman (2002) observed that pollination of rapeseed crop (*B. campestris* L. var. toria) by insect foragers gave maximum yield of 9.16 q/ha which was 133.33 per cent higher than the self-pollinated treatment.

Singh *et al.* (2004) reported that the effect of bee pollination on yield attributing characters and seed yield of toria was significantly different from each other. The mean number of siliqua /plant, length of one siliqua, number of seeds /siliqua, 1000 –seed weight and seed yield in g / plot and q/ha were recorded to be 88.3, 5.11, 3.13, 2117.52 and 11.74, respectively. In open pollinated (OP) which were significantly higher over bee pollinated (BP) and self-pollinated (SP) were the lowest.

Singh and Choudhary (2005) observed that the increase in mean yield in mustard crop, *B. juncea* L. due to honeybee pollination was 61.71 per cent. The mean increase in seed germination was recorded to be 600.00 per cent due to insect/honeybee pollination in mustard crop.

Atmowidi *et al.* (2007) studied that diversity of pollinator insects affected to reproductive success of mustard. The number of pods, seeds per pod, and seed weight per plant was higher in non-caged plants (14.9 pods, 12.8 seeds, and 6.4 g, respectively) than those in caged plants (5.4 pods, 6.5 seeds, and 0.6 g, respectively). When plants were exposed to pollinators, the number of pods, seeds per pod, seeds per plant, and seed weight increased by 178.8, 98.2, 932.5, and 931.9%, respectively. Additionally, insect

pollinations also increased *B. rapa* seed germinations. Seed germination was higher in non-caged plants (92.72%) than that in caged-plants (90.3%). The number of seed set of *B. rapa* increased with the increasing individual number of pollinators.

Sharma *et al.* (2008) reported the effect of insects pollination on the seed yield and quality of carrot (cv. Pusa Yamdagni) during 2002 -03 to 2003-04, the treatment open pollination resulted in the highest seed yield per plant (69.20 and 74.93 g), number of primary umbels (1.50 and 1.54) and secondary umbels (0.99 and 1.12), germination percentage (92.6 and 92.7 %) and vigour index (1416 and 1442), respectively. Open pollination was at par with pollination of caged plants by *A. cerana indica* and *A. mellifera* with regards to total seedling length (12.4 and 13.5, 9.8 and 11.3 and 8.2 and 9.3 cm), but was superior to the control (4.1 and 3.5 cm).

Kumari *et al.* (2012) conducted studies at Punjab Agricultural University, Ludhiana during 2010-11 on the influence of number of *A. mellifera* L. visits (1-5 visits per flower) on seed setting in *B. juncea* (cv. RLC-1) and *B. napus* (cv. GSC-6) and revealed that number of seeds per pod (4.14 seeds) and seed weight per pod (77.47 mg) were the highest in *B. napus* flowers which received five visits of *A. mellifera* but were on par with one to four bee visits. However, seed weight was significantly highest (6.94 mg) in pods resulted from flowers which received five visits of *A. mellifera*, followed by that in four bee visits (4.42 mg) and three bee visits (4.17 mg). Number of seeds per pod (3.97 seeds), seed weight per pod (130.14 mg) and per seed weight (8.81 mg) were the highest in flowers which received five visits of *A. mellifera* but were on par with one to four bee visits of *A. mellifera* on *B. juncea* flowers .

Chhuneja *et al.* (2013) studied the effect of number of bee visits in seed setting of *B. juncea* (cv. RLC-1) and *B. napus* (cv. GSC-6) at Punjab Agricultural University, Ludhiana and recorded maximum number of seeds per pod (20.65 seeds/ pod) in *B. juncea* resulted from eight visits on a single flower which was significantly higher than that from seven visits (17.00 seeds/pod), whereas the lowest was in zero visit (4.30 seeds) and one visit (8.05 seeds). Similarly, seed weight per pod and seed weight (121.63 mg and

5.91 mg) was the highest in eight visits and the lowest in zero visit (13.36 mg and 3.16 mg) and one visit (35.33 mg and 4.74 mg).

Kumari *et al.* (2013a) reported that in *B. napus* (cv. GSC-6), the maximum number of pods per plant, pod length, number of seeds per pod and thousand seed weight were observed in open pollination (1117.83 pods, 7.04 cm, 24.61 seeds/pod and 4.32 g, respectively) which was significantly higher than that in *A. mellifera* pollination (442.03 pods, 6.09 cm, 21.75 seeds/pod and 3.52 g, respectively) and significantly the lowest were observed in pollinators' exclusion (248.00 pods, 5.22 cm, 15.88 seeds/pod and 2.92 g, respectively). Similarly, seed yield per plant, seed yield per ha, oil content and germination percentage was also significantly highest in open pollination (89.14 g, 8811.11 kg/ha, 34.09% and 86%, respectively) compared to pollination by *A. mellifera* (39.92 g, 6855.55 kg/ha, 30.37% and 82.67%, respectively) and the least observed in pollinators' exclusion (16.29 g, 5016.66 kg/ha, 24.39% and 72.83%, respectively).

Kumari *et al.* (2013b) reported that in *B. juncea* (cv. RLC-1), the maximum number of pods per plant, pod length, number of seeds per pod and thousand seed weight were observed in open pollination (1137.16 pods, 4.93 cm, 13.98 seeds/pod and 4.63 g, respectively) as compared to *A. mellifera* pollination (506.16 pods, 4.24 cm, 12.42 seeds/pod and 3.97 g, respectively) and in pollinators' exclusion (222.26 pods, 3.76 cm, 9.95 seeds/pod and 3.8 g, respectively). Similarly, seed yield per plant, seed yield per ha, oil content and germination percentage was also found highest in open pollination (90.93 g, 9127.77 kg/ha, 30.08% and 90.75%, respectively) compared to crop pollinated by *A. mellifera* (30.59 g, 7066.66 kg/ha, 25.87% and 87.25%, respectively) and in pollinators' exclusion (13.57 g, 5066.66 kg/ha, 22.78% and 79.96%, respectively).

Shakeel and Inayatullah (2013) studied the impact of insect pollinators on the yield of two canola (*B. napus*) varieties ('Ganyou' and 'Oscar') and found that yields were similar between the two cultivars but differs significantly between pollinated and covered plants for three yield parameters (i.e., total yield, number of seeds per siliqua, and weight of 100 seeds). In pollinated plots, these were 189.3 ± 1.7 pods/plant, 15.0 ± 0.9 seeds/siliqua and 0.55 ± 0.02

g as compared to covered plots 142.2 ± 2.4 pods/plant, 11.0 ± 0.8 seeds/silique and 0.37 ± 0.01 g.

Pudasaini *et al.* (2014) observed the highest germination percent on *Apis cerana* F. pollinated plot seeds (90.50%) followed by *Apis mellifera* L. pollinated plots (87.25%) and lowest on control plots (42.00%) seeds. Similarly, seed test weight observed on *Apis cerana* F. pollinated plots (3.22 gm/ 1000 seed), *Apis mellifera* L. pollinated plots (2.93 gm/1000 seed) and control plots (2.26 gm/ 1000 seed).

Bhowmik *et al.* (2014) observed significant increase in per cent pod setting, number of seeds per silique and mean weight of 100 seeds in open pollinated plants of *B. juncea* by 6.41, 52.80 and 240 per cent, respectively as compared to the controlled plants where insect pollinators were excluded. It was also determined that the length of silique and the diameter of seed increased by 47.22 and 141.66 per cent, respectively, in the open pollinated flower than controlled one. Further, pollination increases the germinability of the resulting seeds to 36 ± 3 per cent as germination in open pollinated seeds was 96 ± 3.2 per cent where as in control only 60 ± 5.6 per cent seeds germinated. Lower seed yield was assumed to be probably due to the availability of less number of viable pollen.

Sharma and Abrol (2014) found that toria crops benefit greatly from cross pollination. They found that the number of silique per plant in toria under open pollination (OP) was (279.33 silique/plant) that formed under caged conditions (128.99 silique/plant). Seed weight was lower under caged conditions than under OP, and a greater number of seeds and better quality seeds were obtained from OP. The combined effect was that OP yielded 1.80 times more seed than plants having no access to insect pollinators.

Kamel *et al.* (2015) observed that the number of pods per plant, seeds per pod, weight of 1000 seeds, yield per plant and yield per feddan (1 fed = 0.42 ha) were higher in open pollinated plants (2117.7 pods, 24.6 seeds, 3.13 g seeds, 32.0 g seeds, and 677.6 kg seeds, respectively) than those of caged plants (1315.4 pods, 18.2 seeds, 2.4 g seeds 18.9 g seeds and 248.64 kg seeds, respectively) in *B. napus*. Also, insect pollination increased canola seed germination. Seed germination was higher in non-caged plants (95.2%) than in caged plants (87.8%).

Patidar *et al.* (2017) studied the yield of mustard through honey bee pollinator. The present study contained three pollination treatments *viz.*, Plants caged Pollinator Exclusion (PE), Plants caged with bee hive (BP) and Plants kept open to all pollinators (OP). The comparative data pertaining to modes of pollination in mustard crop revealed that highest values of mean no. of siliqua/plant (186.44), no. of seeds/siliqua (13.82) and seed yield (20.54 q/ha) were obtained from OP followed by BP and it was recorded lowest in PE.

Devi *et al.* (2017) studied that the highest seed set, seed siliqua-1 and 1000 seed weight was obtained by open pollination followed by hand pollination. The minimum seed set, seed siliqua-1 and 1000 seed weight was observed in case of pollinators exclusion.

Hossain *et al.* (2017) studied that the experiment has consisted of three different ways of insect visitors foraging for pollination of mustard flowers *viz.*, Open field (Control), Netting with honey bee and Netting without honey bee. BARI Sharisha-8 [*Brassica juncea* (L.) Czernajew] was used as planting material. The yield and yield contributing traits were significantly influenced by different ways of insect visitors foraging for pollination. The maximum (3.50 g) 1000- seed weight was recorded from treatment T2 followed by T3 and the lowest 1000- seed weight (2.68 g) was recorded from T3. The highest seed yield (2.45 t ha⁻¹) was exhibited from treatment T2 followed by T1 whereas the lowest seed yield (1.67 t ha⁻¹) was recorded from T3. Finally, it can be concluded that, providing honey bee colonies to the flowering mustard field can substantially contribute to the yield.

Nagpal *et al.* (2017) conducted a field experiment on effect of different modes of pollination on yield parameters of Indian mustard showed that the maximum number of pods/plant, pod length, pod setting (%), number of seeds/pod, thousand seed weight, seed yield/ plot, seed germination (%), seed vigour and oil content (508.72 pods/plant, 5.69 cm, 86.32%, 15.66 seeds/pod, 6.87 g, 17.63 q/ha, 89.20%, 628.12 and 39.42%, respectively) were in open pollination followed by that in bee pollination (404.56 pods/plant, 4.92 cm, 78.33%, 14.26 seeds/pod, 6.39 g, 15.57 q/ha, 85.20%, 542.54 and 38.36%, respectively) and pollinators exclusion (287.56 pods/plant, 3.89 cm, 65.87%, 12.24 seeds/pod, 5.30 g, 13.01 q/ha, 78.40%, 385.54 and

37.04%, respectively). Seed yield increased by 35.50 and 19.66 per cent in open pollinated and *Apis mellifera* pollinated plots, respectively as compared to pollinators exclusion.

Wankhede *et al.* (2018) reported that higher yield contributing characters like number of fruits (19.20 fruit/plant), Number of seeds (283 seeds/fruit), Test wt (10.72 g/fruit) and total yield (69.55 q/ha) were recorded in 10 per cent jaggary solution and found to be the best attractant followed by 5 per cent jaggary solution and 10 per cent sugar solution comparing with open pollination and pollination without insect.

Giri *et al.* (2018) reported that the maximum pod setting 76.24 pod/plant and 83.50 percent seed setting were recorded in open pollination followed by bee-pollination with 71.20 pod/plant and 78.25 percent seed setting and minimum pod setting 69.12 pod/plant and 71.80 percent seed setting in self-pollination.

Subedi and Subedi (2019) reported that the significant difference was observed in the number of pods, number of seeds per pods and weight of 100 dry seeds in control and open pollination.

Hossain *et al.* (2018) studied that the yield and yield contributing traits were significantly influenced by different ways of insect visitors foraging for pollination. The maximum (3.50 g) 1000-seed weight was recorded from treatment Netting with honeybee followed by Netting without honeybee and the lowest 1000- seed weight (2.68 g) was recorded from Netting without honeybee. The highest seed yield (2.45 t ha⁻¹) was exhibited from treatment Netting with honeybee followed by Open field (Control) whereas the lowest seed yield (1.67 t ha⁻¹) was recorded from Netting without honeybee.

Mahadik *et al.* (2019) reported that honey solution 5% recorded 105.07 number of pods/plant, 16.40 number of seeds/pod, 5.69 wrinkled seed/pod, fruit weight 0.35 kg/ 5 plants, net yield 19.3 q/ha and found superior followed by Jaggary solution 10% (103.8 number of pods/plants, 15.40 number of seeds/pods, 6.05 wrinkled seed/pod, 3.46, fruit weight 0.27 kg/ 5 plants, net yield of 18.00 q/ha) and lowest with open pollination and pollination without insects.

Manchare *et al.* (2019) studied different bee attractants *viz.*, Coconut water 10%, Sugar solution 10%, Sugarcane juice 10%, Jaggery solution 10%,

Molasses 10%, Honey solution 10% and Pomegranate juice 5% and found that the highest number of fruits / plant (35.88) and the highest number of seeds / fruit (41.4) were recorded in the treatment of honey solution 10 per cent. Significantly higher test weight (29.57 g), seed yield (2.19 kg/5 plants) and seed yield (4.81 q/ha) was recorded in Honey solution 10%. Next effective treatments were jaggery solution 10 per cent (3.82 q/ha), molasses 10 per cent (3.56 q/ha) and sugarcane juice 10 per cent (3.34 q/ha). The least effect on yield was found in treatment Open pollination without spray (2.72 q/ha) and Pollination without insect (1.14 q/ha).

Chapter III

MATERIALS AND METHODS

This chapter deals with a concise description of the location of the study area, experimental details, observation recorded, methodology and techniques employed for analysis of observations during the course of the investigation.

The present investigation entitled, "**Studies on the impact of Bee Pollination on yield parameters of Mustard (*Brassica juncea* L.)**" was carried in the assigned experimental field of mustard crop and the apiary at RVSKVV- Krishi Vigyan Kendra, Morena, Madhya Pradesh, during 2021-22. The Krishi Vigyan Kendra is situated at 26.47°N latitude, 77.98°E longitude, and 177m AMSL. The mean annual minimum and a maximum temperature range from 7 to 42°C. The average annual precipitation received is 753.7 mm.

3.1 To study the pollinator fauna of mustard.

The research was carried out during the *Rabi* crop season of 2021-22. During the flowering season, no pesticides were used on the experimental field. Certain insects that visited and occurred on plants were surveyed using the direct count observation approach. During the peak flowering season in the mustard crop field, observations were made for distinct groups of pollinators visiting the mustard crop field at 0800, 1000, 1200, 1400 and 1600 hours for five minutes in each square meter area from three sites. Unknown insects were captured using appropriate collection protocols, then identified with the assistance of a major adviser and members. To estimate the pollinator fauna as well as the predominance (in percent value) of a given group, the observed data were aggregated time-wise and group-wise. The dominance per cent was computed by multiplying the total number of genera seen by the number of species observed in each insect order group.

3.2 To study the foraging behaviour of honey bees in mustard.

The research was conducted during the *Rabi* season of 2021-22. The mustard crop was cultivated in an unsprayed agricultural field to examine pollinator fauna. At weekly intervals, observations were made on the number of bees visiting in each square meter area from five spots for five minutes at

two hourly intervals from 0800 to 1800 hours. The observations began at 10% flowering and were repeated weekly until the flowering phase was completed. The amount of time that different honey bee species spent on live flowers was also recorded. The data was then averaged over time and even across species to determine which group and when it dominated over the other species. The data was then square root transformed and statistical analysis was performed.

3.3 To study the different bee attractant for attract the *Apis mellifera* in mustard.

Details of the experiment:

Design	: RBD
Crop	: Mustard
Variety	: RVM- I
Plot size	: 6.0 m x 3.0 m
Spacing (RxP)	: 45 cm x 15 cm
No. of replication	: 3
No. of treatments	: 9 (including control)
Fertilizer doses	: As recommended
Date of Sowing	: 24/10/2021

The experiment was laid out in Randomized Block Design (RBD) with nine treatments replicated thrice. The treatment details are as follows:

- T1: Open pollination with Sugar solution @ 10%
- T2: Open pollination with Coconut water @ 10%
- T3: Open pollination with Jaggery @ 10%
- T4: Open pollination with Coriander @ 1.25%
- T5: Open pollination with Onion solution @ 10%
- T6: Open pollination with Sugarcane juice @ 10%
- T7: Open pollination with Bee-Q @ 1.25 %
- T8: Open pollination with Pomegranate juice @ 10%
- T9: Open pollination Without Treatment (Control)

All of the treatments were applied when the crop was 10% flowering. Various pests and diseases were controlled, but no pesticides were employed

during the flowering time. For growing good seed production plots, an agronomical package of practices was followed. Starting at 10% blooming, the attractants were applied three times at a 10-day interval. A one-meter square area was randomly selected and marked in each plot, and the number of *A. mellifera* bees visiting the flowers in that area every five minutes was recorded. During the flowering season, observations were obtained at five separate time slots: 0800, 1000, 1200, 1400, and 1600 hours, and the observed data was averaged on a daily basis. These observations were made one day before the spray and one, three, and five days after the spray. The data was square root transformed and statistical analysis was performed after the mean of all the observations was averaged.

3.4 Impact of bee pollination on quality and quantity parameters of mustard.

Details of the experiment:

Design	: RBD
Crop	: Mustard
Variety	: RVM- I
Plot size	: 6.0 m x 3.0 m
Spacing (RxP)	: 45 cm x 15 cm
No. of replication	: 3
No. of treatments	: 11 (including control)
Fertilizer doses	: As recommended
Date of Sowing	: 24/10/2021

The mustard crop sowing practises were started in the second fortnight of October 2021, according to all recommended agronomic package of practises. Throughout the crop season, pesticides were not sprayed on the field. Open pollination (T1 to T9), caged with bees or (BP) Bee Pollination (T10), and caged without bees or Without Insect Pollination (WIP) (T11) were the treatments.

The trial used a Randomized Block Design (RBD) layout, with eleven treatments replicated three times over 33 plots. The following are the treatment details:

T1-T9- Open pollination treated with bee attractants (OP): These plots were not caged, and they were always exposed/open to pollination by all agencies. Except for the T10 and T11, All treatments were applied at the 10% blooming stage of the crop. The treatments from T1 to T8 were sprayed three times during the flowering season of the crop. The first spray was applied when the mustard crop was 10% flowering. The second spray was applied 10 days after the first, and the third spray was applied 10 days after the second. The following are the treatment names, concentrations, and formulations:

T1: Open pollination with Sugar solution @ 10%

T2: Open pollination with Coconut water @ 10%

T3: Open pollination with Jaggery @ 10%

T4: Open pollination with Coriander @ 1.25%

T5: Open pollination with Onion solution @ 10%

T6: Open pollination with Sugarcane juice @ 10%

T7: Open pollination with Bee-Q @ 1.25 %

T8: Open pollination with Pomegranate juice @ 10%

T9: Open pollination Without Treatment (Control)

T10- Caged with Bees or Bee pollination (BP): The plots were caged before the beginning of flowers throughout the night to eliminate natural pollination in the treatment of bee pollination. At the start of flowering, the crop was caged and sprayed with chlorpyrifos 20 EC to kill all insects inside the cage and eliminate their contribution to pollination. Following the pesticide waiting time, a bee colony containing *Apis mellifera* L. was employed in a standard deep LT wooden hive box and held immediately at the beginning of flowering, not later than 10% flowering, until flowering ended. To assist the bees' movement in and out of the cage, specific beehive boxes with back and front entrances were maintained open in one of the cage's borders. The colony's strength was determined by the amount of flora available. Water was delivered to the colony on a regular basis. Before the flowering stage began, fine nylon mosquito net cages of 4x3x2 m were placed on a standing crop, large enough to allow honey bees to travel freely inside the cage. The nets were made using 16-mesh nylon material, which was adequate to keep insects out of the cage while allowing other physical factors to pass through. Iron pipes are utilised to construct the cage, which holds the nylon net in place and is tightened using cords. Lower edges of the mosquito net were touched to the ground and sufficiently pressed under the soil so as to exclude hovering insects away from the covered plants. A zipped entry was kept at one corner of the net to allow manual entry for data recording and other operations. Care

was taken to immediately close the zip of the cage after entry into the cage and exit of the cage. The bee colony was removed when all the floral bloom was exhausted. The cage was also removed after the completion of flowering.

T11- Caged Without Bees or Without insect pollination (WIP): The mosquito net's lower edges were touched to the ground and firmly pushed into the soil to keep hovering insects away from the covered plants. One corner of the net was retained zipped to allow manual entrance for data recording and other functions. After entering and exiting the cage, care was made to seal the zip as soon as possible. After the flowering had completely exhausted, the cage were removed.

Qualitative and Quantitative parameters-

The following quantitative and qualitative parameters were gathered from each treatment in order to examine the influence of different modes of bee pollination on improving mustard yield and quality. In each replication, observations were made on five randomly selected (avoiding edges) plants for six different characters: number of siliquae/ plants, siliqua length (cm), number of seeds/ siliquae, total number of seeds/ plants, seed yield per plant (g), 1000 seeds weight (g), and required transformation was applied and statistical analysis was performed.

Method of observations-

The effective methods of observations for different characters are described below:

Siliquae from five randomly selected plants was tagged in each replication of different treatments. At maturity, they were manually harvested and the following quantitative and qualitative yield parameters were recorded.

Number of siliquae per plant

From five randomly selected plants, number of siliquae on each plant were counted and average number of siliquae per plant was calculated for each of the replicated plot.

Siliqua length (cm):

Ten siliquae were selected random from each of the five randomly selected plants from each of the replicated plots. The length of these

randomly selected siliquae was measured with centimetre scale. The mean pod length per siliquae was then worked out for each of the replicated plot.

Number of seeds per siliqua

Ten siliquae were selected random from each of the five randomly selected plants from each of the replicated plots during harvesting. The number of seeds in each siliqua was counted and average seeds per siliquae were calculated for each of the replicated plot.

Total number of seeds per plant

All the siliquae were collected from each of the five randomly selected plants from each of the replicated plots during harvesting. The total number of seed in each siliqua from all the plants was counted and average number of seeds per plant were calculated for each of the replicated plot.

Seed yield per plant (g)

This observation was recorded by weighing total number of seeds per plant from all the five randomly selected plant in each of the replicated plot and average number of seeds per plant were calculated for each of the replicated plot.

1000 seeds weight (g)

This observation was recorded by weighing 1000 dried seeds sample from each replicated plot by using electronic weighing balance.

Statistical analysis

The collected data were cleared & stored into Microsoft Excel spread sheets after the completion of data collection work from the study areas for further analysis. Summarized data was presented in the form of tables and figures. For the effectiveness of bee attractants, data were transformed using the square root transformation as per the method described by Gomez and Gomez (1986).

For the analysis of the effect of bee pollination on qualitative and quantitative characters, the data were tested for normality and no data transformations were required. The data were then subjected to statistical analysis by adopting appropriate method of "Analysis of variance" as suggested by Fisher and Yates, 1963. Wherever, variance ratio (calculated 'F'

values) was found significant, critical difference (C.D.) values were computed by following formula for making comparison between the treatments.

