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Original research article

Diversity and Abundance of Pollinators Affecting Seed Production in Radish (*Raphanus sativa*)

Deepak Kumar Sharma and Dharam Pal Abrol*

Division of Entomology, Sher-e- Kashmir University of Agricultural Sciences & Technology, Faculty of Agriculture, Chatha Jammu-180009, J&K, India

Abstract Investigations were conducted to determine the impact of insect pollinators affecting seed production in Radish. Observations revealed that honey bees *Apis cerana*, *A. mellifera*, *A. dorsata*, *A. florea* were the important flower visitors and comprised more than 83 per cent of the flower visiting insects. Of all the honeybees, *A. cerana* was the most abundant followed by *A. mellifera*>*A. dorsata*>*A. florea*. The activity of honeybees increased with temperature and sunshine and decreased with relative humidity, wind speed, rainfall and evaporation. The influence of flowering seasonality had significant effect on population dynamics of bees as maximum population of all the bee species were observed after 12 days of flowering. Open pollination was found to be superior to both hand pollination and self pollination treatments. The number of siliquae produced, 1000 seed weight, seed yield per plant, and seed germination (%) was significantly higher in bee pollinated plots compared to open pollination and self pollination. Open pollination and hand pollination resulted in 118 and 76 per cent enhanced seed yield in radish as compared to control.

Keywords Insect pollinators, *Apis dorsata*, *A. florea*, *A. mellifera*, *A. cerana*, Foraging behavior, Seed production

INTRODUCTION

Radish (*Raphanus sativus* L.) is one of the important vegetable crops grown in India. India is next only to China in area and production of vegetables. India contributes about 13 per cent to the world vegetable production (Smita, 2005). Radish is a quick growing and short duration vegetable crop. It belongs to family Brassicaceae (Cruciferae), originated in Europe and Asia (Thompson and Kelly, 1957). The tender tuberous roots of radish used raw as salad and cooked as vegetable. Seeds are used for obtaining non-drying fatty oil, which is suitable for soap making, illuminating and also for edible purposes.

Radish is a cross-pollinated species with perfect flowers. It is pollinated by a variety of pollinating insects attracted to the abundance of flowers over an extended blooming period. As with most other cultivated members of the Brassicaceae family, radish is self-incompatible. Therefore, each pollination event comes from an outcross between two different radish plants of the same population.

The bee pollination, not only increased the yield but also improved the quality of the crop. Such improvements have also been reported by some workers. The seed set, numbers of seeds per siliqua and test weight were significantly higher in open pollinated radish plants compared to wind and self-pollinated plants (Verma and Phogat, 1994). Bee pollination plays a crucial role in enhancing both the quality and quantity of radish seed production. Numerous studies have demonstrated a significant increase in yield-related parameters when an ample number of pollinators are present. In a study conducted by Prasad *et al*. in 1989, it was observed that plots lacking any pollinators exhibited the lowest siliqua

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*Corresponding author. E-mail: dharam_abrol@rediffmail.com