Table 3.1: Skeleton of ANOVA

Source of variance	Degree of Freedom (d.f.)	Sum of Square (S.S.)	Mean Sum of Square (M.S.S.)	F _{Cal.}	F _{Tab.}
Replication	(r-1)	SSR	MSR	MSR/MSE	
Treatment	(t-1)	SSTr	MSTr	MSTr/MSE	
Error	(r-1)(t-1)	SSE	MSE		
Total	(r.t-1)	TSS			

Where, r = number of replications

t = number of treatments

MSR = replication mean sum of square

MSTr = treatment mean sum of square

MSE = error mean sum of square

The significant differences between different treatments were judged by using critical differences (C.D.) which was calculated as follows:

$$S.E.m \pm = \sqrt{\frac{EMss}{r}}$$

$$(S.E.)d = S.E.m \times \sqrt{2}$$

CD = S.E.d x t at 5%, for error degree of freedom

Where,

S.E.d = Standard error of differences between two treatment means.

E.M.S. = Error mean sum of square (Error variance)

R = Number of replications

C.D. = Critical difference

T = Value for fishers table for error degree of Freedom at 5%

e.d.f = Error degree of freedom.



Plate 3.1: (A) Setting of cage net for bee pollination, (B) Spray of bee attractants, (C) Observing the insect pollinators by using sweep net method and (D) Taking observations of foraging activities of bee species.

Chapter IV

RESULTS

The present investigation entitled “**Studies on the impact of Bee Pollination on yield parameters of Mustard (*Brassica juncea* L.)**” was carried in the assigned experimental field of Mustard and the apiary at RVSKVV- Krishi Vigyan Kendra, Morena, Madhya Pradesh, during 2021-22. The data obtained from the present study were critically examined and statistically analysed as per statistical designs adopted and the results obtained are presented under the following heads:

- 4.1 To study the pollinators fauna of mustard.
- 4.2 To study the foraging behaviour of honey bees in mustard crop.
- 4.3 To study the different bee attractant for attract the *Apis mellifera* in mustard.
- 4.4 Impact of bee pollination on quality and quantity parameters of mustard.

4.1 To study the pollinators fauna of mustard.

The experimental field was observed carefully during the study period and the insect pollinators visiting the mustard crop (*Brassica juncea* L.) were collected and identified with the help of insect collections and literature available in the department of Entomology, Central Library and with the help of members of the advisory committee. All the identified insect visitors along with their scientific names and systemic positions are listed in Table 4.1. A total of 36 species belonging to 8 orders viz., Hymenoptera (12), Diptera (9), Lepidoptera (6), Coleoptera (3), Hemiptera (2), Orthoptera (2), Neuroptera (1) and Odonata (1) visited mustard flowers.

The Hymenopteran visitors comprising of 12 species belonged to 6 families. Among them, Apidae was the most diverse family comprising 6 species (*A. mellifera* Linnaeus, *A. cerana indica* Fabricius, *A. dorsata* Fabricius, *A. florea* Fabricius, *Tetragonula laeviceps* Smith and *Ceratina sexmaculata* Smith), Scollidae family comprising 2 species (*Scolia (Discolia) binolata* Fabricius and *Compsomeriella* sp. Betrem), Megachilidae, Xylocopidae, Anthophoridae and Sphecidae families comprising single

species (*Megachile disjuncta* Fabricius, *Xylocopa iridipennis* Lepeletier, *Anthophora* sp. Latreille and *Sphex* sp. Linnaeus, respectively). These species of insect pollinators were followed in order of their diversity by Dipterans comprising 9 species belonging to 4 families. Among them, Syrphidae was the most dominant family comprising 5 species (*Syrphus corollae* Fabricius, *Episyrphus veltiatus* De Geer, *Episyrphus balteatus* De Geer, *Metasyrphus confrater* Wiedemann and *Eristalis* sp. Latreille), Muscidae family comprising 2 species (*Musca domestica* Linnaeus and *Atherigona orientalis* (Schiner), Tephritidae and Calliphoridae both comprising single species (*Bactrocera* sp. Macquart and *Calliphora vicina* Robineau-Desvoidy). The third most diverse insect order was Lepidoptera comprising 6 species belonging to 3 families. The Vespidae family comprises 3 species (*Vespa orientalis* Linnaeus, *Polistes gallicus* Linnaeus and *Vespula squamosa* Drury), Pieridae family comprises 2 species (*Spodoptera exigua* Hubner and *Pieris brassicae* Linnaeus) and Lycaenidae family with *Lampides boeticus* Linnaeus. The next diverse insect order was Coleoptera comprising 3 species belonging to 2 families. The Coccinellidae family comprises 2 species (*Coccinella septumpunctata* Linnaeus and *Cheilomenes sexmaculata* Fabricius) and the Curculionidae family comprises single species (*Hypera brunneipennis* Boheman). The least diversified orders were Orthoptera (comprising 2 species from 2 families) viz., Acrididae (*Schistocera americana* Drury) and Tettigoniidae (*Neoconocephalus* sp. Karny), Hemiptera (comprising 2 species) viz., Pentatomidae (*Nezara viridula* Linnaeus and *Bagrada hilaris* Burmeister) and Neuroptera and Odonata each comprising single species viz., Chrysopidae (*Chrysoperla carnea* Steph.) and Aeshnidae (*Hemianax ephippiger* Burmister), respectively.

Hymenopterans were the most abundant pollinators (33.33 per cent), followed by the orders Diptera (25.00 per cent), Lepidoptera (16.67 per cent), and Coleoptera (8.33 per cent) throughout the flowering season of the mustard crop, as shown in Table 4.2 and Fig. 4.1. The abundance of Orthoptera and Hemiptera was found to be the same, at 5.56 per cent. The orders Neuroptera and Odonata comprised the least pollinators, accounting for 2.78% of the total.

Table 4.1: List of insect pollinators' fauna of mustard crop observed and collected during Rabi 2021-22 flowering season.

S. No.	Common Name	Scientific Name	Family	Order
1	European honey bee	<i>Apis mellifera</i> Linnaeus	Apidae	Hymenoptera
2	Rock bee	<i>Apis dorsata</i> Fabricius		
3	Indian honeybee	<i>Apis cerana indica</i> Fabricius		
4	Little honeybee	<i>Apis florea</i> Fabricius		
5	Stingless bee	<i>Tetragonula laeviceps</i> Smith		
6	Small carpenter bee	<i>Ceratina sexmaculata</i> Smith		
7	Leaf cutter bee	<i>Megachile disjuncta</i> Fabricius	Megachilidae	
8	Carpenter bee	<i>Xylocopa iridipennis</i> Lepeletier	Xylocopidae	
9	Digger bee	<i>Anthophora</i> sp. Latreille	Anthophoridae	
10	Scolid wasp	<i>Scolia (Discolia) binolata</i> Fabricius	Scollidae	
11		<i>Campsomeriella</i> sp. Betrem		
12	Digger wasps	<i>Sphex</i> sp. Linnaeus	Sphecidae	
13	Syrphid fly	<i>Syrphus corollae</i> Fabricius	Syrphidae	Diptera
14		<i>Episyrphus veltiatus</i> De Geer		
15	Hover fly	<i>Episyrphus balteatus</i> De Geer		
16		<i>Metasyrphus confrater</i> Wiedemann		
17	Drone fly	<i>Eristalis</i> sp. Latreille		
18	House fly	<i>Musca domestica</i> Linnaeus	Muscidae	
19	Orientalis house fly	<i>Atherigona orientalis (Schiner)</i>		
20	Tephritid fruit fly	<i>Bactrocera</i> sp. Macquart	Tephritidae	
21	Blow flies	<i>Calliphora vicina</i> Robineau-Desvoidy	Calliphoridae	
22	Green stink bug	<i>Nezara vridula</i> Linnaeus	Pentatomidae	Hemiptera
23	Shield bug	<i>Bagrada hilaris</i> Burmeister		
24	Green lacewing	<i>Chrysoperla carnea</i> (Steph.)	Chrysopidae	Neuroptera
25	Lady bird beetle	<i>Coccinella septumpunctata</i> Linnaeus	Coccinellidae	Coleoptera
26		<i>Cheilomenes sexmaculata</i> Fabricius		
27	Egyptian alfalfa weevil	<i>Hypera brunneipennis</i> Boheman	Curculionidae	
28	Dragon fly	<i>Hemianax ephippiger</i> Burmister	Aeshnidae	Odonata
29	Pea blue butterfly	<i>Lampides boeticus</i> Linnaeus	Lycaenidae	Lepidoptera
30	Beet armyworm	<i>Spodoptera exigua</i> Hubner	Pieridae	
31	Cabbage butterfly	<i>Pieris brassicae</i> Linnaeus		
32	Oriental hornet	<i>Vespa orientalis</i> Linnaeus	Vespidae	
33	Paper wasp	<i>Polistes gallicus</i> Linnaeus		
34	Yellow jacket	<i>Vespula squamosa</i> Drury		
35	American bird grasshopper	<i>Schistocera americana</i> Drury	Acrididae	Orthoptera
36	Broad-tipped katydid	<i>Neoconocephalus</i> sp. Karny	Tettigoniidae	

Table 4.2: Group-wise per cent dominance of insect pollinators' fauna of mustard crop observed during *Rabi* 2021-22 flowering season.

Sr. No.	Insect Order	No of species	Dominance (%)
1	Hymenoptera	12	33.33
2	Diptera	9	25.00
3	Lepidoptera	6	16.67
4	Coleoptera	3	8.33
5	Hemiptera	2	5.56
6	Orthoptera	2	5.56
7	Neuroptera	1	2.78
8	Odonata	1	2.78

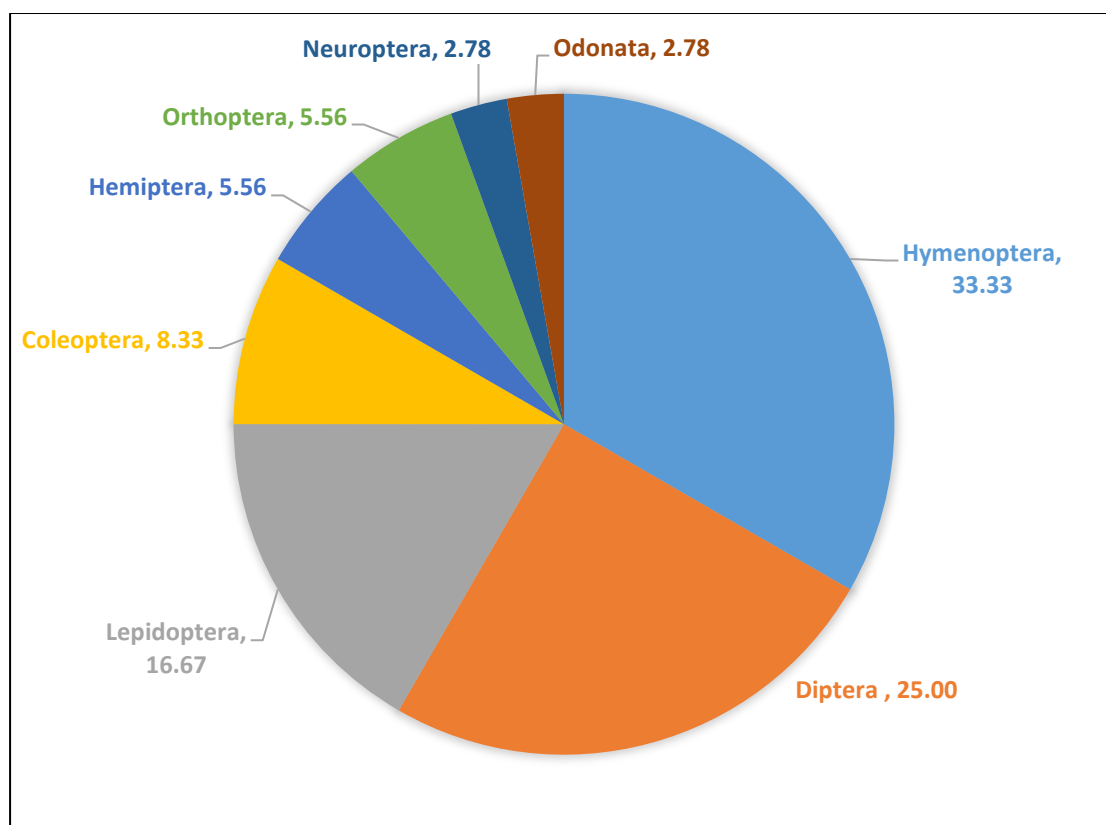


Figure 4.1: Dominance of insect pollinators' fauna of mustard crop observed during *Rabi* 2021-22 flowering season.

4.2 To study the foraging behaviour of honey bees in mustard crop.

4.2.1 Bee abundance of different bee species on mustard crop

Observations on the abundance of different species of honey bee on the flowers of the mustard crop were recorded on the first day of every standard meteorological week at two hours intervals starting from 0800 hours to 1800 hours from the last week of December 2021 to the first week of February 2022. The abundance was recorded in the number of honeybees of a particular species visiting a 1 m² area of the field in 5 minutes. In general, due to very low temperatures in the morning hours in the weeks of December 2021 and January 2022, there was no honey bee activity at 0800 hrs all through the study period. However, the very negligible activity of different honey bee species was observed at 1800 hrs in the evening also.

4.2.1.1. Bee abundance of *Apis mellifera* on mustard crop

Apis mellifera bee abundance in the mustard crop was observed over several weeks in 2021-22 and at varied time intervals, as shown in Table 4.3. Data on abundance indicated that the average population of *Apis mellifera* on a weekly basis varied from 10.67 to 20.50 bees/ m²/5 min on the first (24 December) and fourth (15th January) weeks of the flowering season, respectively. Minimum abundance (10.67 bees/m²/5 min) was recorded during the first (24th December) flowering week and increased gradually with consecutive weeks up to the peak period of flowering, i.e., 4th week (15th January) with 20.50 bees/m²/5 min and later started decreasing with the cessation of flowering in the mustard crop, i.e., 7th week (5th February) with 10.83 bees/m²/5 min.

Apis mellifera abundance was maximum (33.00 bees/m²/5 min) at 1200 hrs during the fourth (15th January) week of observation, with no bee abundance seen at 1800 hrs during the first (24th December), second (1st January), and seventh (5th February) weeks, and at 0800 hrs across all of the weeks of the observation period.

The mean number of *A. mellifera* bees on mustard flowers during different day hours ranged from 7.00 to 25.14 bees/m²/5 min. The maximum abundance (25.14 bees/m²/5 min) was reported around 1200 hrs, which

differs considerably from typical visits at other times of the day. The next time interval with the highest bee visitation was 1400 hrs (24.71 bees/m²/5 min), followed by 1000 hours (17.57 bees/m²/5 min) and 1600 hrs (17.29 bees/m²/5 min). At 1800 hours (7.00 bees/m²/5 min), *A. mellifera* visits were at their lowest.

Table 4.3: Abundance of *Apis mellifera* on the flowers of mustard crop under open pollination during Rabi 2021-22.

Date of observation	Bee Abundance (No. of bees/ m ² / 5min)						
	Hours of the day						
	800	1000	1200	1400	1600	1800	Mean
24-Dec	0.00	13.00	20.00	17.00	14.00	0.00	10.67
01-Jan	0.00	19.00	25.00	23.00	17.00	0.00	14.00
08-Jan	0.00	21.00	26.00	30.00	18.00	10.00	17.50
15-Jan	0.00	23.00	33.00	32.00	20.00	15.00	20.50
22-Jan	0.00	19.00	31.00	30.00	19.00	13.00	18.67
29-Jan	0.00	15.00	24.00	22.00	17.00	11.00	14.83
05-Feb	0.00	13.00	17.00	19.00	16.00	0.00	10.83
Mean	0.00	17.57	25.14	24.71	17.29	7.00	-

4.2.1.2. Bee abundance of *Apis dorsata* on mustard crop

Apis dorsata bee abundance on the mustard crop was observed over several weeks in 2021-22 and at varied time intervals, as shown in Table 4.4. Data on abundance indicated that the average population of *Apis dorsata* on a weekly basis varied from 5.83 to 17.67 bees/ m²/5 min on the first (24 December) and fourth (15th January) weeks of the flowering season, respectively. Minimum abundance (5.83 bees/m²/5 min) was recorded during the first (24th December) flowering week and increased gradually with consecutive weeks up to the peak period of flowering, i.e., 4th week (15th January) with 17.67 bees/m²/5 min and later started decreasing with the cessation of flowering in the mustard crop, i.e., 7th week (5th February) with 8.17 bees/m²/5 min.

Apis dorsata abundance was maximum (27.00 bees/m²/5 min) at 1400 hrs during the fourth (15th January) week of observation, with no bee abundance seen at 1800 hrs during the first (24th December), second (1st

January), sixth (29th January) and seventh (5th February) weeks, and at 0800 hrs across all of the weeks of the observation period.

The mean number of *A. dorsata* bees on mustard flowers during different day hours ranged from 3.86 to 19.71 bees/m²/5 min. The maximum abundance (19.71 bees/m²/5 min) was reported around 1400 hrs, which differs considerably from typical visits at other times of the day. The next time interval with the highest bee visitation was 1000 hrs (18.14 bees/m²/5 min), followed by 1200 hours (15.29 bees/m²/5 min) and 1600 hrs (12.43 bees/m²/5 min). At 1800 hours (3.86 bees/m²/5 min), *A. dorsata* visits were at their lowest.

Table 4.4: Abundance of *Apis dorsata* on the flowers of mustard crop under open pollination during Rabi 2021-22.

Date of observation	Bee Abundance (No. of bees/ m ² / 5min)						
	Hours of the day						
	800	1000	1200	1400	1600	1800	Mean
24-Dec	0.00	9.00	8.00	11.00	7.00	0.00	5.83
01-Jan	0.00	18.00	15.00	20.00	10.00	0.00	10.50
08-Jan	0.00	22.00	17.00	24.00	14.00	8.00	14.17
15-Jan	0.00	26.00	23.00	27.00	20.00	10.00	17.67
22-Jan	0.00	21.00	18.00	22.00	16.00	9.00	14.33
29-Jan	0.00	17.00	14.00	19.00	12.00	0.00	10.33
05-Feb	0.00	14.00	12.00	15.00	8.00	0.00	8.17
Mean	0.00	18.14	15.29	19.71	12.43	3.86	-

4.2.1.3. Abundance of *A. cerana indica* on mustard crop

Apis cerana indica bee abundance on the mustard crop was observed over several weeks in 2021-22 and at varied time intervals, as shown in Table 4.5. Data on abundance indicated that the average population of *Apis cerana indica* on a weekly basis varied from 3.50 to 9.50 bees/ m²/5 min on the first (24 December) and fourth (15th January) weeks of the flowering season, respectively. Minimum abundance (3.50 bees/m²/5 min) was recorded during the first (24th December) flowering week and increased gradually with consecutive weeks up to the peak period of flowering, i.e., 4th week (15th January) with 9.50 bees/m²/5 min and later started decreasing with the

cessation of flowering in the mustard crop, i.e., 7th week (5th February) with 4.83 bees/m²/5 min.

Apis cerana indica abundance was maximum (18.00 bees/m²/5 min) at 1000 hrs during the fourth (15th January) week of observation, with no bee abundance seen at 1800 hrs and 0800 hrs across all of the weeks of the observation period.

The mean number of *A. cerana indica* bees on mustard flowers during different day hours ranged from 7.57 to 13.14 bees/m²/5 min. The maximum abundance (13.14 bees/m²/5 min) was reported around 1000 hrs, which differs considerably from typical visits at other times of the day. The next time interval with the highest bee visitation was 1200 hrs (11.00 bees/m²/5 min), followed by 1400 hours (9.14 bees/m²/5 min). At 1600 hrs (7.57 bees/m²/5 min), *A. cerana indica* visits were at their lowest.

Table 4.5: Abundance of *Apis cerana indica* on the flowers of mustard crop under open pollination during Rabi 2021-22.

Date of observation	Bee Abundance (No. of bees/ m ² / 5min)						
	Hours of the day						
	800	1000	1200	1400	1600	1800	Mean
24-Dec	0.00	8.00	7.00	6.00	0.00	0.00	3.50
01-Jan	0.00	13.00	11.00	9.00	9.00	0.00	7.00
08-Jan	0.00	16.00	13.00	11.00	10.00	0.00	8.33
15-Jan	0.00	18.00	15.00	13.00	11.00	0.00	9.50
22-Jan	0.00	17.00	14.00	12.00	10.00	0.00	8.83
29-Jan	0.00	11.00	9.00	7.00	7.00	0.00	5.67
05-Feb	0.00	9.00	8.00	6.00	6.00	0.00	4.83
Mean	0.00	13.14	11.00	9.14	7.57	0.00	-

4.2.1.4. Comparative abundance of different bee species on mustard crop

The comparative abundance of different bee species on the mustard crop at varied time intervals are shown in Table 4.6. The cumulative mean abundance among the various bees appearing on mustard flowers revealed that *A. mellifera* (15.29 bees/m²/5 min) was the predominant visitor followed by *A. dorsata* (11.57 bees/m²/5 min). *A. cerana indica* was the least abundant visitor of mustard flowers in the present investigations. A significant difference

was recorded in relation to the number of various bees visiting the mustard flowers. It was found that *A. mellifera*, *A. dorsata* and *A. indica* constituted 45.40, 34.37 and 20.23 per cent, respectively of the different bee species that visited the mustard crop. Bees were most abundant during 1400 hrs (17.86 bees/m²/5 min) followed by the number of bees during 1200 hrs, 1000 hrs, 1600 hrs and 1800 hrs (17.14, 16.29, 12.43 and 3.62 bees/m²/5 min). As far as the abundance of different bee species at six-hour slots is concerned, it can be seen from Table 4.6 that the visits of different bee species varied greatly. The population density of various bees declined sharply by 1800 hrs out of three different bee species recorded during the period of investigation. The three *Apis* species were found to be fairly abundant.

Table 4.6: Comparative abundance of different honey bee species on the flowers of mustard crop under open pollination during *Rabi* 2021-22.

Foraging time (Hours of the day)	Bee Abundance (No. of bees/ m ² / 5min)			
	<i>Apis mellifera</i>	<i>Apis dorsata</i>	<i>Apis cerana indica</i>	Mean
800	0.00	0.00	0.00	0.00
1000	17.57	18.14	13.14	16.29
1200	25.14	15.29	11.00	17.14
1400	24.71	19.71	9.14	17.86
1600	17.29	12.43	7.57	12.43
1800	7.00	3.86	0.00	3.62
Mean	15.29	11.57	6.81	-
% of total bees	45.40	34.37	20.23	-

4.2.2. Foraging speed of different bee species on mustard crop

Observations on the foraging speed of different species of honey bee on the flowers of the mustard crop were recorded on the first day of every standard meteorological week at two-hour intervals starting from 0800 hours to 1800 hours from the last week of December 2021 to the first week of February 2022. The foraging speed was recorded in terms of time spent (seconds) per flower. In general, due to very low temperatures in the morning hours in the weeks of December 2021 and January 2022, there was no honey bee foraging at 0800 hrs all through the study period. However, the very negligible activity of different honey bee species was observed at 1800 hrs in the evening also.

4.2.2.1. Foraging speed of *Apis mellifera* on mustard crop

The foraging speed of *Apis mellifera* on the mustard crop was observed over several weeks in 2021-22 and at varied time intervals, as shown in Table 4.7. Data on the foraging speed of *A. mellifera* recorded during different weeks over the times revealed that the mean weekly foraging speed ranged between 1.49 to 2.95 seconds corresponding to the first and fourth week of the blooming period, respectively. The maximum foraging speed of *A. mellifera* (2.95 sec) was in the fourth week which was followed by the fifth week (2.50 sec), third week (2.43 sec), sixth week (2.28 sec), second week (1.70 sec), seventh week (1.62 sec) and first week (1.49 sec) of the flowering season.

The least time spent by *A. mellifera* (2.01 sec) was recorded at 1200 hrs during the first week of the observation and the highest (5.97 sec) at 1400 hrs during the fourth week of the observation.

As far as times of the day were concerned, the mean foraging speed of *A. mellifera* bees over different day hours ranged from 1.46 to 3.66 seconds. Significantly the maximum time spent per flower (3.66 sec) was recorded at 1400 hrs followed by that at 1600 hrs (2.88 sec), 1000 hrs (2.49 sec), 1200 hrs (2.33 sec) and 1800 h (1.46 sec).

Table 4.7: Foraging speed of *Apis mellifera* on the flowers of mustard crop under open pollination during *Rabi* 2021-22.

Date of observation	Foraging Speed (sec/ flower)						
	Hours of the day						
	800	1000	1200	1400	1600	1800	Mean
24-Dec	0.00	2.19	2.01	2.51	2.22	0.00	1.49
01-Jan	0.00	2.43	2.22	2.98	2.59	0.00	1.70
08-Jan	0.00	2.62	2.43	3.82	3.15	2.54	2.43
15-Jan	0.00	2.92	2.62	5.97	3.42	2.75	2.95
22-Jan	0.00	2.59	2.53	4.12	3.22	2.55	2.50
29-Jan	0.00	2.42	2.39	3.51	2.99	2.39	2.28
05-Feb	0.00	2.25	2.14	2.74	2.57	0.00	1.62
Mean	0.00	2.49	2.33	3.66	2.88	1.46	-

4.2.2.2. Foraging speed of *Apis dorsata* on mustard crop

The foraging speed of *Apis dorsata* on the mustard crop was observed over several weeks in 2021-22 and at varied time intervals, as shown in Table 4.8. Data on the foraging speed of *A. dorsata* recorded during different weeks over the times revealed that the mean weekly foraging speed ranged between 2.49 to 4.06 seconds corresponding to the first and fourth week of the blooming period, respectively. The maximum time spent per flower by *A. dorsata* (4.06 sec) was in the fourth week followed by the fifth week (3.60 sec), third week (3.53 sec), sixth week (2.93 sec), second week (2.72 sec), seventh week (2.64 sec) and first week (2.49 sec) of the flowering season.

The least time spent by *A. dorsata* (2.51 sec) was recorded at 1200 hrs during the first week of the observation and the highest (8.47 sec) at 1600 hrs during the fourth week of the observation.

As far as times of the day were concerned, the mean foraging speed of *A. dorsata* bees over different day hours ranged from 1.39 to 6.16 seconds. Significantly the maximum time spent per flower (6.16 sec) was recorded at 1600 hrs followed by that at 1400 hrs (4.88 sec), 1000 hrs (3.57 sec), 1200 hrs (2.83 sec) and 1800 h (1.39 sec).

Table 4.8: Foraging speed of *Apis dorsata* on the flowers of mustard crop under open pollination during *Rabi* 2021-22.

Date of observation	Foraging Speed (sec/ flower)						
	Hours of the day						
	800	1000	1200	1400	1600	1800	Mean
24-Dec	0.00	3.21	2.51	4.22	5.01	0.00	2.49
01-Jan	0.00	3.51	2.72	4.59	5.48	0.00	2.72
08-Jan	0.00	3.62	2.93	5.15	6.32	3.14	3.53
15-Jan	0.00	3.92	3.12	5.42	8.47	3.42	4.06
22-Jan	0.00	3.59	3.03	5.22	6.62	3.16	3.60
29-Jan	0.00	3.71	2.89	4.99	6.01	0.00	2.93
05-Feb	0.00	3.41	2.64	4.57	5.24	0.00	2.64
Mean	0.00	3.57	2.83	4.88	6.16	1.39	-

4.2.2.3. Foraging speed of *Apis cerana indica* on mustard crop

The foraging speed of *Apis cerana indica* on a mustard crop was observed over several weeks in 2021-22 and at varied time intervals, as

shown in Table 4.9. Data on the foraging speed of *A. cerana indica* recorded during different weeks over the times revealed that the mean weekly foraging speed ranged between 3.49 to 4.49 seconds corresponding to the first and fourth week of the blooming period, respectively. The maximum time spent per flower by *A. cerana indica* (4.49 sec) was in the fourth week followed by the fifth week (4.08 sec), third week (4.00 sec), sixth week (3.93 sec), second week (3.72 sec), seventh week (3.64 sec) and first week (3.49 sec) of the flowering season.

The least time spent by *A. cerana indica* (3.01 sec) was recorded at 1200 hrs during the first week of the observation and the highest (10.97 sec) at 1600 hrs during the fourth week of the observation.

As far as times of the day were concerned, the mean foraging speed of *A. cerana indica* bees over different day hours ranged from 3.33 to 8.66 seconds. Significantly the maximum time spent per flower (8.66 sec) was recorded at 1600 hrs followed by that at 1400 hrs (6.88 sec), 1000 hrs (4.57 sec) and 1200 hrs (3.33 sec).

Table 4.9: Foraging speed of *Apis cerana indica* on the flowers of mustard crop under open pollination during *Rabi* 2021-22.

Date of observation	Foraging Speed (sec/ flower)						
	Hours of the day						
	800	1000	1200	1400	1600	1800	Mean
24-Dec	0.00	4.21	3.01	6.22	7.51	0.00	3.49
01-Jan	0.00	4.51	3.22	6.59	7.98	0.00	3.72
08-Jan	0.00	4.62	3.43	7.15	8.82	0.00	4.00
15-Jan	0.00	4.92	3.62	7.42	10.97	0.00	4.49
22-Jan	0.00	4.59	3.53	7.22	9.12	0.00	4.08
29-Jan	0.00	4.71	3.39	6.99	8.51	0.00	3.93
05-Feb	0.00	4.41	3.14	6.57	7.74	0.00	3.64
Mean	0.00	4.57	3.33	6.88	8.66	0.00	-

4.2.2.4. Comparative foraging speed of different bee species on mustard crop

Data on the comparative foraging speed of different bee species on mustard flowers at different hours of the day have been presented in Table 4.10. The time spent per flower by three bee species differed significantly.

The mean foraging speed during different hours of the day varied from 1.46 to 3.66 seconds for *A. mellifera*. It spent the least time per flower 1.46 seconds at 1800 hrs, which was followed by 2.33, 2.49, 2.88 and 3.66 seconds at 1200, 1000, 1600 and 1400 hours, respectively. The mean foraging speed varied from 1.39 to 6.16 seconds for *A. dorsata* during different hours of the day. It had spent an average time per flower of 1.39 seconds during 1800 hrs as compared to other *Apis* species followed by 2.83, 3.57, 4.88 and 6.16 seconds at 1200, 1000, 1400 and 1600 hrs, respectively. In the end, the mean foraging speed during different hours of the day varied from 3.33 to 8.66 seconds for *A. cerana indica*. It spent a maximum time per flower of 8.66 seconds at 1600 hrs. It followed by 6.88, 4.57 and 3.33 seconds at 1400, 1000 and 1200 hrs, respectively. Hence, it was found to be the least effective in pollination as it spent the highest time per flower.

Table 4.10: Comparative foraging speed of different honey bee species on the flowers of mustard crop under open pollination during Rabi 2021-22.

Foraging time (Hours of the day)	Foraging Speed (sec/ flower)			
	<i>Apis mellifera</i>	<i>Apis dorsata</i>	<i>Apis cerana indica</i>	Mean
800	0.00	0.00	0.00	0.00
1000	2.49	3.57	4.57	3.54
1200	2.33	2.83	3.33	2.83
1400	3.66	4.88	6.88	5.14
1600	2.88	6.16	8.66	5.90
1800	1.46	1.39	0.00	0.95
Mean	2.14	3.14	3.91	-

4.2.3. Foraging rate of different bee species on mustard crop

Observations on the foraging rate of different species of honey bee on the flowers of the mustard crop were recorded on the first day of every standard meteorological week at two-hour intervals starting from 0800 hours to 1800 hours from the last week of December 2021 to the first week of February 2022. The foraging speed was recorded in terms of the number of flowers visited per minute. In general, due to very low temperatures in the morning hours in the weeks of December 2021 and January 2022, there was no honey bee activity at 0800 hrs all through the study period. However, the

very negligible activity of different honey bee species was observed at 1800 hrs in the evening also.

4.2.2.1. Foraging rate of *A. mellifera* on mustard crop

The foraging rate of *Apis mellifera* on the mustard crop was observed over several weeks in 2021-22 and at varied time intervals, as shown in Table 4.11. Data on the foraging rate of *A. mellifera* recorded during different weeks over the times revealed that the mean weekly foraging rate ranged between 6.67 to 20.33 flowers visited/ min corresponding to the first and fourth week of the blooming period, respectively. Following a progressive increase to the highest level at peak blooming, i.e., the fourth week (20.33 flowers visited /min), it gradually decreased to 8.33 flowers visited /min as flowering came to an end (seventh week).

At 1200 hours during the fourth week of the observation, the maximum foraging rate of *A. mellifera* (30.00 flowers visited/min) was reported, while the lowest (7.00 flowers visited/min) was recorded at 1400 hrs during the first week of the observation. During the first, second, and seventh weeks of the monitoring period, *A. mellifera* showed no foraging activity at 1800 hrs.

The mean foraging rate of *A. mellifera* bees throughout different day hours ranged from 10.71 to 21.43 flowers visited/min, regardless of the week. At 1200 hours, *A. mellifera* had the highest foraging rate (21.43 flowers visited/min), followed by 1600 hours (18.57 flowers visited/min), 1000 hours (14.43 flowers visited/min), 1400 hours (13.00 flowers visited/min), and 1800 hours (10.71 flowers visited/min).

Table 4.11: Foraging rate of *Apis mellifera* on the flowers of mustard crop under open pollination during *Rabi* 2021-22.

Date of observation	Forging Rate (No. of flower/ min)						
	Hours of the day						
	800	1000	1200	1400	1600	1800	Mean
24-Dec	0.00	9.00	13.00	7.00	11.00	0.00	6.67
01-Jan	0.00	14.00	21.00	13.00	17.00	0.00	10.83
08-Jan	0.00	17.00	26.00	16.00	22.00	18.00	16.50
15-Jan	0.00	22.00	30.00	19.00	27.00	24.00	20.33
22-Jan	0.00	16.00	25.00	15.00	22.00	19.00	16.17
29-Jan	0.00	12.00	19.00	11.00	18.00	14.00	12.33
05-Feb	0.00	11.00	16.00	10.00	13.00	0.00	8.33
Mean	0.00	14.43	21.43	13.00	18.57	10.71	-

4.2.2.2. Foraging rate of *A. dorsata* on mustard crop

The foraging rate of *Apis dorsata* on the mustard crop was observed over several weeks in 2021-22 and at varied time intervals, as shown in Table 4.12. Data on the foraging rate of *A. dorsata* recorded during different weeks over the times revealed that the mean weekly foraging rate ranged between 3.33 to 16.17 flowers visited / min corresponding to the first and fourth week of the blooming period, respectively. Following a progressive increase to the highest level at peak blooming, i.e., the fourth week (16.17 flowers visited /min), it gradually decreased to 5.00 flowers/min as flowering came to an end (seventh week).

At 1200 hours during the fourth week of the observation, the maximum foraging rate of *A. dorsata* (25.00 flowers visited/min) was reported, while the lowest (2.00 flowers visited/min) was recorded at 1600 hrs during the first week of the observation. During the first, second, sixth and seventh weeks of the monitoring period, *A. dorsata* showed no foraging activity at 1800 hrs.

The mean foraging rate of *A. dorsata* bees throughout different day hours ranged from 6.57 to 16.43 flowers visited/min, regardless of the week. At 1200 hours, *A. dorsata* had the highest foraging rate (16.43 flowers visited/min), followed by 1000 hours (13.29 flowers visited/min), 1400 hours (9.71 flowers visited/min), 1600 hours (8.00 flowers visited/min), and 1800 hours (6.57 flowers visited/min).

Table 4.12: Foraging rate of *Apis dorsata* on the flowers of mustard crop under open pollination during *Rabi* 2021-22.

Date of observation	Forging Rate (No. of flower/ min)						
	Hours of the day						
	800	1000	1200	1400	1600	1800	Mean
24-Dec	0.00	6.00	8.00	4.00	2.00	0.00	3.33
01-Jan	0.00	11.00	16.00	9.00	8.00	0.00	7.33
08-Jan	0.00	17.00	21.00	12.00	11.00	14.00	12.50
15-Jan	0.00	22.00	25.00	17.00	14.00	19.00	16.17
22-Jan	0.00	17.00	20.00	11.00	10.00	13.00	11.83
29-Jan	0.00	12.00	14.00	9.00	6.00	0.00	6.83
05-Feb	0.00	8.00	11.00	6.00	5.00	0.00	5.00
Mean	0.00	13.29	16.43	9.71	8.00	6.57	-

4.2.2.3. Foraging rate of *A. cerana indica* on mustard crop

The foraging rate of *Apis cerana indica* on the mustard crop was observed over several weeks in 2021-22 and at varied time intervals, as shown in Table 4.13. Data on the foraging rate of *A. cerana indica* recorded during different weeks over the times revealed that the mean weekly foraging rate ranged between 1.17 to 10.67 flowers visited / min corresponding to the first and fourth week of the blooming period, respectively. Following a progressive increase to the highest level at peak blooming, i.e., the fourth week (10.67 flowers visited /min), it gradually decreased to 2.50 flowers/min as flowering came to an end (seventh week).

At 1200 hours during the fourth week of the observation, the maximum foraging rate of *A. cerana indica* (21.00 flowers visited/min) was reported, while the lowest (1.00 flowers visited/min) was recorded at 1400 hrs during the first week of the observation. During the first week at 1600 hrs and 1800 hrs across all of the weeks of the monitoring period, *A. cerana indica* showed no foraging activity.

The mean foraging rate of *A. cerana indica* bees throughout different day hours ranged from 5.14 to 12.29 flowers visited/min, regardless of the week. At 1200 hours, *A. cerana indica* had the highest foraging rate (12.29 flowers visited/min), followed by 1000 hours (9.86 flowers visited/min), 1400 hours (7.00 flowers visited/min) and 1600 hours (5.14 flowers visited/min).

Table 4.13: Foraging rate of *Apis cerana indica* on the flowers of mustard crop under open pollination during *Rabi* 2021-22.

Date of observation	Forging Rate (No. of flower/ min)						
	Hours of the day						
	800	1000	1200	1400	1600	1800	Mean
24-Dec	0.00	2.00	4.00	1.00	0.00	0.00	1.17
01-Jan	0.00	8.00	12.00	6.00	5.00	0.00	5.17
08-Jan	0.00	13.00	17.00	10.00	8.00	0.00	8.00
15-Jan	0.00	18.00	21.00	14.00	11.00	0.00	10.67
22-Jan	0.00	15.00	16.00	11.00	7.00	0.00	8.17
29-Jan	0.00	9.00	10.00	4.00	3.00	0.00	4.33
05-Feb	0.00	4.00	6.00	3.00	2.00	0.00	2.50
Mean	0.00	9.86	12.29	7.00	5.14	0.00	-

4.2.2.4. Comparative foraging speed of different bee species on mustard crop

Data on the comparative foraging rate of different bee species on mustard flowers at different hours of the day have been presented in Table 4.14. The number of flowers visited/ min by three bee species differed significantly. The mean foraging rate during different hours of the day varied from 10.71 to 21.43 flowers visited/ min for *A. mellifera*. It had the highest foraging rate as compared to other *Apis* species (21.43 flowers visited/ min) at 1200 hrs, which was followed by 18.57, 14.43, 13.00 and 10.71 flowers visited/ min at 1600, 1000, 1400 and 1800 hours, respectively. Hence, it was found to be most effective in pollination as it spent the highest number of flowers/ min. The mean foraging rate varied from 6.57 to 16.43 flowers visited/ min for *A. dorsata*. It had the average foraging rate as compared to other *Apis* species (16.43 flowers visited/ min) at 1200 hrs, which was followed by 13.29, 9.71, 8.00 and 6.57 flowers visited/ min at 1000, 1400, 1600 and 1800 hours, respectively. In the end, the mean foraging rate during different hours of the day varied from 5.14 to 12.29 flowers visited/ min for *A. cerana indica*. It had the least foraging rate as compared to other *Apis* species i.e., 12.29 flowers visited/ min at 1200 hrs, which was followed by 9.86, 7.00 and 5.14 flowers visited/ min at 1000, 1400 and 1800 hours, respectively. Hence, it was found to be the least effective in pollination as it spent the lowest number of flowers/ min.

Table 4.14: Comparative foraging rate of different honey bee species on the flowers of mustard crop under open pollination during *Rabi* 2021-22.

Foraging time (Hours of the day)	Mean number of flowers visited/ min			
	<i>Apis mellifera</i>	<i>Apis dorsata</i>	<i>Apis cerana indica</i>	Mean
800	0.00	0.00	0.00	0.00
1000	14.43	13.29	9.86	12.52
1200	21.43	16.43	12.29	16.71
1400	13.00	9.71	7.00	9.90
1600	18.57	8.00	5.14	10.57
1800	10.71	6.57	0.00	5.76
Mean	13.02	9.00	5.71	-

4.3 To study the different bee attractant for attract the *Apis mellifera* in mustard.

The effect of attractants on *A. mellifera* visitation was investigated, and observations on bee visitation to mustard crops sprayed with various bee attractants under open pollination conditions starting at 10% flowering stage were recorded and briefly described based on the number of sprays.

4.3.1 First spray

The efficacy of several bee attractant sprays in the mustard crop was evaluated during the flowering stage with the first spray at 10% flowering stage to achieve proper and efficient pollination and improve the qualitative and quantitative characteristics of the mustard, and the results are listed in Table 4.15.

The treatments applied to the crop the day before spray was found to be non-significant. Bee activity ranged from 19.67 to 20.67 bees/m²/5min at this time.

The efficiency of the treatment 1 day after spraying with Bee-Q @ 1.25 per cent was found to be considerably more successful and superior in attracting greater numbers of bees, with 40.33 bees/m²/5min, followed by Jaggery @ 10 per cent with 39.00 bees/m²/5min. Sugarcane juice @10 per cent and sugar solution @ 10 per cent were found at par which attracted 36.33 and 35.67 bees/m²/5min, respectively. The subsequent treatments drew *A. mellifera* visits ranging from 26.33 to 32.67 bees/m²/5min, which was significantly lower than the previous treatments but still attracted more bees than open pollination without treatment (23.33 bees/m²/5min).

A similar pattern of bee visits to the treated plots was seen on the third day after the first spray. Bee-Q @ 1.25 per cent was determined to be the most successful and superior treatment in attracting more bees, drawing 35.33 bees/m²/5min, followed by Jaggery @ 10 per cent, which attracted 31.67 bees/m²/5min. Sugarcane juice @10 per cent and sugar solution @ 10 per cent were found at par which attracted 28.33 and 35.67 bees/m²/5min, respectively. The rest of the treatments attracted *A. mellifera* visits varying

from 26.00 to 23.00 bees/m²/5min, which were significantly lower than the above treatments but attracted more bees than Coconut water @ 10 per cent (21.33 bees/m²/5min), which was statistically at par to open pollination without treatment (21.67 bees/m²/5min).

Treatments Bee-Q @ 1.25 per cent and Jaggery @ 10 per cent were shown to be efficacious in attracting the maximum number of bees on the 5th day following the first spray, with 28.33 and 27.33 bees/m²/5min, respectively, being superior to other treatments with statistically similar results. Sugarcane

Table 4.15: Effectiveness of different bee attractants in 1st spray to attract the *Apis mellifera* L. in mustard crop during Rabi 2021-22.

Treatments	Number of bee visits/m ² /5 min				
	1 DBS	1 DAS	3 DAS	5 DAS	Average
T1: Open pollination with Sugar solution @ 10%	20.33 (4.56)*	35.67 (6.01)	27.67 (5.31)	25.00 (5.05)	29.44 (5.47)
T2: Open pollination with Coconut water @ 10%	20.00 (4.53)	26.33 (5.18)	21.33 (4.67)	22.33 (4.78)	23.33 (4.88)
T3: Open pollination with Jaggery @ 10%	20.00 (4.53)	39.00 (6.28)	31.67 (5.67)	27.33 (5.28)	32.67 (5.76)
T4: Open pollination with Coriander @ 1.25%	19.67 (4.49)	29.33 (5.46)	23.00 (4.85)	23.00 (4.85)	25.11 (5.06)
T5: Open pollination with Onion solution @ 10%	20.33 (4.56)	31.00 (5.61)	24.33 (4.98)	23.67 (4.92)	26.33 (5.18)
T6: Open pollination with Sugarcane juice @ 10%	20.67 (4.6)	36.33 (6.07)	28.33 (5.37)	26.33 (5.18)	30.33 (5.55)
T7: Open pollination with Bee-Q @ 1.25 %	20.67 (4.6)	40.33 (6.39)	35.33 (5.99)	28.33 (5.37)	34.67 (5.93)
T8: Open pollination with Pomegranate juice @ 10%	19.67 (4.49)	32.67 (5.76)	26.00 (5.15)	24.33 (4.98)	27.67 (5.31)
T9: Open pollination Without Treatment (Control)	19.67 (4.49)	23.33 (4.88)	21.67 (4.71)	20.67 (4.60)	21.89 (4.73)
C.D. at 5%	NS	0.086	0.090	0.111	0.052
SEm ±	0.039	0.028	0.029	0.036	0.017

*values in parentheses are square root transformed; NS- Non significant; DBS – Day Before Spray; DAS – Day After Spray

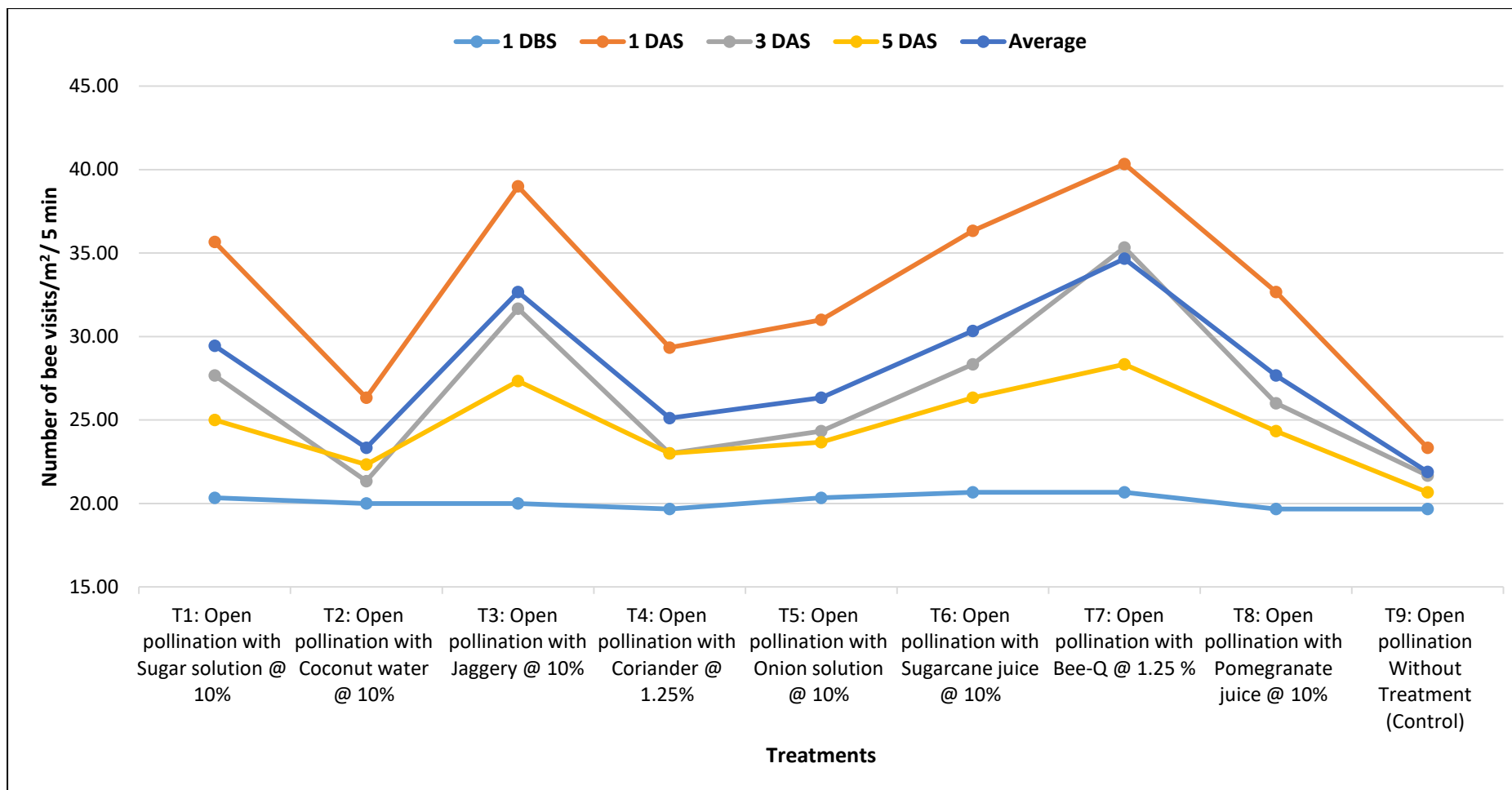


Figure 4.2: Graph showing the effectiveness of different bee attractants in 1st spray to attract the *Apis mellifera* L. in mustard crop during *Rabi* 2021-22.

juice @ 10 per cent, which attracted 26.33 bees/m²/5min, was followed by Sugar solution @ 10 per cent, which attracted 25.00 bees/m²/5min and was statistically at par to Pomegranate juice @ 10 per cent, which attracted 24.33 bees/m²/5min. The least successful treatment, however, was Coconut water @ 10 per cent, which attracted 22.33 bees/m²/5min, compared to the untreated control, which attracted 20.67 bees/m²/5min.

On average, the plot treated with Bee-Q @ 1.25 per cent was determined to be the most successful and superior treatment in attracting more bees, drawing 34.67 bees/m²/5min, followed by Jaggery @ 10 per cent, which attracted 32.67 bees/m²/5min. Furthermore, sugarcane juice @ 10 per cent attracted 30.33 bees/m²/5min, whereas sugar solution @ 10 per cent attracted 29.44 bees/m²/5min. Pomegranate juice @ 10 per cent (27.67 bees/m²/5min), Onion solution @ 10 per cent (26.33 bees/m²/5min), Coriander @ 1.25 per cent (25.11 bees/m²/5min) and Coconut water @ 10 per cent (23.33 bees/m²/5min) were the remaining treatments that attracted *A. mellifera* visits varying significantly. All of these treatments were much less effective in attracting visitors than the previous treatments, although they did attract more bees than open pollination without treatment (21.89 bees/m²/5min).

4.3.2 Second spray

The efficacy of several bee attractant sprays in the mustard crop was evaluated during the flowering stage with the second spray in order to achieve proper and efficient pollination and improve the qualitative and quantitative characteristics of the mustard, and the results are listed in Table 4.16.

A day before the second spray, bee activity of *A. mellifera* was observed ranging from 20.00 to 23.33 bees/m²/5min. The effectiveness of the treatment Bee-Q @ 1.25 per cent was found at 23.33 bees/m²/5min as the flowering stage is going to complete. The least influencing treatment observed was Coconut water @ 10 per cent (20.33 bees/m²/5min) which was statistically at par with untreated control (20.00 bees/m²/5min).

The efficiency of the treatment 1 day after the second spray with Bee-Q @ 1.25 per cent was found to be considerably more successful and superior in attracting greater numbers of bees, with 43.67 bees/m²/5min, followed by

Table 4.16: Effectiveness of different bee attractants in 2nd spray to attract the *Apis mellifera* L. in mustard crop during Rabi 2021-22.

Treatments	Number of bee visits/m ² /5 min				
	1 DBS	1 DAS	3 DAS	5 DAS	Average
T1: Open pollination with Sugar solution @ 10%	22.00 (4.74)	37.67 (6.18)	34.33 (5.9)	27.67 (5.31)	33.22 (5.81)
T2: Open pollination with Coconut water @ 10%	20.33 (4.56)	33.67 (5.85)	28.00 (5.34)	23.67 (4.92)	28.44 (5.38)
T3: Open pollination with Jaggery @ 10%	22.67 (4.81)	41.67 (6.49)	36.67 (6.1)	29.67 (5.49)	36.00 (6.04)
T4: Open pollination with Coriander @ 1.25%	20.67 (4.6)	34.33 (5.9)	29.67 (5.49)	24.67 (5.02)	29.56 (5.48)
T5: Open pollination with Onion solution @ 10%	21.33 (4.67)	35.00 (5.96)	32.00 (5.7)	25.33 (5.08)	30.78 (5.59)
T6: Open pollination with Sugarcane juice @ 10%	22.33 (4.78)	39.67 (6.34)	35.00 (5.96)	28.33 (5.37)	34.33 (5.90)
T7: Open pollination with Bee-Q @ 1.25 %	23.33 (4.88)	43.67 (6.65)	37.67 (6.18)	30.33 (5.55)	37.22 (6.14)
T8: Open pollination with Pomegranate juice @ 10%	21.67 (4.71)	36.00 (6.04)	32.67 (5.76)	26.33 (5.18)	31.67 (5.67)
T9: Open pollination Without Treatment (Control)	20.00 (4.53)	27.67 (5.31)	24.00 (5.95)	21.33 (4.67)	24.33 (4.98)
C.D. at 5%	0.098	0.102	0.133	0.106	0.067
SEm ±	0.032	0.034	0.044	0.035	0.022

*values in parentheses are square root transformed; NS- Non significant; DBS – Day Before Spray; DAS – Day After Spray

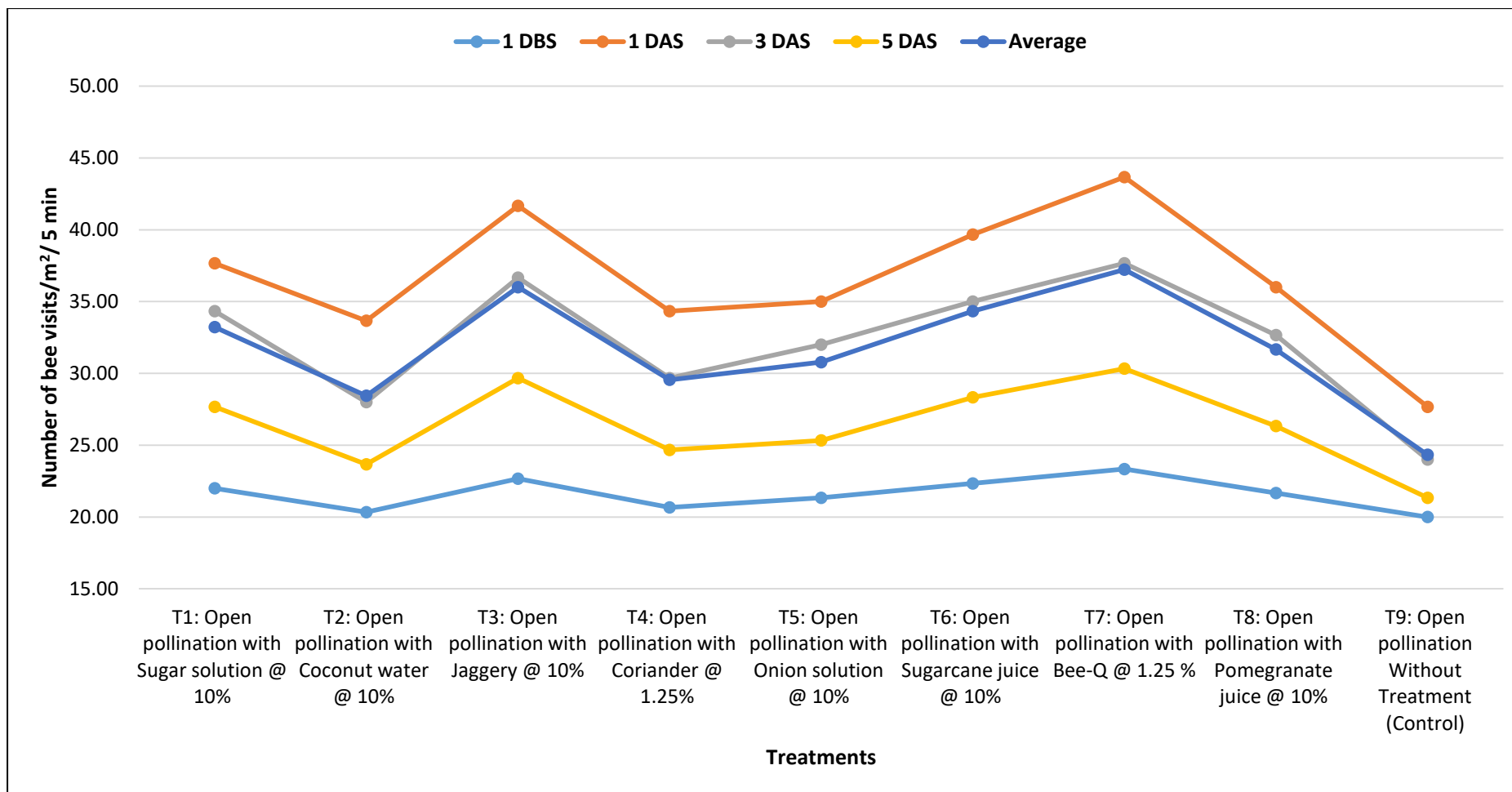


Figure 4.3: Graph showing the effectiveness of different bee attractants in 2nd spray to attract the *Apis mellifera* L. in mustard crop during *Rabi* 2021-22.

Jaggery @ 10 per cent with 41.67 bees/m²/5min. Sugarcane juice @10 per cent and sugar solution @ 10 per cent were found at par which attracted 39.67 and 37.67 bees/m²/5min, respectively. The subsequent treatments drew *A. mellifera* visits ranging from 33.67 to 36.00 bees/m²/5min, which was significantly lower than the previous treatments but still attracted more bees than open pollination without treatment (27.67 bees/m²/5min).

A similar pattern of bee visits to the treated plots was seen on the third day after the second spray. Bee-Q @ 1.25 per cent was determined to be the most successful and superior treatment in attracting more bees, drawing 37.67 bees/m²/5min which was at par with Jaggery @ 10 per cent, which attracted 36.67 bees/m²/5min. Sugarcane juice @10 per cent and sugar solution @ 10 per cent were found at par which attracted 35.00 and 34.33 bees/m²/5min, respectively. The rest of the treatments attracted *A. mellifera* visits varying from 28.00 to 32.67 bees/m²/5min, which were significantly lower than the above treatments but attracted more bees than open pollination without treatment (24.00 bees/m²/5min).

Treatments Bee-Q @ 1.25 per cent and Jaggery @ 10 per cent were shown to be efficacious in attracting the maximum number of bees on the 5th day following the second spray, with 30.33 and 29.67 bees/m²/5min, respectively, being superior to other treatments with statistically similar results. Sugarcane juice @ 10 per cent attracted 28.33 bees/m²/5min which was statistically at par with sugar solution @ 10 per cent attracting 27.67 bees/m²/5min followed by Pomegranate juice @ 10 per cent with 26.33 bees/m²/5min. The least successful treatment, however, was Coconut water @ 10 per cent, which attracted 23.67 bees/m²/5min, compared to the untreated control, which attracted 21.33 bees/m²/5min.

On average, the plot treated with Bee-Q @ 1.25 per cent was determined to be the most successful and superior treatment in attracting more bees, drawing 37.22 bees/m²/5min, followed by Jaggery @ 10 per cent, which attracted 36.00 bees/m²/5min. Furthermore, sugarcane juice @ 10 per cent attracted 34.33 bees/m²/5min, whereas sugar solution @ 10 per cent attracted 33.22 bees/m²/5min. Pomegranate juice @ 10 per cent (31.67 bees/m²/5min), Onion solution @ 10 per cent (30.78 bees/m²/5min), Coriander @ 1.25 per cent (29.56 bees/m²/5min), and Coconut water @ 10 per cent (28.44 bees/m²/5min) were the remaining treatments that attracted *A.*

mellifera visits varying significantly. All of these treatments were much less effective in attracting visitors than the previous treatments, although they did attract more bees than open pollination without treatment (24.33 bees/m²/5min).

4.3.3 Third spray

The efficacy of several bee attractant sprays in the mustard crop was evaluated during the flowering stage with the third spray in order to achieve proper and efficient pollination and improve the qualitative and quantitative characteristics of the mustard, and the results are listed in Table 4.17.

A day before the third spray, bee activity of *A. mellifera* was observed ranging from 21.67 to 25.00 bees/m²/5min. The effectiveness of the treatment Bee-Q @ 1.25 per cent was found at 25.00 bees/m²/5min as the flowering stage is going to complete. The least influencing treatment observed was Coconut water @ 10 per cent (21.67 bees/m²/5min) which was statistically at par with untreated control (21.33 bees/m²/5min).

The efficiency of the treatment 1 day after the third spray with Bee-Q @ 1.25 per cent was found to be considerably more successful and superior in attracting greater numbers of bees, with 44.67 bees/m²/5min which was at par with Jaggery @ 10 per cent (44.33 bees/m²/5min) and sugarcane juice @ 10 per cent, 43.67 bees/m²/5min). The second-best treatment was, sugar solution @ 10 per cent which attracted 42.33 bees/m²/5min and was statistically at par with Pomegranate juice @ 10 per cent (41.67 bees/m²/5min). The subsequent treatments drew *A. mellifera* visits ranging from 36.00 to 39.67 bees/m²/5min, which was significantly lower than the previous treatments but still attracted more bees than open pollination without treatment (29.33 bees/m²/5min).

A similar pattern of bee visits to the treated plots was seen on the third day after the third spray. Bee-Q @ 1.25 per cent was determined to be the most successful and superior treatment in attracting more bees, drawing 37.67 bees/m²/5min which was at par with Jaggery @ 10 per cent, which attracted 36.67 bees/m²/5min. Sugarcane juice @ 10 per cent and sugar solution @ 10 per cent were found at par which attracted 35.00 and 34.33 bees/m²/5min,

Table 4.17: Effectiveness of different bee attractants in 3rd spray to attract the *Apis mellifera* L. in mustard crop during Rabi 2021-22.

Treatments	Number of bee visits/m ² /5 min				
	1 DBS	1 DAS	3 DAS	5 DAS	Average
T1: Open pollination with Sugar solution @ 10%	23.00 (4.85)*	42.33 (6.54)	34.33 (5.9)	29.67 (5.49)	35.44 (6.00)
T2: Open pollination with Coconut water @ 10%	21.67 (4.71)	36.00 (6.04)	30.33 (5.55)	25.33 (5.08)	30.56 (5.57)
T3: Open pollination with Jaggery @ 10%	24.67 (5.02)	44.33 (6.7)	36.67 (6.1)	30.33 (5.55)	37.11 (6.13)
T4: Open pollination with Coriander @ 1.25%	22.33 (4.78)	37.67 (6.18)	31.00 (5.61)	26.33 (5.18)	31.67 (5.67)
T5: Open pollination with Onion solution @ 10%	22.33 (4.78)	39.67 (6.34)	32.00 (5.7)	27.67 (5.31)	33.11 (5.80)
T6: Open pollination with Sugarcane juice @ 10%	23.67 (4.92)	43.67 (6.65)	35.00 (5.96)	31.33 (5.64)	36.33 (6.07)
T7: Open pollination with Bee-Q @ 1.25 %	25.00 (5.05)	44.67 (6.72)	37.67 (6.18)	33.33 (5.64)	37.89 (6.20)
T8: Open pollination with Pomegranate juice @ 10%	22.67 (4.81)	41.67 (6.49)	32.67 (5.76)	28.33 (5.37)	34.22 (5.89)
T9: Open pollination Without Treatment (Control)	21.33 (4.67)	29.33 (5.46)	26.33 (5.18)	23.00 (4.85)	26.22 (5.17)
C.D. at 5%	0.103	0.100	0.101	0.121	0.071
SEm ±	0.034	0.033	0.034	0.040	0.024

*values in parentheses are square root transformed; NS- Non significant; DBS – Day Before Spray; DAS – Day After Spray

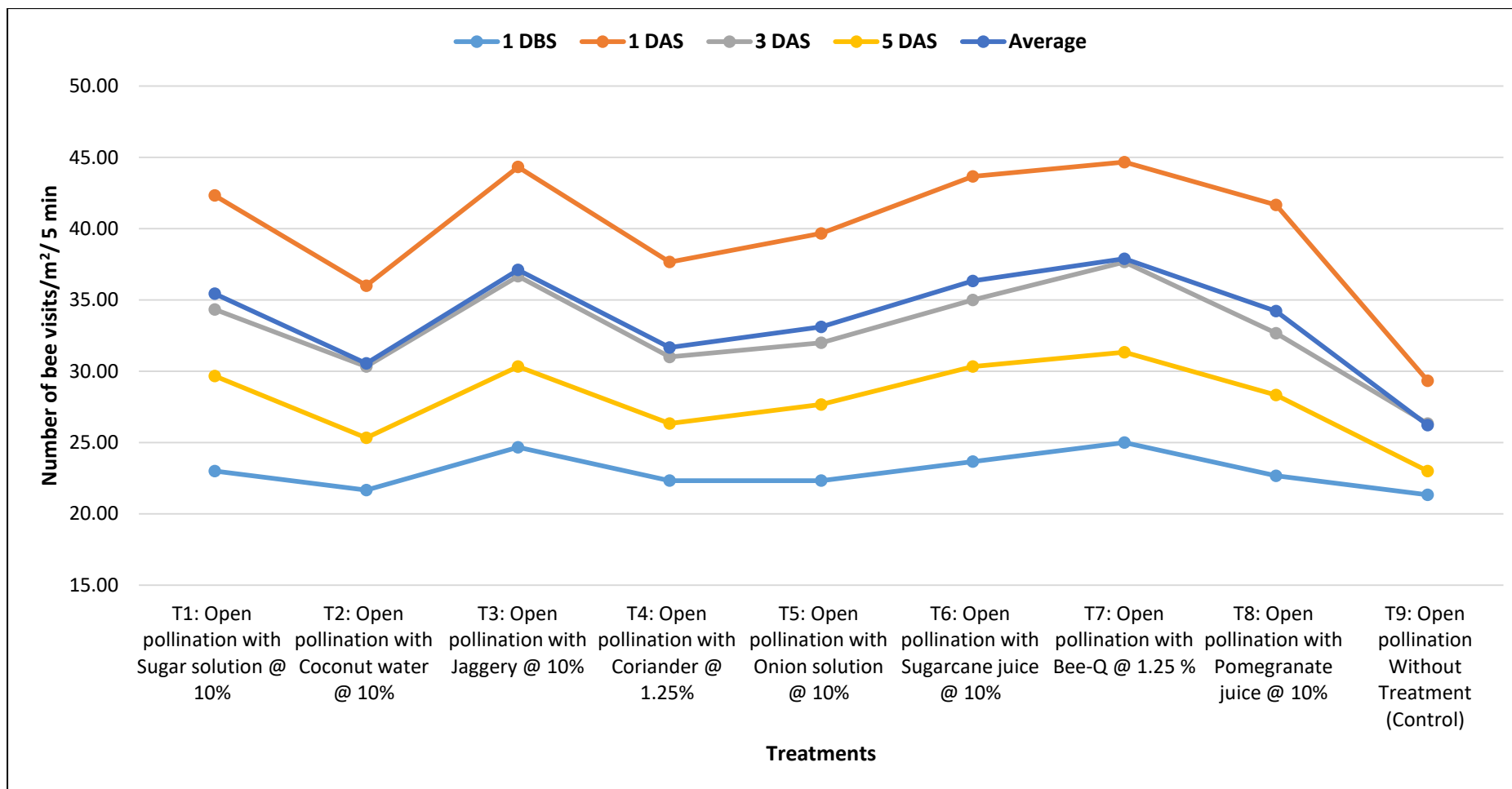


Figure 4.4: Graph showing the effectiveness of different bee attractants in 3rd spray to attract the *Apis mellifera* L. in mustard crop during *Rabi* 2021-22.

respectively. The rest of the treatments attracted *A. mellifera* visits varying from 30.33 to 32.67 bees/m²/5min, which were significantly lower than the above treatments but attracted more bees than open pollination without treatment (26.33 bees/m²/5min).

Treatments Bee-Q @ 1.25 per cent was shown to be efficacious in attracting the maximum number of bees on the 5th day following the third spray, with 33.33 bees/m²/5min, being superior to other treatments. Sugarcane juice @ 10 per cent attracting 31.33 bees/m²/5min and Jaggery @ 10 per cent attracted the 30.33 bees/m²/5min which was statistically at par with sugar solution @ 10 per cent attracting 28.33 bees/m²/5min followed by Pomegranate juice @ 10 per cent (26.33 bees/m²/5min) which was at par with Onion solution @ 10 per cent (27.67 bees/m²/5min). The least successful treatment, however, was Coconut water @ 10 per cent, which attracted 25.33 bees/m²/5min, compared to the untreated control, which attracted 23.00 bees/m²/5min.

On an average, the plot treated with Bee-Q @ 1.25 per cent was determined to be the most successful and superior treatment in attracting more bees, drawing 37.89 bees/m²/5min which was at par with Jaggery @ 10 per cent attracting 37.11 bees/m²/5min which was also at par with sugarcane juice @ 10 per cent attracted 36.33 bees/m²/5min. Furthermore, sugar solution @ 10 per cent attracted 35.44 bees/m²/5min. Pomegranate juice @ 10 per cent (34.22 bees/m²/5min), Onion solution @ 10 per cent (33.11 bees/m²/5min), Coriander @ 1.25 per cent (31.67 bees/m²/5min), and Coconut water @ 10 per cent (30.56 bees/m²/5min) were the remaining treatments that attracted *A. mellifera* visits varying significantly. All of these treatments were much less effective in attracting visitors than the previous treatments, although they did attract more bees than open pollination without treatment (26.22 bees/m²/5min).

4.4 Impact of bee pollination on quality and quantity parameters of mustard.

For evaluating the impact of various combinations of bee pollination on the quality and quantity parameters, eleven treatments were taken for

evaluation and were categorised into (OP) Open Pollination (T1 to T9), Caged with bee or (BP) Bee Pollination (T10) and Without Insect Pollination (WIP) or Caged without bees (T11). The data recorded on the effect of different modes of bee pollination on quantity and quality parameters, viz., number of siliquae/plants, siliqua length (cm), number of seeds/ siliquae, the total number of seeds/ plants, seed yield per plant (g) and 1000 seeds weight (g), are presented in Table 4.18. Data indicated that all the bee attractants sprayed were significantly effective on seed yield and yield attributing characters.

4.4.1 No. of siliquae/plant

Different combinations of the mode of pollinations were studied and the analysis of the observed data in Table 4.18 revealed that the application of various treatments had a significant effect on the number of siliquae per plant. The plot treated with Bee-Q @ 1.25 per cent under open pollination conditions was found superior over all other treatments in producing the highest mean number of siliquae *i.e.*, 209.17 siliquae per plant. This was followed by the plot treated with Jaggery @ 10 per cent under open pollination conditions producing 204.33 siliquae per plant, and Sugarcane juice @ 10 per cent producing 195.00 siliquae per plant. The next best combinations of pollination were the plots treated with sugar solution @ 10 per cent under open pollination, Pomegranate juice @ 10 per cent, onion solution @ 10 per cent, coriander @ 1.25 per cent and Coconut water @ 10 per cent under open pollination producing 190.50, 183.67, 177.67, 173.17 and 167.33 siliquae per plant, respectively. The plot in open pollination conditions without any spray produces 162.50 siliquae per plant and the crop plot caged with bees (or bee pollination) produces 157.33 siliquae per plant. The treatment combination in which the crop was caged without insect pollination was found to be the least effective pollination method in mustard crop and recorded the lowest mean *i.e.*, 150.50 siliquae per plant. From the foregoing discussion, it is clear that various bee attractants had a significant effect on mustard pollination under both experimental and field conditions.

4.4.2 Siliquae Length (cm)

Data on the effect of a different mode of pollinations indicated in Table 4.18 revealed that the application of various treatments had a significant effect

on the length of siliquae. The plot treated with Bee-Q @ 1.25 per cent under open pollination conditions was found superior over all other treatments in producing the highest mean length of siliquae *i.e.*, 4.55 cm per plant. This was followed by the plot treated with Jaggery @ 10 per cent under open pollination conditions producing 4.41 cm siliquae length per plant and Sugarcane juice @ 10 per cent producing 4.30 cm per plant. The next best combinations of pollination were the plots treated with sugar solution @ 10 per cent, Pomegranate juice @ 10 per cent, onion solution @ 10 per cent, coriander @ 1.25 per cent and Coconut water @ 10 per cent under open pollination producing 4.21, 4.07, 3.94, 3.80 and 3.71 cm per plant, respectively. The plot in open pollination conditions without any spray produces 3.61 cm siliquae length per plant and the crop plot caged with bees (or bee pollination) produces 3.50 cm siliquae length per plant. The treatment combination in which the crop was caged without insect pollination was found to be the least effective pollination method in mustard crops and recorded the lowest mean siliquae length *i.e.*, 3.21 cm per plant. From the foregoing discussion, it is clear that various bee attractants had a significant effect in increasing the siliquae length of mustard crops under both experimental and field conditions.

4.4.3 No. of seeds/ siliquae

Data on the effect of a different mode of pollinations indicated in Table 4.18 revealed that the application of various treatments had a significant effect on the no. of seeds/ siliquae. The plot treated with Bee-Q @ 1.25 per cent under open pollination conditions was found superior over all other treatments in producing the highest mean no. of seeds/ siliquae (15.70 seeds/ siliquae). This was followed by the plot treated with Jaggery @ 10 per cent under open pollination conditions producing 15.48 seeds/ siliquae and Sugarcane juice @ 10 per cent producing 14.47 seeds/ siliquae. The next best combinations of pollination were the plots treated with sugar solution @ 10 per cent, Pomegranate juice @ 10 per cent, onion solution @ 10 per cent, coriander @ 1.25 per cent and Coconut water @ 10 per cent under open pollination producing 14.19, 14.04, 13.74, 13.41 and 13.04 seeds/ siliquae, respectively. The plot in open pollination conditions without any spray produces 12.84 seeds/ siliquae and the crop plot caged with bees (or bee pollination)

produces 12.61 seeds/ siliquae. The treatment combination in which the crop was caged without insect pollination was found to be the least effective pollination method for the mustard crop and recorded the lowest mean no. of seeds/ siliquae (12.24 seeds/ siliquae). These results indicated that the application of attractants has a significant effect on increasing the number of seeds/pods. This was possible due to maximum visits of different species of honey bees that increased the impact of pollination.

4.4.4 Total no. of seeds/ plant

Data on the effect of a different mode of pollination indicated in Table 4.18 revealed that the application of various treatments had a significant effect on the total no. of seeds/ plants. The plot treated with Bee-Q @ 1.25 per cent under open pollination conditions was found superior over all other treatments in producing the highest mean no. of seeds/ plants (3198.63 seeds/ plant). This was followed by the plot treated with Jaggery @ 10 per cent under open pollination conditions producing 3158.62 seeds/ plant and Sugarcane juice @ 10 per cent producing 2822.59 seeds/ plant. The next best combinations of pollination were the plots treated with sugar solution @ 10 per cent, Pomegranate juice @ 10 per cent, onion solution @ 10 per cent, coriander @ 1.25 per cent and Coconut water @ 10 per cent under open pollination producing 2695.28, 2576.46, 2431.03, 2323.02 and 2176.47 seeds/ plant, respectively. The plot in open pollination conditions without any spray produces 2086.24 seeds/ plant and the crop plot caged with bees (or bee pollination) produces 1988.08 seeds/ plant. The treatment combination in which the crop was caged without insect pollination was found to be the least effective pollination method for the mustard crop and recorded the lowest mean no. of seeds/ plant (1749.58 seeds/ plant). These results indicated that the application of attractants has a significant effect on increasing the no. of seeds/plants.

4.4.5 Seed yield/ plant (g)

The quantitative seed production of the mustard crop is the ultimate expression of the symbiotic relationship it had with diverse floral visitors as a consequence of the pollination and fertilization process. As observed in this experiment, mustard yields an average of 8.79 to 13.78 g seeds/ plant and the

observations are listed in Table 4.18. The plot treated with Bee-Q @ 1.25 per cent under open pollination conditions was found superior over all other treatments in producing the highest mean seed yield/ plant (13.78g/ plant). This was followed by the plot treated with Jaggery @ 10 per cent under open pollination conditions producing 13.40g/ plant and Sugarcane juice @ 10 per cent producing 12.88g/ plant. The next best combinations of pollination were the plots treated with sugar solution @ 10 per cent, Pomegranate juice @ 10 per cent, onion solution @ 10 per cent, coriander @ 1.25 per cent and Coconut water @ 10 per cent under open pollination producing 12.37g, 11.99g, 11.50g, 10.97g and 10.32g / plant, respectively. The plot in open pollination conditions without any spray produces 9.76g/ plant and the crop plot caged with bees (or bee pollination) produces 9.15g/ plant. The treatment combination in which the crop was caged without insect pollination was found to be the least effective pollination method for the mustard crop and recorded the lowest mean seed yield/ plant (8.79g/ plant). These results indicated that the application of attractants has a significant effect on increasing the seed yield/ plant.

4.4.6 1000 seeds weight (g)

Seed weight is a direct indicator of seed health and vigour, and it is used to assess the economic characteristics (quantitative and qualitative) characteristics of the plant. A bolder and heavier seed is the outcome of proper post-pollination and fertilization growth processes, and it is seen to be superior to normal or shrivelled seeds. Especially in a crop like mustard where seed has much economic importance like edible oil extraction, cattle feed, etc., a bolder seed is an indicator of high oil extraction per cent. The 1000 seed weight thus is an index of basic seed characteristics. Different combinations of the mode of pollination were studied and the analysis of the observed data in Table 4.18 revealed that the insect pollination had a significant effect on the weight of 1000 seeds of the mustard crop. As observed in this experiment, the 1000 seeds' weight of the mustard crop ranges from 2.96g to 3.35g. The plot treated with Bee-Q @ 1.25 per cent under open pollination conditions was found superior over all other treatments in producing the highest mean 1000 seeds weight (3.35g). This was followed

by the plot treated with Jaggery @ 10 per cent under open pollination conditions producing 3.30g and Sugarcane juice @ 10 per cent producing 3.27g. The next best combinations of pollination were the plots treated with sugar solution @ 10 per cent, Pomegranate juice @ 10 per cent, onion solution @ 10 per cent, coriander @ 1.25 per cent and Coconut water @ 10 per cent under open pollination producing 3.23g, 3.19g, 3.19g, 3.14g and 3.10g, respectively. The plot in open pollination conditions without any spray produces 3.04g and the crop plot caged with bees (or bee pollination) produces 2.98g. The treatment combination in which the crop was caged without insect pollination was found to be the least effective pollination method for the mustard crop and recorded the lowest mean 1000 seeds weight (2.96g). These results indicated that the application of attractants has a significant effect in increasing the 1000 seeds' weight.

Table 4.18: Effect of bee pollination on quality and quantity parameters of mustard crop during *Rabi* 2021-22.

Treatments	No. of siliquae / plant	Siliquae Length (cm)	No. of seeds/ siliquae	Total no. of seeds/ plant	Seed yield/ plant (g)	1000 seeds weight (g)
T1: Open pollination with Sugar solution @ 10%	190.50	4.21	14.19	2695.28	12.37	3.23
T2: Open pollination with Coconut water @ 10%	167.33	3.71	13.04	2176.47	10.32	3.10
T3: Open pollination with Jaggery @ 10%	204.33	4.41	15.48	3158.62	13.40	3.30
T4: Open pollination with Coriander @ 1.25%	173.17	3.80	13.41	2323.02	10.97	3.14
T5: Open pollination with Onion solution @ 10%	177.67	3.94	13.74	2431.03	11.50	3.19
T6: Open pollination with Sugarcane juice @ 10%	195.00	4.30	14.47	2822.59	12.88	3.27
T7: Open pollination with Bee-Q @ 1.25 %	209.17	4.55	15.70	3198.63	13.78	3.35
T8: Open pollination with Pomegranate juice @ 10%	183.67	4.07	14.04	2576.46	11.99	3.19
T9: Open pollination Without Treatment (Control)	162.50	3.61	12.84	2086.24	9.76	3.04
T9: Caged with Bees or Bee Pollination (OP)	157.33	3.50	12.61	1988.08	9.15	2.98
T10: Caged without bees or Without Insect Pollination (WIP)	150.50	3.21	12.24	1749.58	8.79	2.96
C.D. at 5%	3.622	0.052	0.134	4.890	0.074	0.065
SEm ±	1.227	0.017	0.045	1.657	0.025	0.022

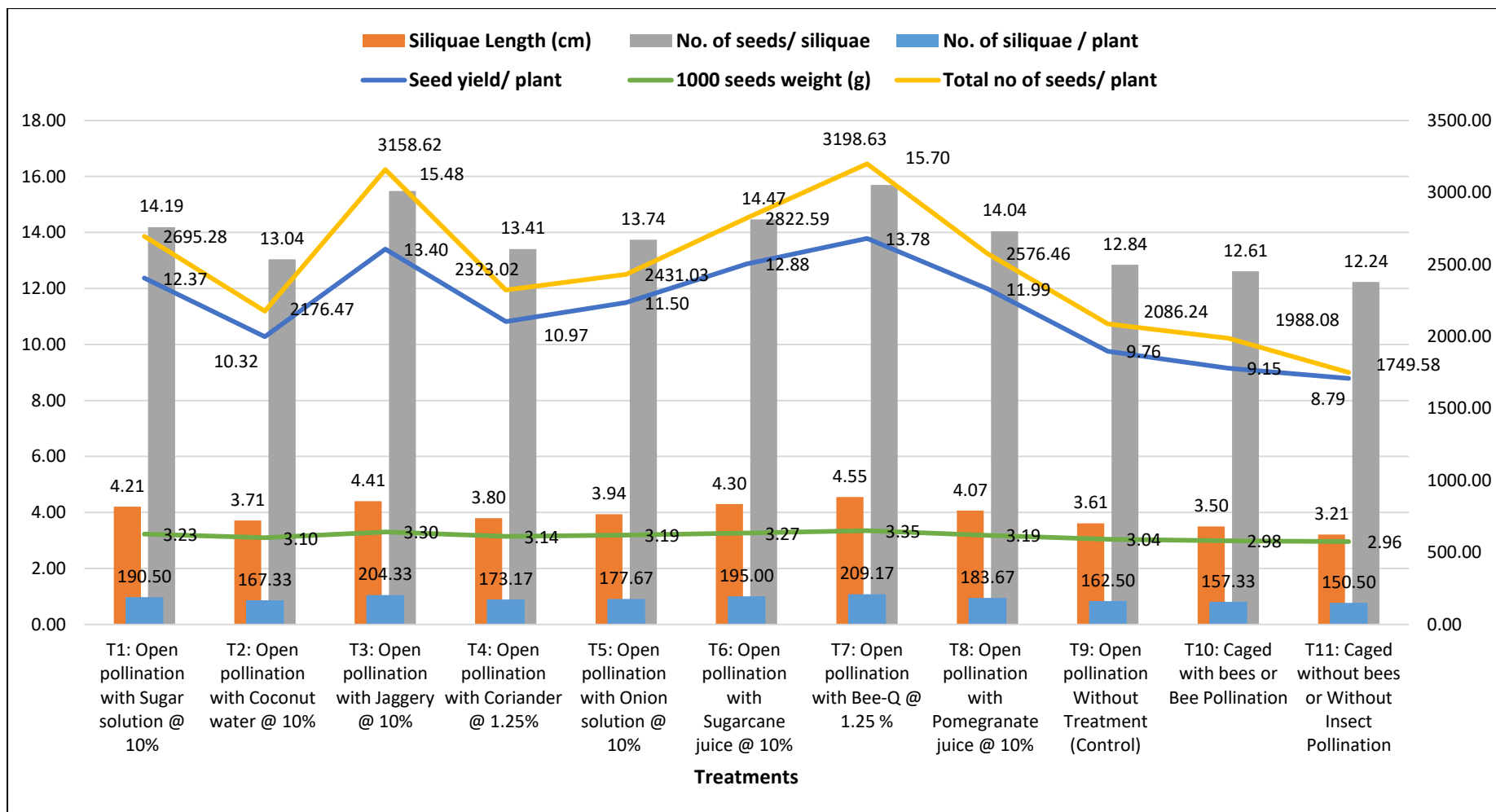


Figure 4.5: Graph showing the effect of bee pollination on quality and quantity parameters of mustard crop during *Rabi* 2021-22.

Chapter V

DISCUSSION

The result of investigation on “**Studies on the impact of Bee Pollination on yield parameters of Mustard (*Brassica juncea* L.)**” are presented in preceding chapters. The finding of the investigation are discussed in light of previously available information here under the following heads:

- 5.1 To study the pollinators fauna of mustard.
- 5.2 To study the foraging behaviour of honey bees in mustard crop.
- 5.3 To study the different bee attractant for attract the *Apis mellifera* in mustard.
- 5.4 Impact of bee pollination on quality and quantity parameters of mustard.

5.1 To study the pollinators fauna of mustard.

The experimental field was observed carefully during the study period and the insect pollinators visiting the mustard crop (*Brassica juncea* L.) were collected and identified with the help of insect collections and literature available in the Department of Entomology, Central Library and with the help of members of the advisory committee. All the identified insect visitors along with their scientific names and systemic positions are listed in Table 4.1.

The current investigation's findings are nearly identical to those published by previous researchers. Kunjwal *et al.* (2014) discovered 30 species from the Hymenoptera, Diptera, Lepidoptera, and Coleoptera groups visiting mustard, *B. juncea* flowers and we also recorded maximum hymenopteran insect pollinators. In comparison to other bees, *A. mellifera* was shown to be the most numerous species in all kinds of *B. juncea*. In addition, Kamel *et al.* (2015) discovered 21 insect pollinators from 14 families and four orders visiting canola, *B. napus* flowers. Ahmad (2005) found 22 and 16 Hymenopteran species, as well as 7 and 5 Dipteran species, visiting mustard blossoms. Honey bees were the most common Hymenoptera pollinators, followed by other insects. *Apis cerana*, *A. mellifera*, *Halictid* bees,

Halictus sp., and *Lasioglossum* sp. were the most common visitors and important pollinators of Brassica crops, according to Abrol (1989).

5.2 To study the foraging behaviour of honey bees in mustard crop.

5.2.1 Bee abundance of different bee species on mustard crop

Observations on the abundance of different species of honey bee on the flowers of the mustard crop were recorded on the first day of every standard meteorological week at two hours intervals starting from 0800 hours to 1800 hours from the last week of December 2021 to the first week of February 2022.

The current results correspond previous findings Khatkar (1996) found that the abundance of *A. dorsata*, *A. mellifera*, and *A. florea* on RH-8812 was 2.63, 3.20, and 6.50 bees/m²/min, respectively, and 1.93, 2.47, and 5.1 bees/m²/min on RH-30 and in the present investigations *A. mellifera*, *A. dorsata* and *A. indica* constituted 45.40, 34.37 and 20.23 per cent, respectively. At Hisar, the abundance of *A. mellifera*, *A. dorsata*, and *A. florea* on *B. rapa* was 8.89, 3.24, and 1.86 bees/m²/5 min, respectively, and they made up 51.78, 18.87, and 10.83 percent of the overall insect population, according to Priti (1996). *Apis florea* was not observed throughout the present investigation period. According to Singh *et al.* (2018), the order Hymenoptera contributed the most percent relative abundance and average insect population, and honeybee activity was maximum at 1200h and 1500h, respectively. But we recorded the bee activity maximum at 1400 hrs and minimum at 0800 hrs. The abundance and diversity of various insect pollinators on mustard (*Brassica juncea*) were researched by Goswami and Khan (2014). The mustard bloom was visited by 19 insect pollinators from the two orders *viz.*, Hymenoptera and Diptera, with Hymenopterans having the maximum abundance (percent of insect/ m²/2 min), followed by Dipterans and others. We also recorded maximum number of hymenopterans. The most frequent Hymenopterans were honeybees (*Apis* bees), followed by non-*Apis* bees and scolid wasps.

In contrast to the current findings, Roy *et al.* (2014) indicated that insect visits were most active during the middle of the day, from 12 p.m. to 2 p.m. The abundance of *A. dorsata* was the highest (18%) among the three

honey bee species, followed by *A. cerana* (15%) and *A. florea* (12%). (4 percent). It was discovered that varied meteorological conditions have an impact on honeybee abundance.

5.2.2. Foraging speed of different bee species on mustard crop

Observations on the foraging speed of different species of honey bee on the flowers of the mustard crop were recorded on the first day of every standard meteorological week at two-hour intervals starting from 0800 hours to 1800 hours from the last week of December 2021 to the first week of February 2022. The foraging speed was recorded in terms of time spent (seconds) per flower. In general, due to very low temperatures in the morning hours in the weeks of December 2021 and January 2022, there was no honey bee foraging at 0800 hrs all through the study period. However, the very negligible activity of different honey bee species was observed at 1800 hrs in the evening also.

The current findings support those of Rana and Kumar (1999), who found that *A. cerana indica* spent 22.1 percent more time per day pollinating cauliflower blooms than *A. mellifera*. Per hour, the average number of *A. cerana indica* and *A. mellifera* per inflorescence was 4.75 and 2.06, respectively. *A. cerana indica* pollen foragers, nectar foragers, and nectar robbers spent 5.14, 6.34, and 6.05 seconds on each blossom, respectively, while *A. mellifera* pollen foragers, nectar foragers, and nectar robbers spent 6.62, 7.37, and 5.26 seconds. According to Nagpal *et al.* (2020), the average duration spent per flower by different *Apis* spp. throughout different day periods ranged from 3.25 to 4.20 seconds. Over various day periods, the average duration spent per flower by several *Apis* spp. ranged from 3.25 to 4.20 seconds. At 1200-1400 h on *Brassica juncea*, *Apis mellifera*, *Apis dorsata*, and *Apis cerana indica* spent the least amount of time per flower (2.02 seconds, 2.38 seconds, and 2.97 seconds, respectively). According to Manhare *et al.* (2017), *Apis cerana indica* activity was greater in the third week of December 2016 (69.71 bees/5min/m²). It had the highest visitation at 1200 hours (98.62 bees/5min/m²). At 1200 hours, *Apis dorsata* had the highest foraging activity (61.12 bees/5min/m²). In *Apis cerana indica*, the

lowest was recorded at 1700 hours (1.25 bees/5 minutes/m²), whereas in *Apis dorsata*, the lowest was observed at 1700 hours (0.75 bees/5 minutes/m²). *Apis cerana* visits peaked at 1100 hours (66.06 bees/5min/m²), according to Painkra and Shaw (2016). At 1100 hrs. (11.75 bees/5min/m²), *Apis dorsata* had the highest foraging activity, whereas at 1700 hrs. (0.50 bee/5min/m²), it had the lowest. According to Choudhary and Kumar (2007), *Apis mellifera* began foraging around 09:05 a.m., peaked between 11:00 and 16:00 a.m., and then began to fall dramatically.

5.2.3. Foraging rate of different bee species on mustard crop

Observations on the foraging rate of different species of honey bee on the flowers of the mustard crop were recorded on the first day of every standard meteorological week at two-hour intervals starting from 0800 hours to 1800 hours from the last week of December 2021 to the first week of February 2022. The foraging speed was recorded in terms of the number of flowers visited per minute. In general, due to very low temperatures in the morning hours in the weeks of December 2021 and January 2022, there was no honey bee activity at 0800 hrs all through the study period. However, the very negligible activity of different honey bee species was observed at 1800 hrs in the evening also.

The current findings are in agreement with those of the other professionals. According to Kumar *et al.* (2003), the foraging rate (number of capitulum visited by bees/minutes) indicated that *Apis mellifera* L. visited a larger number of capitulum (12.85) as compared to *Apis cerana indica* (10.98). For both species, the foraging rate was highest at 1:00 p.m. and lowest at 10:00 a.m. The foraging speed (time spent by a bee per capitulum in seconds) demonstrated that *A. mellifera* spent more time (6.69 seconds / capitulum) than *Apis cerana*, with the peak at 2:00 pm and lowest at 10:00 am. Choudhary and Singh (2007) found that the mean foraging rate of *A. mellifera* (5.0) was greater than that of *A. dorsata* (3.92) and *A. florea* (2.91). Because of the low temperature and fog water deposited on the floral parts, *A. mellifera* was not seen on coriander flowers until 07:00 h, but its population grew afterwards. At 14:00 h, the greatest foraging rate of *A. mellifera* was

reported (13.6 umbels visited min⁻¹). This species visited an average of 1 plant and a maximum of 3.10 plants per five minutes.

In contrast to Kumar (2004) results, *Apis* spp. foraging rate (number of flowers visited per 3 minutes) on different Brassica cultivars demonstrated that *A. dorsata*. During both years, foraging speed observations indicated that *Apis* spp. spent the most time on juncea cultivars, followed by Toria and sarson. *A. dorsata* spent the most time on flower among the *Apis* spp., followed by *A. mellifera*, *A. cerana indica*, and *A. florea*.

5.3 To study the different bee attractant for attract the *Apis mellifera* in mustard.

The effect of attractants on *A. mellifera* visitation was investigated, and observations on bee visitation to mustard crops sprayed with various bee attractants under open pollination conditions starting at 10% flowering stage were recorded and briefly described based on the number of sprays.

5.3.1 First spray

The treatments applied to the crop the day before spray was found to be non-significant. Bee activity ranged from 19.67 to 20.67 bees/m²/5min at this time. On average, the plot treated with Bee-Q @ 1.25 per cent was determined to be the most successful and superior treatment in attracting more bees, drawing 34.67 bees/m²/5min, followed by Jaggery @ 10 per cent, which attracted 32.67 bees/m²/5min. All the treatments were much less effective in attracting visitors than the previous treatments, although they did attract more bees than open pollination without treatment (21.89 bees/m²/5min).

5.3.2 Second spray

A day before the second spray, bee activity of *A. mellifera* was observed ranging from 20.00 to 23.33 bees/m²/5min. The effectiveness of the treatment Bee-Q @ 1.25 per cent was found at 23.33 bees/m²/5min as the flowering stage is going to complete. All the treatments attract more bees than open pollination without treatment (24.33 bees/m²/5min).

5.3.3 Third spray

A day before the third spray, bee activity of *A. mellifera* was observed ranging from 21.67 to 25.00 bees/m²/5min. The effectiveness of the treatment Bee-Q @ 1.25 per cent was found at 25.00 bees/m²/5min as the flowering stage is going to complete. All the treatments were much less effective in attracting visitors than the previous treatments, although they did attract more bees than open pollination without treatment (26.22 bees/m²/5min).

The present findings are in line with the findings of Manchare *et al.* (2020) who stated that the bee attractants were sprayed twice, first at 10% blooming and again at 50% flowering. According to the results of bee foraging activity, the intensity of *Apis dorsata* increased one day after spraying and decreased seven days later. Spraying bee attractants, such as honey solution 10%, jaggery solution 10%, and molasses 10%, attracted the greatest number of *Apis dorsata* up to the fifth day after the first spray and the seventh day after the second spray. The results in the present investigation are partially in line with the findings of Jayaramappa and Bhargava (2015) reported that the usage of bee attractants, Bee-Q and Fruit Boost in the pollination of watermelon at different concentrations and showed that, Bee-Q at 12.5 gm/lit and Fruit boost at 0.5 ml/lit of watermelon plots attracted several bee foragers than the control plots. The similar results were reported by Venkataramgowda *et al.*, (2013) who studied on use of Bee-Q and Fruit Boost as the bee attractants in the pollination of Niger and were observed for two weeks and an estimation of seed yield was determined. Bee-Q at 12.5 gm/lit and Fruit boost at 0.75 ml/lit were found to dramatically increase the number of bee foragers in Niger plots when compared to control plots. In addition, plots sprayed with these bee attractants significantly enhanced the seed set, seed weight, and germination of Niger. More *et al.* (2020) reported that there was significant difference between the bee visitation in different treatments and sprays. The bee visits on one, three and five days after second spray of bee attractants was 13.57, 15.89 and 15.89 bees/m²/5 minute, respectively and for third spray it was 14.11, 16.25 and 14.82 bees/m²/5 minute, respectively.

5.4 Impact of bee pollination on quality and quantity parameters of mustard.

For evaluating the impact of various combinations of bee pollination on the quality and quantity parameters, eleven treatments were taken for evaluation and were categorised into (OP) Open Pollination (T1 to T9), Caged with bee or (BP) Bee Pollination (T10) and Without Insect Pollination (WIP) or Caged without bees (T11). The data recorded on the effect of different modes of bee pollination on quantity and quality parameters, viz., number of siliquae/plants, siliqua length (cm), number of seeds/ siliquae, the total number of seeds/ plants, seed yield per plant (g) and 1000 seeds weight (g), are presented in Table 4.18. All of the bee attractants sprayed had a significant effect on seed yield and yield attributing features, according to the results.

5.4.1 No. of siliquae/plant

The plot treated with Bee-Q @ 1.25 per cent under open pollination conditions was found superior over all other treatments in producing the highest mean number of siliquae *i.e.*, 209.17 siliquae per plant. This was followed by the plot treated with Jaggery @ 10 per cent under open pollination conditions producing 204.33 siliquae per plant, and Sugarcane juice @ 10 per cent producing 195.00 siliquae per plant. The treatment combination in which the crop was caged without insect pollination was found to be the least effective pollination method in mustard crop and recorded the lowest mean *i.e.*, 150.50 siliquae per plant. From the foregoing discussion, it is clear that various bee attractants had a significant effect on mustard pollination under both experimental and field conditions.

The results discussed above are in consistent with the findings of Kumari *et al.* (2013a) who reported that in *B. napus* (cv. GSC-6), the maximum number of pods per plant, pod length, number of seeds per pod and thousand seed weight were observed in open pollination (1117.83 pods, 7.04 cm, 24.61 seeds/pod and 4.32 g, respectively) which was significantly higher than that in *A. mellifera* pollination (442.03 pods, 6.09 cm, 21.75 seeds/pod and 3.52 g, respectively) and significantly the lowest were observed in pollinators' exclusion (248.00 pods, 5.22 cm, 15.88 seeds/pod and 2.92 g, respectively). Kamel *et al.* (2015) observed that the number of pods per plant,

seeds per pod, weight of 1000 seeds, yield per plant and yield per feddan (1 fed = 0.42 ha) were higher in open pollinated plants (2117.7 pods, 24.6 seeds, 3.13 g seeds, 32.0 g seeds, and 677.6 kg seeds, respectively) than those of caged plants (1315.4 pods, 18.2 seeds, 2.4 g seeds 18.9 g seeds and 248.64 kg seeds, respectively) in *B. napus*. Manchare *et al.* (2019) investigated different bee attractants, including Pomegranate juice 5%, Coconut water 10%, Sugarcane juice 10%, Sugar solution 10%, Molasses 10%, Jaggery solution 10%, Honey solution 10%, and discovered that the treatment of honey solution 10% produced the highest number of fruits / plant (35.88) and the highest number of seeds / fruit (41.4). In honey solution 10 percent, the test weight was significantly higher (29.57 g). The crop treated with a 10% honey solution produced the maximum seed yield (2.19 kg/5 plants) and seed yield per hectare (4.81 q/ha). The least yielding methods were open pollination without spray (2.72 q/ha) and pollination without insects (1.14 q/ha). The next most effective treatments were 10% jaggery solution (3.82 q/ha), 10% molasses (3.56 q/ha), and 10% sugarcane juice (3.34 q/ha). Patidar *et al.* (2017) studied the yield of mustard through honey bee pollinator. The present study contained three pollination treatments *viz.*, Plants caged Pollinator Exclusion (PE), Plants caged with bee hive (BP) and Plants kept open to all pollinators (OP). The comparative data pertaining to modes of pollination in mustard crop revealed that highest values of mean no. of siliqua/plant (186.44), no. of seeds/siliqua (13.82) and seed yield (20.54 q/ha) were obtained from OP followed by BP and it was recorded lowest in PE.

5.4.2 Siliquae Length (cm)

The plot treated with Bee-Q @ 1.25 per cent under open pollination conditions was found superior over all other treatments in producing the highest mean length of siliquae *i.e.*, 4.55 cm per plant. This was followed by the plot treated with Jaggery @ 10 per cent under open pollination conditions producing 4.41 cm siliquae length per plant and Sugarcane juice @ 10 per cent producing 4.30 cm per plant. The treatment combination in which the crop was caged without insect pollination was found to be the least effective pollination method in mustard crops and recorded the lowest mean siliquae length *i.e.*, 3.21 cm per plant.

The present results discussed above are in confirmation with the findings of Kumari *et al.* (2013b) who reported that in *B. juncea* (cv. RLC-1), the maximum number of pods per plant, pod length, number of seeds per pod and thousand seed weight were observed in open pollination (1137.16 pods, 4.93 cm, 13.98 seeds/pod and 4.63 g, respectively) which was significantly higher than that in *A. mellifera* pollination (506.16 pods, 4.24 cm, 12.42 seeds/pod and 3.97 g, respectively) and significantly the lowest were observed in pollinators' exclusion (222.26 pods, 3.76 cm, 9.95 seeds/pod and 3.8 g, respectively). Bhowmik *et al.* (2014) observed significant increase in per cent pod setting, number of seeds per siliqua and mean weight of 100 seeds in open pollinated plants of *B. juncea* by 6.41, 52.80 and 240 per cent, respectively as compared to the controlled plants where insect pollinators were excluded. It was also determined that the length of siliqua and the diameter of seed increased by 47.22 and 141.66 per cent, respectively, in the open pollinated flower than controlled one.

5.4.3 No. of seeds/ siliquae

The plot treated with Bee-Q @ 1.25 per cent under open pollination conditions was found superior over all other treatments in producing the highest mean no. of seeds/ siliquae (15.70 seeds/ siliquae). This was followed by the plot treated with Jaggery @ 10 per cent under open pollination conditions producing 15.48 seeds/ siliquae and Sugarcane juice @ 10 per cent producing 14.47 seeds/ siliquae. The treatment combination in which the crop was caged without insect pollination was found to be the least effective pollination method for the mustard crop and recorded the lowest mean no. of seeds/ siliquae (12.24 seeds/ siliquae). These results indicated that the application of attractants has a significant effect on increasing the number of seeds/pods. This was possible due to maximum visits of different species of honey bees that increased the impact of pollination.

The results studies are in support of the previous studies as Kamel *et al.* (2015) observed that the number of pods per plant, seeds per pod, weight of 1000 seeds, yield per plant and yield per feddan (1 fed = 0.42 ha) were higher in open pollinated plants (2117.7 pods, 24.6 seeds, 3.13 g seeds, 32.0 g seeds, and 677.6 kg seeds, respectively) than those of caged plants

(1315.4 pods, 18.2 seeds, 2.4 g seeds 18.9 g seeds and 248.64 kg seeds, respectively) in *B. napus*. Manchare *et al.* (2019) investigated different bee attractants, including Pomegranate juice 5%, Coconut water 10%, Sugarcane juice 10%, Sugar solution 10%, Molasses 10%, Jaggery solution 10%, Honey solution 10%, and discovered that the treatment of honey solution 10% produced the highest number of fruits / plant (35.88) and the highest number of seeds / fruit (41.4). In honey solution 10 percent, the test weight was significantly higher (29.57 g). The crop treated with a 10% honey solution produced the maximum seed yield (2.19 kg/5 plants) and seed yield per hectare (4.81 q/ha). Subedi and Subedi (2019) reported that the significant difference was observed in the number of pods, number of seeds per pods and weight of 100 dry seeds in control and open pollination.

5.4.4 Total no. of seeds/ plant

The plot treated with Bee-Q @ 1.25 per cent under open pollination conditions was found superior over all other treatments in producing the highest mean no. of seeds/ plants (3198.63 seeds/ plant). This was followed by the plot treated with Jaggery @ 10 per cent under open pollination conditions producing 3158.62 seeds/ plant and Sugarcane juice @ 10 per cent producing 2822.59 seeds/ plant. The treatment combination in which the crop was caged without insect pollination was found to be the least effective pollination method for the mustard crop and recorded the lowest mean no. of seeds/ plant (1749.58 seeds/ plant). These results indicated that the application of attractants has a significant effect on increasing the no. of seeds/plants.

The results were in partial confirmation with the present findings of the studies of Hossain *et al.* (2017) who reported that the experiment has consisted of three different ways of insect visitors foraging for pollination of mustard flowers *viz.*, Open field (Control), Netting with honey bee and Netting without honey bee. BARI Sharisha-8 [*Brassica juncea* (L.) Czernajew] was used as planting material. The yield and yield contributing traits were significantly influenced by different ways of insect visitors foraging for pollination. The maximum (3.50 g) 1000- seed weight was recorded from treatment Netting with honeybee followed by Without netting honeybee and

the lowest 1000- seed weight (2.68 g) was recorded from Without netting honeybee. The highest seed yield (2.45 t ha⁻¹) was exhibited from treatment Netting with honeybee followed by Open field (Control) whereas the lowest seed yield (1.67 t ha⁻¹) was recorded from Without netting honeybee. Finally, it can be concluded that, providing honey bee colonies to the flowering mustard field can substantially contribute to the yield. Mahadik *et al.* (2019) reported that the treatment honey solution 5% recorded 105.07 number of pods/plant, 16.40 number of seeds/pod, 5.69 wrinkled seed/pod, fruit weight 0.35 kg/ 5 plants, net yield 19.3 q/ha and found superior among all other treatments. Followed by Jaggery solution 10% showing results of 103.8 number of pods/plants, 15.40 number of seeds/pods, 6.05 wrinkled seed/pod, 3.46, fruit weight 0.27 kg/ 5 plants, net yield of 18.00 q/ha. Lowest results showed by treatments with open pollination and pollination without insects.

5.4.5 Seed yield/ plant (g)

The plot treated with Bee-Q @ 1.25 per cent under open pollination conditions was found superior over all other treatments in producing the highest mean seed yield/ plant (13.78g/ plant). This was followed by the plot treated with Jaggery @ 10 per cent under open pollination conditions producing 13.40g/ plant and Sugarcane juice @ 10 per cent producing 12.88g/ plant. The treatment combination in which the crop was caged without insect pollination was found to be the least effective pollination method for the mustard crop and recorded the lowest mean seed yield/ plant (8.79g/ plant). These results indicated that the application of attractants has a significant effect on increasing the seed yield/ plant.

The present findings are completely in line with the findings of Nagpal *et al.* (2017) who conducted a field experiment on effect of different modes of pollination on yield parameters of Indian mustard showed that the maximum number of pods/plant, pod length, pod setting (%), number of seeds/pod, thousand seed weight, seed yield/ plot, seed germination (%), seed vigour and oil content (508.72 pods/plant, 5.69 cm, 86.32%, 15.66 seeds/pod, 6.87 g, 17.63 q/ha, 89.20%, 628.12 and 39.42%, respectively) were in open pollination followed by that in bee pollination (404.56 pods/plant, 4.92 cm, 78.33%, 14.26 seeds/pod, 6.39 g, 15.57 q/ha, 85.20%, 542.54 and

38.36%, respectively) and pollinators exclusion (287.56 pods/plant, 3.89 cm, 65.87%, 12.24 seeds/pod, 5.30 g, 13.01 q/ha, 78.40%, 385.54 and 37.04%, respectively). Seed yield increased by 35.50 and 19.66 per cent in open pollinated and *Apis mellifera* pollinated plots, respectively as compared to pollinators exclusion. Manchare *et al.* (2019) investigated different bee attractants, including Pomegranate juice 5%, Coconut water 10%, Sugarcane juice 10%, Sugar solution 10%, Molasses 10%, Jaggery solution 10%, Honey solution 10%, and discovered that the treatment of honey solution 10% produced the highest number of fruits / plant (35.88) and the highest number of seeds / fruit (41.4). In honey solution 10 percent, the test weight was significantly higher (29.57 g). The crop treated with a 10% honey solution produced the maximum seed yield (2.19 kg/5 plants) and seed yield per hectare (4.81 q/ha). The least yielding methods were open pollination without spray (2.72 q/ha) and pollination without insects (1.14 q/ha). The next most effective treatments were 10% jaggery solution (3.82 q/ha), 10% molasses (3.56 q/ha), and 10% sugarcane juice (3.34 q/ha).

5.4.6 1000 seeds weight (g)

As observed in this experiment, the 1000 seeds' weight of the mustard crop ranges from 2.96g to 3.35g. The plot treated with Bee-Q @ 1.25 per cent under open pollination conditions was found superior over all other treatments in producing the highest mean 1000 seeds weight (3.35g). This was followed by the plot treated with Jaggery @ 10 per cent under open pollination conditions producing 3.30g and Sugarcane juice @ 10 per cent producing 3.27g. The treatment combination in which the crop was caged without insect pollination was found to be the least effective pollination method for the mustard crop and recorded the lowest mean 1000 seeds weight (2.96g). These results indicated that the application of attractants has a significant effect in increasing the 1000 seeds' weight.

The current findings are consistent with those of Pudasaini *et al.* (2014), who found that *Apis cerana F.* pollinated plot seeds germination was highest (90.50 percent), followed by *Apis mellifera L.* pollinated plots (87.25 percent), and control plot seeds germination was lowest (42.00 percent). Seed test weights of *Apis cerana F.* pollinated plots (3.22 gm/1000 seed) and

Apis mellifera L. pollinated plots (2.93 gm/1000 seed) were similar, whereas control plots (2.26 gm/1000 seed) were the lowest. Atmowidi *et al.* (2007) studied that diversity of pollinator insects affected to reproductive success of mustard. The number of pods, seeds per pod, and seed weight per plant was higher in non-caged plants (14.9 pods, 12.8 seeds, and 6.4 g, respectively) than those in caged plants (5.4 pods, 6.5 seeds, and 0.6 g, respectively). When plants were exposed to pollinators, the number of pods, seeds per pod, seeds per plant, and seed weight increased by 178.8, 98.2, 932.5, and 931.9%, respectively. Additionally, insect pollinations also increased *B. rapa* seed germinations.

Chapter VI

SUMMARY, CONCLUSION AND SUGGESTIONS FOR FURTHER WORK

The present investigations entitled, “**Studies on the impact of Bee Pollination on yield parameters of Mustard (*Brassica juncea* L.)**” was carried in the assigned experimental field of Mustard and the apiary at RVSKVV- Krishi Vigyan Kendra, Morena, Madhya Pradesh, during 2021-22. In this chapter the salient findings of the investigations are summarized and meaningful conclusions have been made as under.

6.1 To study the pollinators fauna of mustard.

The experimental field was observed carefully during the study period and the insect pollinators visiting the mustard crop (*Brassica juncea* L.) were collected and identified with the help of insect collections and literature available in the department of entomology and with the help of members of the advisory committee. All the identified insect visitors along with their scientific names and systemic positions are listed in Table 4.1. A total of 36 species belonging to 8 orders viz., Hymenoptera (12), Diptera (9), Lepidoptera (6), Coleoptera (3), Hemiptera (2), Orthoptera (2), Neuroptera (1) and Odonata (1) visited mustard flowers.

Hymenopterans were the most abundant pollinators (33.33 per cent), followed by the orders Diptera (25.00 per cent), Lepidoptera (16.67 per cent), and Coleoptera (8.33 per cent) throughout the flowering season of the mustard crop. The abundance of Orthoptera and Hemiptera was found to be the same, at 5.56 per cent. The orders Neuroptera and Odonata have the least pollinators, accounting for 1% of the total.

6.2 To study the foraging behaviour of honey bees in mustard crop.

6.2.1 Bee abundance of different bee species on mustard crop

Observations on the abundance of different species of honey bee on the flowers of the mustard crop were recorded at every standard meteorological week at two hours intervals starting from 0800 hours to 1800 hours from the last week of December 2021 to the first week of February

2022. The abundance was recorded in the number of honeybees of a particular species visiting a 1 m² area of the field in 5 minutes. In general, due to very low temperatures in the morning hours in the weeks of December 2021 and January 2022, there was no honey bee activity at 0800 hrs all through the study period.

6.2.1.1. Bee abundance of *Apis mellifera* on mustard crop

Data on abundance indicated that the minimum average population of *Apis mellifera* on a weekly basis was observed to be at 10.67 bees/ m²/5 min on the first week (24th December) of the flowering season maximum average population of *Apis mellifera* was observed to be at 20.50 bees/ m²/5 min during fourth week (15th January) when the flowering season was at its peak. The mean abundance of *A. mellifera* bees on mustard flowers during different day hours was recorded to be minimum at 7.00 bees/m²/5 min on 1800 hours and maximum at 25.14 bees/m²/5 min on 1200 hrs.

6.2.1.2. Bee abundance of *Apis dorsata* on mustard crop

Data on abundance indicated that the minimum average population of *Apis dorsata* on a weekly basis was observed to be at 5.83 bees/ m²/5 min on the first week (24th December) of the flowering season maximum average population of *Apis dorsata* was observed to be at 17.67 bees/ m²/5 min during fourth week (15th January) when the flowering season was at its peak. The mean abundance of *A. dorsata* bees on mustard flowers during different day hours was recorded to be minimum at 3.86 bees/m²/5 min on 1800 hours and maximum at 19.71 bees/m²/5 min on 1400 hrs.

6.2.1.3. Abundance of *A. cerana indica* on mustard crop

Data on abundance indicated that the minimum average population of *Apis cerana indica* on a weekly basis was observed to be at 3.50 bees/ m²/5 min on the first week (24th December) of the flowering season maximum average population of *Apis cerana indica* was observed to be at 9.50 bees/ m²/5 min during fourth week (15th January) when the flowering season was at its peak. The mean abundance of *A. cerana indica* bees on mustard flowers during different day hours was recorded to be minimum at 7.57 bees/m²/5 min on 1600 hours and maximum at 13.14 bees/m²/5 min on 1000 hrs.

6.2.1.4. Comparative abundance of different bee species on mustard crop

The comparative mean abundance among the various bees appearing on mustard flowers revealed that *A. mellifera* (15.29 bees/m²/5 min) was the predominant visitor followed by *A. dorsata* (11.57 bees/m²/5 min). *A. cerana indica* was the least abundant visitor of mustard flowers. A significant difference was recorded in relation to the number of various bees visiting the mustard flowers. It was found that *A. mellifera*, *A. dorsata* and *A. indica* constituted 45.40, 34.37 and 20.23 per cent, respectively. Bees were most abundant during 1400 hrs (17.86 bees/m²/5 min) and least abundant during 1800 hrs (3.62 bees/m²/5 min). The three *Apis* species were found to be fairly abundant at six-hour intervals, but numbers of other bee species varied greatly.

6.2.2. Foraging speed of different bee species on mustard crop

Observations on the foraging speed of different species of honey bee on the flowers of the mustard crop were recorded on standard meteorological week at two-hour intervals starting from 0800 hours to 1800 hours during the flowering period. The foraging speed was recorded in terms of time spent (seconds) per flower. In general, due to very low temperatures in the morning hours in the weeks of December 2021 and January 2022, there was no honey bee foraging at 0800 hrs all through the study period.

6.2.2.1. Foraging speed of *Apis mellifera* on mustard crop

Data on the foraging speed of *A. mellifera* recorded during different weeks over the times revealed that the mean weekly foraging speed ranged between 1.49 to 2.95 seconds corresponding to the first and fourth week of the blooming period, respectively. The least time spent by *A. mellifera* (2.01 sec) was recorded at 1200 hrs during the first week of the observation and the highest (5.97 sec) at 1400 hrs during the fourth week of the observation. As far as times of the day were concerned, the mean foraging speed of *A. mellifera* bees over different day hours ranged from 1.46 to 3.66 seconds recorded at 1800 hrs to 1400 hrs, respectively.

6.2.2.2. Foraging speed of *Apis dorsata* on mustard crop

Data on the foraging speed of *A. dorsata* recorded during different weeks over the times revealed that the mean weekly foraging speed ranged between 2.49 to 4.06 seconds corresponding to the first and fourth week of the blooming period, respectively. The least time spent by *A. dorsata* (2.51 sec) was recorded at 1200 hrs during the first week of the observation and the highest (8.97 sec) at 1600 hrs during the fourth week of the observation. As far as times of the day were concerned, the mean foraging speed of *A. dorsata* bees over different day hours ranged from 1.39 to 6.16 seconds recorded at 1800 hrs to 1600 hrs, respectively.

6.2.2.3. Foraging speed of *Apis cerana indica* on mustard crop

Data on the foraging speed of *A. cerana indica* recorded during different weeks over the times revealed that the mean weekly foraging speed ranged between 3.49 to 4.49 seconds corresponding to the first and fourth week of the blooming period, respectively. The least time spent by *A. cerana indica* (3.01 sec) was recorded at 1200 hrs during the first week of the observation and the highest (10.97 sec) at 1600 hrs during the fourth week of the observation. As far as times of the day were concerned, the mean foraging speed of *A. cerana indica* bees over different day hours ranged from 3.33 to 8.66 seconds recorded at 1200 hrs to 1600 hrs, respectively.

6.2.2.4. Comparative foraging speed of different bee species on mustard crop

The results revealed that the time spent per flower by three bee species differed significantly. The mean foraging speed during different hours of the day varied from 1.46 to 3.66 seconds for *A. mellifera* at 1800 hrs to 1400 hrs, respectively which was the lowest among the three species. The mean foraging speed varied from 1.39 to 6.16 seconds for *A. dorsata* during 1800 hrs to 1600 hours of the day, respectively. In the end, the mean foraging speed during different hours of the day varied from 3.33 to 8.66 seconds for *A. cerana indica* 1200 hrs to 1600 hrs, respectively which was the maximum time spent per flower. Hence, it was found to be the least effective in pollination.

6.2.3. Foraging rate of different bee species on mustard crop

Observations on the foraging rate of different species of honey bee on the flowers of the mustard crop were recorded on standard meteorological week at two-hour intervals starting from 0800 hours to 1800 hours from the last week of December 2021 to the first week of February 2022. The foraging speed was recorded in terms of the number of flowers visited per minute. In general, due to very low temperatures in the morning hours in the weeks of December 2021 and January 2022, there was no honey bee activity at 0800 hrs all through the study period.

6.2.3.1. Foraging rate of *A. mellifera* on mustard crop

Data on the foraging rate of *A. mellifera* recorded during different weeks over the times revealed that the mean weekly foraging rate ranged between 6.67 to 20.33 flowers visited/ min corresponding to the first and fourth week of the blooming period, respectively. The mean foraging rate of *A. mellifera* bees throughout different day hours ranged from 10.71 to 21.43 flowers visited/min, regardless of the week at 1800 hrs to 1200 hrs, respectively.

6.2.3.2. Foraging rate of *A. dorsata* on mustard crop

Data on the foraging rate of *A. dorsata* recorded during different weeks over the times revealed that the mean weekly foraging rate ranged between 3.33 to 16.17 flowers visited/ min corresponding to the first and fourth week of the blooming period, respectively. The mean foraging rate of *A. dorsata* bees throughout different day hours ranged from 6.57 to 16.43 flowers visited/min, regardless of the week at 1800 hrs to 1000 hrs, respectively.

6.2.3.3. Foraging rate of *A. cerana indica* on mustard crop

Data on the foraging rate of *A. cerana indica* recorded during different weeks over the times revealed that the mean weekly foraging rate ranged between 1.17 to 10.67 flowers visited/ min corresponding to the first and fourth week of the blooming period, respectively. The mean foraging rate of *A. cerana indica* bees throughout different day hours ranged from 5.14 to 12.29 flowers visited/min, regardless of the week at 1600 hrs to 1200 hrs, respectively.

6.2.3.4. Comparative foraging speed of different bee species on mustard crop

The results revealed that the number of flowers visited/ min by three bee species differed significantly. The mean foraging rate during different hours of the day varied from 10.71 to 21.43 flowers visited/ min for *A. mellifera* during 1800 to 1200 hrs, respectively which was the highest among the three species. Hence, it was found to be most effective in pollination as it spent the highest number of flowers/ min. The mean foraging rate varied from 6.57 to 16.43 flowers visited/ min for *A. dorsata* during 1800 to 1200 hrs, respectively. In the end, the mean foraging rate during different hours of the day varied from 5.14 to 12.29 flowers visited/ min for *A. cerana indica* during 1800 to 1200 hrs, respectively which was the lowest among the three species. Hence, it was found to be the least effective in pollination as it spent the lowest number of flowers/ min.

6.3 To study the different bee attractant for attract the *Apis mellifera* in mustard.

The effect of attractants on *A. mellifera* visitation was investigated, and observations on bee visitation to mustard crops sprayed with various bee attractants under open pollination conditions starting at 10% flowering stage.

6.3.1 First spray

The treatments applied to the crop the day before spray was found to be non-significant. Bee activity ranged from 19.67 to 20.67 bees/m²/5min at this time. On average, the plot treated with Bee-Q @ 1.25 per cent (34.67 bees/m²/5min) was determined to be the most successful and superior treatment in attracting more bees, followed by Jaggery @ 10 per cent (32.67 bees/m²/5min). The lowest effect was observed in Coconut water @ 10 per cent (23.33 bees/m²/5min) except open pollination without treatment (21.89 bees/m²/5min).

6.3.2 Second spray

A day before the second spray, bee activity of *A. mellifera* was observed ranging from 20.00 to 23.33 bees/m²/5min. The effectiveness of the treatment Bee-Q @ 1.25 per cent was found at 23.33 bees/m²/5min as the flowering stage is going to complete. The least influencing treatment observed

was Coconut water @ 10 per cent (20.33 bees/m²/5min) which was statistically at par with untreated control (20.00 bees/m²/5min). On average, the plot treated with Bee-Q @ 1.25 per cent was determined to be the most successful and superior treatment in attracting more bees (37.22 bees/m²/5min), followed by Jaggery @ 10 per cent (36.00 bees/m²/5min). The lowest effect was observed in Coconut water @ 10 per cent (28.44 bees/m²/5min) except open pollination without treatment (24.33 bees/m²/5min).

6.3.3 Third spray

A day before the third spray, bee activity of *A. mellifera* was observed ranging from 21.67 to 25.00 bees/m²/5min. The effectiveness of the treatment Bee-Q @ 1.25 per cent was found at 25.00 bees/m²/5min as the flowering stage is going to complete. The least influencing treatment observed was Coconut water @ 10 per cent (21.67 bees/m²/5min) which was statistically at par with untreated control (21.33 bees/m²/5min). On an average, the plot treated with Bee-Q @ 1.25 per cent was determined to be the most successful and superior treatment in attracting more bees (37.89 bees/m²/5min) which was at par with Jaggery @ 10 per cent (37.11 bees/m²/5min) which was also at par with sugarcane juice @ 10 per cent (36.33 bees/m²/5min). The lowest effect was observed in Coconut water @ 10 per cent (30.56 bees/m²/5min) except open pollination without treatment (26.22 bees/m²/5min).

6.4 Impact of bee pollination on quality and quantity parameters of mustard.

For evaluating the impact of various combinations of bee pollination on the quality and quantity parameters, eleven treatments were taken for evaluation and were categorised into (OP) Open Pollination (T1 to T9), Caged with bee or (BP) Bee Pollination (T10) and Without Insect Pollination (WIP) or Caged without bees (T11). Data indicated that all the bee attractants sprayed were significantly effective on seed yield and yield attributing characters.

6.4.1 No. of siliquae/plant

The plot treated with Bee-Q @ 1.25 per cent under open pollination conditions was found superior over all other treatments in producing the highest mean number of siliquae *i.e.*, 209.17 siliquae per plant. When the crop was caged without insect pollination was found to be the least effective pollination method in mustard crop and recorded the lowest mean *i.e.*, 150.50 siliquae per plant.

6.4.2 Siliquae Length (cm)

The plot treated with Bee-Q @ 1.25 per cent under open pollination conditions was found superior over all other treatments in producing the highest mean length of siliquae *i.e.*, 4.55 cm per plant followed by the plot treated with Jaggery @ 10 per cent producing 4.41 cm siliquae length per plant. When the crop was caged without insect pollination was found to be the least effective pollination method in mustard crops and recorded the lowest mean siliquae length *i.e.*, 3.21 cm per plant.

6.4.3 No. of seeds/ siliquae

The plot treated with Bee-Q @ 1.25 per cent under open pollination conditions was found superior over all other treatments in producing the highest mean no. of seeds/ siliquae (15.70 seeds/ siliquae) followed by the plot treated with Jaggery @ 10 per cent conditions producing 15.48 seeds/ siliquae. When the crop was caged without insect pollination was found to be the least effective pollination method for the mustard crop and recorded the lowest mean no. of seeds/ siliquae (12.24 seeds/ siliquae).

6.4.4 Total no. of seeds/ plant

The plot treated with Bee-Q @ 1.25 per cent under open pollination conditions was found superior over all other treatments in producing the highest mean no. of seeds/ plants (3198.63 seeds/ plant) followed by the plot treated with Jaggery @ 10 per cent producing 3158.62 seeds/ plant. When the crop was caged without insect pollination was found to be the least effective pollination method for the mustard crop and recorded the lowest mean no. of seeds/ plant (1749.58 seeds/ plant).

6.4.5 Seed yield/ plant (g)

As observed in this experiment, mustard yields an average of 8.79 to 13.78 g seeds/ plant. The plot treated with Bee-Q @ 1.25 per cent under open pollination conditions was found superior over all other treatments in producing the highest mean seed yield/ plant (13.78g/ plant) followed by the plot treated with Jaggery @ 10 per cent (13.40g/ plant). When the crop was caged without insect pollination was found to be the least effective pollination method for the mustard crop and recorded the lowest mean seed yield/ plant (8.79g/ plant).

6.4.6 1000 seeds weight (g)

A bolder and heavier seed is the outcome of proper post-pollination and fertilization growth processes, and it is seen to be superior to normal or shrivelled seeds. Especially in a crop like mustard where seed has much economic importance like edible oil extraction, cattle feed, etc., a bolder seed is an indicator of high oil extraction per cent. As observed in this experiment, the 1000 seeds' weight of the mustard crop ranges from 2.96g to 3.35g. The plot treated with Bee-Q @ 1.25 per cent under open pollination conditions was found superior over all other treatments in producing the highest mean 1000 seeds weight (3.35g) followed by the plot treated with Jaggery @ 10 per cent (3.30g). When the crop was caged without insect pollination was found to be the least effective pollination method for the mustard crop and recorded the lowest mean 1000 seeds weight (2.96g).

CONCLUSION

During the study period, the key results arrived were of the significant importance to farmers who are involved in growing mustard crop primarily for seed production purpose and also for dry fodder purposes. These key findings are discussed here under:

- A total of 36 species belonging to 8 orders viz., Hymenoptera (12), Diptera (9), Lepidoptera (6), Coleoptera (3), Hemiptera (2), Orthoptera (2), Neuroptera (1) and Odonata (1) visited mustard flowers. Hymenopterans were the most abundant pollinators (33.33 per cent), followed by the orders Diptera (25.00 per cent), Lepidoptera (16.67 per cent), and

Coleoptera (8.33 per cent) throughout the flowering season of the mustard crop.

- The comparative mean abundance among the various bees appearing on mustard flowers revealed that *A. mellifera* (15.29 bees/m²/5 min) was the predominant visitor followed by *A. dorsata* (11.57 bees/m²/5 min). *A. cerana indica* (6.81 bees/m²/5 min) was the least abundant visitor of mustard flowers. It was found that *A. mellifera*, *A. dorsata* and *A. indica* constituted 45.40, 34.37 and 20.23 per cent, respectively. Bees were most abundant during 1400 hrs (17.86 bees/m²/5 min) and least abundant during 1800 hrs (3.62 bees/m²/5 min).
- The mean foraging speed during different hours of the day varied from 1.46 to 3.66 seconds for *A. mellifera* at 1800 hrs to 1400 hrs, respectively which was the lowest among the three species. In the end, the mean foraging speed during different hours of the day varied from 3.33 to 8.66 seconds for *A. cerana indica* 1200 hrs to 1600 hrs, respectively which was the maximum time spent per flower.
- The mean foraging rate during different hours of the day varied from 10.71 to 21.43 flowers visited/ min for *A. mellifera* during 1800 to 1200 hrs, respectively which was the highest among the three species. Hence, it was found to be most effective in pollination as it spent the highest number of flowers/ min. In the end, the mean foraging rate during different hours of the day varied from 5.14 to 12.29 flowers visited/ min for *A. mellifera* during 1800 to 1200 hrs, respectively being the lowest.
- Observations on effectiveness of bee attractants revealed that Bee-Q @ 1.25 per cent was found to be the superior bee attractant followed by, Jaggery solution @ 10 per cent. The lowest number of bees were attracted in the plots sprayed with Coconut water @10 per cent, except open pollination without any treatment spray.
- The highest no. of siliquae/ plant was observed in Bee-Q @ 1.25 per cent with 209.17 siliquae per plant and lowest in Coconut water @ 10 per cent (167.33 siliquae per plant) among bee attractants. The lowest mean no. of

siliquae/ plant *i.e.*, 150.50 siliquae per plant was observed in the plot caged without insect pollinators.

- The highest siliquae length was observed in Bee-Q @ 1.25 per cent with 4.41 cm and lowest in Coconut water @ 10 per cent (3.71 cm) among bee attractants. The lowest mean siliquae length *i.e.*, 3.21 cm was observed in the plot caged without insect pollinators.
- The highest no. of seeds/ siliquae was observed in Bee-Q @ 1.25 per cent with 15.70 seeds/ siliquae and lowest in Coconut water @ 10 per cent (13.04 seeds/ siliquae) among bee attractants. The lowest mean seeds/ siliquae *i.e.*, 12.24 cm was observed in the plot caged without insect pollinators.
- The highest no. of seeds/ plant was observed in Bee-Q @ 1.25 per cent with 3198.63 seeds/ plant and lowest in Coconut water @ 10 per cent (2176.47 seeds/ plant) among bee attractants. The lowest mean seeds/ plant *i.e.*, 1749.58 seeds/ plant was observed in the plot caged without insect pollinators.
- The highest seed yield/ plant was observed in Bee-Q @ 1.25 per cent with 13.78g/ plant and lowest in Coconut water @ 10 per cent (10.32g / plant) among bee attractants. The lowest mean seed yield / plant *i.e.*, 8.79g/ plant was observed in the plot caged without insect pollinators.
- The highest 1000 seeds weight was observed in Bee-Q @ 1.25 per cent with 3.35g and lowest in Coconut water @ 10 per cent (3.10g) among bee attractants. The lowest mean 1000 seeds weight *i.e.*, 2.96g was observed in the plot caged without insect pollinators.

SUGGESTIONS FOR FURTHER WORK:

Throughout the study, there are several areas where more research on crop pollination ecology in the region is needed. The following are some of the points: -

1. While the current research is focused on oilseed crops, similar research might be undertaken on food crops, vegetables, and fruits in

order to boost yields both quantitatively and qualitatively to satisfy future demands.

2. For annual crops, fruits, and other items, the research can be extended throughout the entire year.
3. Experiments on the efficacy of bee attractants at various doses and with attractants other than those used in the current study can be conducted in order to uncover and explore other options for farmers.
4. Other efficient strategies for increasing mustard seed output and qualitative characteristics with the aid of honey bees must be developed.
5. There are several chances to undertake analogous investigations on other bee species, such as the stingless bee (*Tetragonula iridipennis*), and so on.

BIBLIOGRAPHY

- Abrol, D. P. (1989). Studies on ecology and behaviour of insect pollinators frequenting strawberry blossoms and their impact on yield and fruit quality. *Trop. Ecol.* **30**: 96-100
- Abrol, D.P. and Kapil, R. P. (1996). Studies on abundance and importance of insect pollinators for oil seed production. *J. Insect Sci.*, **9**(2): 172-174.
- Ahmad, A.A. (2005). Hymenopterous and dipterous pollinators diversity on various flowering plants in Riyadh, Saudi Arabia. *Assiut Journal of Agricultural Sciences*, **36**(1): 69-83.
- Ahmad, R. (1992). Effect of honey bee pollination on fruit yield of cucumber crop. *Pakistan J. Zool.* **24**: 88-90.
- Ahmed, B. and Rehman. (2002). Population dynamics of insect foragers and their effect on seed yield of rapeseed (*Brassica campestris* L. var. toria). *Indian Bee J.* **64**(3-4): 1-5.
- Akhtar, T.; Aziz, A. M.; Naeem Muhammad, S.A. and B. (2018). Diversity and relative abundance of pollinators faun of canola (*Brassica napus* L.) var. Chakwal Sarsoon) in Pothor Region. *Khan Pakistan. Pakistan J. Zool.* **50**(2): 567-573.
- Alam, M.M.; Begum, F. and Roy, P. (2014). Yield and yield attributes of rapeseed– mustard (*Brassica*) genotypes grown under late sown condition. *Bangladesh J. Agril. Res.* **39**:311-36.
- Allsopp, P.G. and Cherry, R. H. (1991). Attraction of *Apis mellifera* L. (Hymenoptera: Apidae) to volatile compounds. *Australian J. Ento.* **30**(3): 219-220.
- Anil. (2015). Role of Flower Visitors in Pollination and Seed Set of Mustard [*Brassica Juncea* (L.) Czern Coss] (Doctoral dissertation, University of Agricultural Sciences, GKVK).
- Anonymous. (2018). Report of Ministry of Environment, Forest and Climate Change (MoEF&CC) and Directorate of Rapeseed Mustard Research, Bharatpur.
- Anonymous, (2021). Ministry of Farmer's Welfare, Govt. of India. <https://www.indiastatagri.com/table/agriculture/selected-state-wise-area-production-productivity-r/1423601>
- Arya, D. R.; Sihag, R. C. and Yadav, P. R. (1994). Diversity, abundance and foraging activity of Insect pollinator of Sunflower (*Helianthus annus* L.) at Hisar (India). *Indian Bee J.*, **56**: 172-178.

- Atmowidi, T.; Buchori, D.; Manuwoto, S.; Suryobroto, B. and Hidayat, P. (2007). Diversity of pollinator insects in relation to seed set of mustard, *Brassica rapa* L. (Cruciferae). *Hayati J. Biosci.* **14**: 155-161.
- Awasthi, (2020). Morphological and molecular diversity analysis of Indian mustard (*Brassica juncea* L.). Ph.D. (Ag.) Thesis, RVSKVV, Gwalior, M.P., India.
- Bajjiya, M.R. and Abrol, D.P. (2017). Flower Visiting Insect Pollinators of Mustard (*Brassica Napus*) in Jammu Region. *J. Pharmaco. and Phytochem.* **6**(5): 2380-2386.
- Bendifallah, L.; Louadi, K. and Doumandji, S. (2013). Bee fauna potential visitors of coriander flowers *Coriandrum sativum* L. (Apiaceae) in the Mitidja area (Algeria). *J. Apiculture Science.* **2**:125-128.
- Bernard, E. and Vaissiera Froissart, R. (1996). Pollination of cantaloupes under spunbonded. Row cover by Honey bees (Hym. Apidae) in West Africa. *J. Economic Ento.* **19**(5): 1213-1222.
- Bhattacharya, S.; Sinha, S.; Dey, P.; Das, M. and Maiti, M.K. (2012). Production of nutritionally desirable fatty acids in seed oil of Indian mustard (*Brassica juncea* L.) by metabolic engineering. *Phytochem. Rev.* **11**:197–209.
- Bhowmik, B.; Mitra, B. and Bhadra, K. (2014). Diversity of insect pollinators and their effect on the crop yield of *Brassica juncea* L., NPJ-93, from southern West Bengal. *Inter. J. Recent Scientific Res.* **5**: 1207-1213.
- Bisht, D.S.; Naim, M. and Mehrotra, K.N. (1983). Studies on role of honey bees in rapeseed production. In: *Proceedings of the Second International Conference on Apiculture in Tropical Climates* held on February 29- March 4 at New Delhi. pp. 491-496.
- Chambó. D.E; Garcia. C.R; Escocard de Oliveiral. T.N; and Duarte-Júnior. B. J. (2011). Honey bee visitation to sunflower: effects on pollination and plant genotype. *Sci. agric.* (Piracicaba, Braz.) **68**(6) Piracicaba Nov./Dec.
- Chand, H. and Singh, B. (1995). Effect of pollination by *Apis cerana* F. on yield of mustard, *Brassica juncea* L. *Indian Bee Journal*, **57**(1): 173-174.
- Chandel, Y. S.; Kumar, A. and Srivastva, S. (2000). Comparative performance of *Apis mellifera* L. viz., *Apis cerana*. Fab. ontoria (*Brassica campestris* Var. toria) in mid hill zone of H.P. India. *Indian J. Agri. Res.* **34**(4): 264-267.

- Chaudhary, O.P.; Singh, Jage. (2007). Diversity, Temporal Abundance, foraging behaviour of Floral visitors and effect of Different modes of pollination on Coriander. (*Coriander Sativum* L.). *J. Species and Aromatic Crops* **16**(1): 8-14 .
- Chaudhary, O.P. and Kumar, R. 2007. Studies on honeybee foraging and pollination in cardamom (*Elettaria cardamomum* Maton.). *Journal of Species and Aromatic Crops.*, **9**(1): 37-42.
- Chaudhary, O.P. (2001). Abundance of wild pollinators on rapeseed and mustard. *Insect Environment*. **7**(3): 141-142.
- Chhuneja, P.K.; Kumari, S. and Singh, J. (2013). Number of bee visits in seed setting of *Brassica* oilseed crops. In: *Proceedings of 4th International Congress on Insect Science* held on February 14- 17, 2013 at Bangalore, India. pp. 67.
- D'Ávila, M.; Marchini, L.C. (2005). Pollination provided by bees in economically important crops in Brazil. *Boletim da Indústria Animal* 62: 79-90. (in Portuguese)
- Dalio, S.J. (2012). Cannabis sativa- An Important Subsistence Pollen Source for *Apis mellifera*. *IOSR Journal of Pharmacy and Biological Sciences* **1**(4): 01-03.
- Das, R. and Jha, S. (2018). Record of Insect Pollinators and their Abundance on Indian Mustard (*Brassica juncea* L.) in New Alluvial Zone of West Bengal. *International J. Pure Applied and Bioscience* **6**(5): 848-853.
- Dash, L.; Konar, A. and Mishra, A. (2019). Population dynamics and Efficacy of some insecticides against mustard aphid on mustard. *J. Entomol. Zool. Stud.* **7**(4): 1038-1041.
- Deshmukh, A.K.; RAO, Mohan, G. and Karve, A. D. (1985). Studies on the effect of honeybees pollination on the yield of safflower. *Indian Bee J.* **47**: 1 – 2.
- Devi, M.; Sharma, K.H.; Thakur, K.R.; Bhardwaj, K.S.; Rana, K.; Thakur, M. and Ram. B. (2017). Diversity of Insect Pollinators in Reference to Seed Set of Mustard (*Brassica juncea* L.), *Int. J. Curr. Microbiol. App. Sci.* **6**(7): 2131-2144.
- Fisher, R. A. and Yates, F. (1963). Statistical tables for biological agricultural and medical research. New York: Hafner.
- Free, J.B. (1999). Pollination in the tropics. *Beekeeping and Development* 51:6-7.

- Giri, K.S.; Chandra, U.; Singh, G.; Gautam, P.M. and Jaishwal, R. (2018). Study the abundance of insect pollinators/visitors in rapeseed-mustard (*Brassica juncea* L.). *J. Entomol. and Zool. Studies*. **6**(2): 2563- 2567.
- Glibert, F. S. (1980). Flowers visiting by hover flies (Syrphidae). *Ann. Rev. Ecol. And Syst.*, **6**: 139 – 170.
- Gomez, K.A. and A.A. Gomez. (1984). Statistical procedures for agricultural research. 2nd ed. Wiley, New York. p. 680.
- Goswami, V. and Khan M. S. (2014). Impact of honey bee pollination on pod set of mustard at Pantnagar. *The Bioscan*. **9**(1): 75-78.
- Hossain, M. I.; Rahman, M. M.; Hossain, M. S.; Chakraborty, R. and Amin, R. (2018). Role of ways of insect visitors foraging for pollination in yield contributing traits of mustard. *J. Biological Research*. **91**(2).
- Hossain. I.M.; Rahman. M.M.; Hossain. S. M.; Chakraborty. R and Amin. R. (2017). Role of ways of insect visitors foraging for pollination in yield contributing traits of mustard. *Department of Entomology; Department of Agronomy, Sher-e-Bangla Agricultural University, Dhaka, Bangladesh*.
- Jayaramappa, K. V. and Bhargava, H. R. (2015). Influence of bee attractants on watermelon (*Citrullus lanatus* L.) for the improvement of the crop. *World Applied Sciences Journal*, **33**(4), 679-683.
- Jayaramappa, K.V., P. Mahesh, H.R. Bhargava. (2011). Influence of Bee-attractants on yield parameters of Ridge Gourd (*Luffa acutangula* L.) Cucurbitaceae. *World Applied Sciences Journal* **15**(4): 457-462.
- Kamel, S.M.; Mahfouz, H.M.; Blal, A., El-Fatah H.; Said, M. and Mahmoud, M.F. (2015). Diversity of insect pollinators with reference to their impact on yield production of canola (*Brassica napus* L.) in Ismailia, Egypt. *Pesticides and Phytomedicine*. **30**(3): 161–168.
- Khatkar, S. (1996). Analysis of factors influencing honey bee visits to different cultivars of oilseed crops. Ph. D. Thesis, Submitted to CCS Haryana Agricultural University, Hisar.
- Kumar, M.; Singh, R. and Chand, H. (2003). Foraging rate and foraging speed of *Apis cerana indica* Fab. and *Apis mellifera* L. in sunflower (*Helianthus annus* L.) Shashpa. **10**(1):27-32.

- Kumar, M. and Jaiswal, B.K. (2012). Relative abundance of insect visitors on coriander (*Coriandrum sativum* L.) flowers. *Journal of Interacademia*. **16**(4): 887-892.
- Kumar, N. (2004). Foraging behaviour of honeybees on oilseed crops. Ph. D Thesis, RAU, Pusa, Bihar.
- Kumari, S.; Chhuneja, P.K. and Singh J. (2012). Seed setting in *Brassica napus* L. and *Brassica juncea* L. viz-a-viz *Apis mellifera* L. visitation frequency. In: *Proceedings of International Conference on Entomology held on February 17-19, 2012 at Punjabi University, Patiala*. pp. 120.
- Kumari, S.; Chhuneja, P.K. and Singh, J. (2013a). Role of insect pollinators in seed yield augmentation of *Brassica napus*. In: *Proceedings of 4th International Congress on Insect Science held on February 14-17, 2013 at Bangalore, India*. pp. 66.
- Kumari, S.; Chhuneja, P.K. and Singh, J. (2013b). Seed yield augmentation by insect pollinators in *Brassica juncea*. In: *Proceedings of 4th International Congress on Insect Science held on February 14-17, 2013 at Bangalore, India*. pp. 67.
- Kunjwal, N.; Kumar Y. and Khan M. S. (2014). Flower visiting insect pollinators of Brown Mustard and their foraging behavior under caged and open pollination. *African J. Agril. Res.* **9**(16): 1278-1286.
- Mahadik, P. B.; Kulkarni, S. R. and Manchare, R. R. (2019). Impact of honey bees as a pollinator on seed production of mustard (*Brassica juncea* L.). *J. Entomol. Zool. Studies* **7**(5): 1380-1383
- Mahindru, N.; Singh, G. and Grewal, G.S. (1998). Comparative abundance and foraging behaviour of insect pollinators of raya (*Brassica juncea* L.) and role of *Apis mellifera* Linnaeus in crop pollination. *J. Insect Science*. **11**(1): 34-37.
- Maity, A.; Chakrabarty, S.K. and Yadav, J.B. (2014). Foraging behaviour of honeybees (*Apis* spp.) (Hymenoptera: Apidae) in hybrid seed production of Indian mustard (*Brassica juncea*). *Indian J. Agricultural Sciences*. **84**(11): 1389-1394.
- Manchare, R.R.; Kulkarni, S.R. and Mahadik, P.B. (2020). Effect of bee attractants on foraging activities of European bees *Apis mellifera* in Bitter gourd (*Momordica charantia* L.). *The Inter. J. Engg. and Sci.* **9**(1): 50-54.

- Manchare, R. R.; Kulkarni, S. R. and Patil, S. D. (2019). Effect of Bee pollination on Seed Yield and Yield Contributing Characters of Bitter Gourd *Momordica Charantia* L. *Chem. sci. rev. lett*, **8**(30), 236-240.
- Mandal, E.; Amin, M. R.; Rahman, H. and Akanda, A. M. (2018). Abundance and foraging behavior of native insect pollinators and their effect on mustard (*Brassica juncea* L.). *Bangladesh J. Zool.* **46**(2), 117-123.
- Manhare, J. S.; Painkra, G. P.; Painkra, K. L. and Bhagat, P. K. (2017). Studies on the foraging activity of Indian honeybee, *Apis cerana indica* Fabr and other honeybee spp. on buckwheat flowers. *J. Plant Development Sciences.* **9**(8): 823-828.
- Manning, R., and I. Wallis. (2005). Seed yields in canola (*Brassica napus* cv. Karoo) depend on the distance of plants from honeybee apiaries. *Aust. J. Exp. Agric.* 45:1307-1313.
- Meena, N.K.; Singh, B.; Kant, K.; Meena, R.D. and Solanki, R.K. (2015). Role of insect pollinators in pollination of seed spices-A review. *Inter. J. Seed Spices.* **5**(1), 1-17.
- Mishra, R.C.; Kumar, J. and Gupta, J.K. (1988). The effect of mode of pollination on yield and oil potential of *Brassica campestris* L. var. sarson with observations on insect pollinators. *J. Apicultural Res.* **27**(3): 186-189.
- More, M. R.; More, S. A. and Bapurao, U. (2020). Effect of bee attractants on foraging behaviour of *Apis mellifera* L. on seed onion crop (*Allium cepa* L.). *J. Entomol. and Zool. Studies* **8**(6): 1510-1512
- Nagpal, K.; Yadav, S.; Kumar, Y. and Singh, R. (2020). Foraging speed of different *Apis* spp. on Indian mustard (*Brassica juncea*) flowers. *J. Entomol. Zool. Studies.* **8**(2): 628-632.
- Nagpal, K.; Kumar, S. Y. Y. and Singh, R. (2017). Effect of pollination modes on yield components in Indian mustard (*Brassica juncea* L.). *J. Oilseed Brassica.* **81**(2): 187-194.
- Naik, A. K.; Pise, V.; Viraktamath, S.; Udikeri, S. S. and Uppar, V. (2014). Evaluation of Indigenous Bee Attractants in Bt Cotton (Bunny BG-I). *Research J. Agricultural Sciences,* **5**(3): 476-479.
- Painkra, G.P. and Shaw S.S. (2016). Foraging behaviour of honey bees in niger flowers in North Zone of Chhattisgarh. *Inter. J. Plant Protection.* **9**(1): 102-108.

- Panda, P.; Satapathy, C. R.; Padhi, J. and Sagar; S. Singh (1996). Effect of *Apis mellifera* pollination on yield of Sunflower. *Indian J. Ent.*, **58**(2): 161 – 164.
- Pandey, A. and Tripathi, S. (2003). Foraging activity of honey bees in mustard. *Annals of Pl. Protec. Sciences*, **11**(2): 378.
- Patidar, K.B., Ojha, N.K. and Khan, U.I. (2017). Role of Honeybee (*Apis mellifera*) in Enhancing Yield of Mustard in Humid Region of Rajasthan, India. *Int. J. Curr. Microbiol. App. Sci.* **6**(7): 1879-1882.
- Patil, B.S.; Viraktamath, S.; Lingappa, S. Giraddi, R.S.; Parmeshwarappa, K. and Bhat, A.R.S. (2000). Effect of Bee-Q and bee here on pollination and yield of sesamum. *Insect Environment*. **54**:151-152.
- Patil, J.S.; Mokat, R.B.; Kamate, G.S. and Mupade, R.V. (2010). Studies on the influence of bee attractants on bee vision of *Apis dorsata* and *Trigona* sp. on onion. *Inter. J. Plant Protection*. **3**(2): 174-178.
- Priti, (1996). Studies on abundance, diversity, foraging behaviour and pollinating efficiency of insect pollinators of some vegetable crops. Ph. D. Thesis, Submitted to CCS Haryana Agricultural University, Hisar.
- Pudasaini, R. B.; Thapa, P. R. and Poudel, (2014). Effect of Pollination on qualitative characteristics of rapeseed seed in Chitwan, Nepal. *Inter. J. Biological, Biomolecular, Agricultural, Food and Biotechnological Engineering*, **8**(12): 1403-1406.
- Rana, V.K.; Raj, D. and Kaushik, R. (1997). Comparative foraging activity of *Apis mellifera* L. and *A. cerana* F. on rapeseed bloom. *J. Entomological Res.* **21**(1): 59-64.
- Rana, K.V. and Sunil, K. (1999). Performance of *Apis mellifera* L. colonies in the high hills of Himachal Pradesh. *Indian J. of Entomology*, **73**(3): 241 – 243.
- Rojeet, S.; Nirajan, S.; Prasad, B. N. and Sudimna, D. (2016). PE-163: Association Liver Enzymes with Blood Pressure in Diabetic Patients. (*KASL*), 2016(1), 196-197.
- Roubik, D.W. (1989). Ecology and natural history of tropical bees. Cambridge University Press, New York.
- Roy, S.; Gayen, A. K.; Mitra, B. and Duttagupta, A. (2014). Diversity, foraging activities of the insect visitors of Mustard (*Brassica juncea* L.) and their role in pollination in West Bengal. *The J. Zoology Studies*. **1**(2): 7-12.

- Sabbahi, R.; D. De Oliveira and J. Marceau. (2005). Influence of honey bee (Hymenoptera: Apidae) density on the production of canola (Crucifera: Brassicaceae). *J. Econ. Entomol.* 98: 367-372.
- Sabbahi, R.; D. De Oliveira; J. Marceau; et E. Houle. (2006). Does the honeybee (Hymenoptera: Apidae) reduce the blooming period of canola. *J. Agron. Crop Sci.* 192: 233–237.
- Shakeel, M. and Inayatullah, M. (2013). Impact of insect pollinators on the yield of canola (*Brassica napus*) in Peshawar, Pakistan *J. Agricultural and Urban Entomology.* **29**(1): 1-5.
- Shakeel, M.; Ali, H.; Ahmad, S.; Said, F.; Khan, K. A.; Bashir, M. A.; Anjum, S.I.; Islam, W.; Ghramh, H.A.; Ansari, M.J. and Ali, H. (2019). Insect pollinators diversity and abundance in *Eruca sativa* Mill. (Arugula) and *Brassica rapa* L.(Field mustard) crops. *Saudi journal of biological sciences.* **26**(7): 1704-1709.
- Sharma, D. and Abrol, D.P. 2014. Effect of insecticides on foraging behaviour and pollination role of *Apis mellifera* L. (Hymenoptera: Apidae) on toria (*Brassica campestris* var. toria) crop. *Egyptian Journal of Biology*, **16**: 79-86.
- Sharma, S. K.; Raj Tilak and Joshi, A. K. (2008). Quality of carrot seeds influenced by insect pollinators under field and controlled conditions. *Seed Research*, **36**(1): 109 – 111.
- Sihag, R.C. (2001). Why should bee-keeping be utilized as an input in agriculture? *Curr. Sci.* **81**(12):1514- 1516.
- Silva, D. P.; De-Serres, J. M.; Souza, D. C.; Hilgert-Moreira, S. B.; Fernandes, M. Z.; Kevan, P. G. and Freitas, B. M. (2013). Efficiency in pollen foraging by honey bees: time, motion, and pollen depletion on flowers of *Sisyrinchium palmifolium* (Asparagales: iridaceae). *J. Pollination Ecology.* 11: 27- 32.
- Singh, J. D. (2018). Relative abundance of *Apis* species on *Brassica napus* bloom. *The Inter. J. Engg. and Sci.* **7**(1): 01-07.
- Singh, A. K. (2018). Foraging by pollinators in pigeon pea. *Indian J. Entomol.* **80**(3): 711-714.
- Singh, A. K. and Thakur, R. K. (2017). Estimation of optimal pesticide application time on guava (*Psidium guajava*) based on temporal foraging activity of pollinators. *Indian J. Ecology*, **44**(2): 375-378.
- Singh, M. and Mall, P. (2020). Diversity and foraging behaviour of insects on mustard crop at Tarai region of Uttarakhand. *Inter. J. Chemical Studies.* **8**(1): 2556-2559.

- Singh, R. and Choudhary, D.K. (2005). Effect of honeybee pollination on yield and quality of mustard, *Brassica juncea* L. Paper presented in International Beekeeping Congress held on November 13-18, 2005 at Bangalore, India. pp. **36**.
- Singh, R. S.; Singh, A. P. B. and Singh, D. V. (2015a). Abundance and foraging activity of bee visitors to pigeon pea. *Progressive Agriculture*, **15**(1): 116-119.
- Singh, R. S.; Singh, A. P. B. and Singh, D. V. (2015b). Foraging Behaviour of The Bee Visitors to Pigeon Pea and Their Role in Its Pollination. *Progressive Agriculture*, **15**(2): 300-302.
- Singh, V.; Dubey, V. K.; Rana, N. and Chandrakar, G., (2018). The relative diversities and abundance of different insect pollinators on mustard. *Int. J. Curr. Microbiol. App. Sci.* **6**(1): 672-676.
- Sinha, S. N.; Atwal, S. S. and Sharma, S. P. (1994). Isolation distance studies in Indian mustard: Some observation on bee visitation. *Seed Research*. **22**:163-167.
- Subedi, N. and Subedi Prasad, I. (2019). Pollinator insects and their impact on crop yield of Mustard in Kusmas, Parbat, Nepal. *Journal of institute of science and technology*, **24**(2): 68-75.
- Subhakar, G. and Sreedevi, K. (2015). Foraging ecology of insect pollinators in bitter gourd. *Indian J. Entomol.* **77**(2): 189-202.
- Sushil, S.N., Stanley, J., Hedau, N.K. and Bhatt, J.C. (2013). Enhancing seed production of three Brassica vegetables by honey bee pollination in north-western Himalayas of India. *Univ. J. Agril. Res.* **1**:49-3.
- Taha, A. El.; Al-Abdulsalam, M. and Al-Kahtani S. (2016). Insect Pollinators and Foraging Behavior of Honey Bees on Alfalfa (*Medicago sativa* L.) in Saudi Arabia. *J. Kansas Entomol. Society.* **89**(1): 92-99.
- Tanda, A.S. (1984). Foraging behaviour of three species of *Apis* on raya in relation to the sugar concentration in its nectar. *Indian Bee Journal* **46**: 5-6.
- Venkataramegowda, S.; Jayaramappa, K.; Menon, A. and Ceballos, R. (2013). Use of bee-attractants in increasing crop productivity in Niger (*Guizotia abyssinica*. L). Brazilian Archives of Biology and Technology. **56**. 365-370.
- Virakamath, S., Patil, B., Murasing, S. and Guruprasad, G. S. (2002). Relative abundance and pollinator of fauna cross-pollinated oilseed crop at Dharwad, Karnataka, India. Paper

presented at 6th AAA *Int. Conf and world Apiexpo* – 2002, 24th February – 1st march, 2002, Bangalore, India (Abst.) 26 P.

Viraktamath, S. A., and Anagoudar, J. A., (2002). Influence of bee attractants in enhancing pollination and yield parameters of cucumber (*Cucumis sativa* L.). 6th Asian Apicultural Association (AAA), International Conference and World APIEXPO February 24 – March 1, 2002, Bangalore, p.62.

Wankhede, H.K.; Kulkarni, S.R. and Pawar, S.A. (2018). Influence of indigenous bee attractants on qualitative and quantitative parameters of cucumber (*Cucumis sativus* L.). *J. Entomol. and Zool. Studies.* **6**(4): 1241-1244

Westcott, L. and Nelson, D. (2001). Canola pollination: an update. *Bee world*, **82**(3), 115-129.

APPENDICES

Appendix I: Analysis of Variance (ANOVA) for effectiveness of different bee attractants in 1st spray to attract the *Apis mellifera* L. in mustard crop during *Rabi* 2021-22. (Table 4.15)

1 Day Before Spray (DBS)			
Source of variation	Degrees of freedom	Sum of Squares	Mean sum of squares
Replications	2.00	0.01	0.00
Treatments	8.00	0.05	0.01
Error	16.00	0.07	0.00
Total	26.00		

1 Day After Spray (DAS)			
Source of variation	Degrees of freedom	Sum of Squares	Mean sum of squares
Replications	2.00	0.01	0.01
Treatments	8.00	6.14	0.77
Error	16.00	0.04	0.00
Total	26.00		

3 Day After Spray (DAS)			
Source of variation	Degrees of freedom	Sum of Squares	Mean sum of squares
Replications	2.00	0.00	0.00
Treatments	8.00	4.72	0.59
Error	16.00	0.04	0.00
Total	26.00		

5 Day After Spray (DAS)			
Source of variation	Degrees of freedom	Sum of Squares	Mean sum of squares
Replications	2.00	0.00	0.00
Treatments	8.00	1.46	0.18
Error	16.00	0.07	0.00
Total	26.00		

Total Average of 1 st Spray			
Source of variation	Degrees of freedom	Sum of Squares	Mean sum of squares
Replications	2.00	0.00	0.00
Treatments	8.00	3.80	0.48
Error	16.00	0.01	0.00
Total	26.00		

Appendix II: Analysis of Variance (ANOVA) for effectiveness of different bee attractants in 2nd spray to attract the *Apis mellifera* L. in mustard crop during *Rabi* 2021-22. (Table 4.16)

1 Day Before Spray (DBS)			
Source of variation	Degrees of freedom	Sum of Squares	Mean sum of squares
Replications	2.00	0.00	0.00
Treatments	8.00	0.34	0.04
Error	16.00	0.05	0.00
Total	26.00		

1 Day After Spray (DAS)			
Source of variation	Degrees of freedom	Sum of Squares	Mean sum of squares
Replications	2.00	0.00	0.00
Treatments	8.00	3.80	0.48
Error	16.00	0.06	0.00
Total	26.00		

3 Day After Spray (DAS)			
Source of variation	Degrees of freedom	Sum of Squares	Mean sum of squares
Replications	2.00	0.00	0.00
Treatments	8.00	3.80	0.48
Error	16.00	0.06	0.00
Total	26.00		

5 Day After Spray (DAS)			
Source of variation	Degrees of freedom	Sum of Squares	Mean sum of squares
Replications	2.00	0.01	0.01
Treatments	8.00	1.96	0.24
Error	16.00	0.06	0.00
Total	26.00		

Total Average of 2 nd Spray			
Source of variation	Degrees of freedom	Sum of Squares	Mean sum of squares
Replications	2.00	0.00	0.00
Treatments	8.00	3.09	0.39
Error	16.00	0.02	0.00
Total	26.00		

Appendix III: Analysis of Variance (ANOVA) for effectiveness of different bee attractants in 3rd spray to attract the *Apis mellifera* L. in mustard crop during *Rabi* 2021-22. (Table 4.17)

1 Day Before Spray (DBS)			
Source of variation	Degrees of freedom	Sum of Squares	Mean sum of squares
Replications	2.00	0.02	0.01
Treatments	8.00	0.40	0.05
Error	16.00	0.06	0.00
Total	26.00		

1 Day After Spray (DAS)			
Source of variation	Degrees of freedom	Sum of Squares	Mean sum of squares
Replications	2.00	0.01	0.00
Treatments	8.00	3.95	0.49
Error	16.00	0.05	0.00
Total	26.00		

3 Day After Spray (DAS)			
Source of variation	Degrees of freedom	Sum of Squares	Mean sum of squares
Replications	2.00	0.01	0.00
Treatments	8.00	2.25	0.28
Error	16.00	0.05	0.00
Total	26.00		

5 Day After Spray (DAS)			
Source of variation	Degrees of freedom	Sum of Squares	Mean sum of squares
Replications	2.00	0.00	0.00
Treatments	8.00	1.62	0.20
Error	16.00	0.08	0.00
Total	26.00		

Total Average of 3 rd Spray			
Source of variation	Degrees of freedom	Sum of Squares	Mean sum of squares
Replications	2.00	0.00	0.00
Treatments	8.00	2.53	0.32
Error	16.00	0.03	0.00
Total	26.00		

Appendix IV: Analysis of Variance (ANOVA) for effect of bee pollination on quality and quantity parameters of mustard crop during *Rabi* 2021-22.

(Table 4.18)

No. of siliquae / plant			
Source of variation	Degrees of freedom	Sum of Squares	Mean sum of squares
Replications	2.00	18.20	9.10
Treatments	10.00	11061.80	1106.18
Error	20.00	90.47	4.52
Total	32.00		

Siliquae Length (cm)			
Source of variation	Degrees of freedom	Sum of Squares	Mean sum of squares
Replications	2.00	0.00	0.00
Treatments	10.00	5.14	0.51
Error	20.00	0.02	0.00
Total	32.00		

No. of seeds/ siliquae			
Source of variation	Degrees of freedom	Sum of Squares	Mean sum of squares
Replications	2.00	0.00	0.00
Treatments	10.00	37.80	3.78
Error	20.00	0.12	0.01
Total	32.00		

Total no. of seeds/ plant			
Source of variation	Degrees of freedom	Sum of Squares	Mean sum of squares
Replications	2.00	1547.32	773.66
Treatments	10.00	6597524.85	659752.49
Error	20.00	164.85	8.24
Total	32.00		

Seed yield/ plant (g)			
Source of variation	Degrees of freedom	Sum of Squares	Mean sum of squares
Replications	2.00	0.03	0.02
Treatments	10.00	87.32	8.73
Error	20.00	0.04	0.00
Total	32.00		

1000 seeds weight (g)			
Source of variation	Degrees of freedom	Sum of Squares	Mean sum of squares
Replications	2.00	0.03	0.02
Treatments	10.00	0.49	0.05
Error	20.00	0.03	0.00
Total	32.00		

VITA

The author of this thesis is Mr. Mahipal Bijarniya s/o Shri Bhanwara Ram born on 02nd November 1999 at Mindkiya, Makrana (Rajasthan). He passed his high school education in 2013 from Karni Senior Secondary School, Mindkiya, Makrana, Nagaur, Rajasthan (RBSE) with 74.50%. He passed his senior secondary examination in 2015 from Kota Career Point Senior Secondary School, Kuchaman City, Nagaur, Rajasthan (RBSE) with 77.00%. He completed his graduation in B.Sc. Agriculture from Sri Karan Narendra College of Agriculture of Sri Karan Narendra Agriculture University, Jobner, Rajasthan in the year 2020 and achieved OGPA of 6.70 / 10. After completion of graduation, he was admitted in College of Agriculture, Rajmata Vijayaraje Scindia Krishi Vishwa Vidyalaya, Gwalior, Madhya Pradesh for M.Sc. (Ag.) Entomology in the year 2022. He did research on the topic “Studies on the impact of Bee Pollination on yield parameters of Mustard (*Brassica juncea* L.)”

Date:

Place: Gwalior

Bijarniya

Mahipal