percentage at 48.3%, in contrast to the other treatments. The plots that had access to all pollinators displayed the highest siliqua per plant at 75.8%, closely followed by plots enclosed with honey bees at 72.3%. Additionally, open-pollinated plots recorded the highest number of Seeds per siliqua at 10.58 along with the highest test weight. Singh and Chamotre (1992) found that in radish plants, the average number of pods per plant, seeds per siliqua, and seed yield per plant were highest in open-pollinated plants (375.55, 6.15, and 26.20 g, respectively) compared to hand-pollinated (222.60, 4.96, and 15.65 g, respectively) and naturally self-pollinated plants (90.50, 3.99, and 5.77 g, respectively). The 1000 seed weight was highest in hand-pollinated plants (20.64 g) compared to naturally self-pollinated (20.44 g) and open-pollinated plants (15.75 g). Verma and Poghat (1994) revealed that seed set, number of seeds per pod, and 100-seed weight were highest in open-pollinated radish, intermediate in wind-pollinated plots, and lowest in self-pollinated plots. Uma and Verma (1994) reported that bee-pollinated radish plants exhibited significantly higher pod set per plant (44.9%), number of seeds per pod (42.3%), 1000 seed weight (44.5 g), and germination rate (72.7%) compared to open-pollination. No pod set was observed in the control plot. Kapila *et al.* (2002) observed that open-pollinated radish plants had more grains per siliqua, higher seed yield per plant, greater 100-seed weight, increased seed set, and longer root length compared to caged plants. This suggests that insect pollination has a positive impact on both seed production and quality in radish plants. Since the crop is pollinated by wild honey bees, wild-flower flies, bumble bees, some Hymenopterans, Dipterans, Coleopterans, Lepidopterans *etc* whose population vary from one location to another. The extent of natural cross-pollination in radish is 65% (Stewart *et al.*, 2002). However, the low seed yield problem in radish prevails ranging from 2 to 20 g/plant in open pollination. The reason for less seed setting could be due to lesser pollinator availability and visitation and only a few reports are available in radish. Hence, in the present study, an experiment was carried out to determine the abundance, diversity and foraging behaviour in relation to abiotic factors and to evaluate the role of insect pollination on quality and quantity of fruit production. The present study was conducted to meet this end.

MATERIALS AND METHODS

1. Study site

The present investigation was carried out in the experimental farm of Division of Entomology, Sher-e-Kashmir university of Agricultural Sciences & Technology main campus Chatha, Jammu located 15 kms from Jammu city ((N 32°41′.5432″, E 74°49′27.8184″) during Rabi-2014-15. The climate of the area is typically subtropical. The study was made on Variety CR (Jammu Radish 45) raised in the month of October. The crop was sown on ridges which are 45 cm apart. 1.5−2.0 cm deep furrow is drawn on the top of each ridge with a pointed stick. The seed was sown in the furrow with proper moisture by dropping seeds in the furrow which is then closed. Before the second irrigation, the plants are thinned out properly. All the recommended agronomic practices were followed for raising the crop.

2. Sampling of pollinating insects

1) Recording of parameters

The study was conducted to determine the abundance and diversity of insects frequenting radish flowers, their foraging ecology and impact on seed production. Observations on pollinator diversity commenced in second week of March. Number of insect pollinators of each species visiting radish were recorded at 10 per cent flowering till its complete cessation. For this purpose, hourly observations on insect counts were made at 0800 to 1800 at 4, 8, 12, 16, 20 days after flowering. Five plots of 1×1 m^2 were marked in the crop and insects recorded by visual counting method from each side of the plot for one minute at hourly intervals in the beginning of each hour (Abrol, 2006). The mean of these observations constituted reading for each hour. Simultaneously, air temperature and relative humidity were recorded with a dry and wet bulb thermometer kept in shade. Sunshine, windfall, wind speed, rainfall and evaporation were obtained from Metrological Observatory of Agronomy Department located near the experimental field. Besides, the insect visitors of radish were also collected using hand net and preserved in Absolute alcohol for further identification.

3. Impact on quality and quantity of radish seed production

The role of insect pollination on quality and quantity of fruit production was evaluated using Hand pollination: Emasculation of pollen from anthers to stigma of receptive flowers, Self-pollination: For this purpose, counted number of plants were enclosed in pollination cages 5×3 meters and Open pollination: Counted number of plants were left for open pollination. On maturity the harvested from each treatment were compared for quantity and physicochemical characteristics which included Siliqua per plant, Seeds/20 Siliquae, 1000 seed weight, Seed yield per plant and Seed germination (%).

4. Statistical analysis

The recorded data were analysed for their variation between different treatments using Statistical Package for The Social Science (SPSS). Various statistical tools used in the experiment were mean, standard deviation and 95% confidence interval (Sokal and Rohlf, 2013).

RESULTS

The studies were conducted to determine the associated pollinators and their role in crop production. The result obtained are presented under the following heads.

1. Diversity of insect pollinators and their percentage composition on radish flowers

The data presented in Table 1 shows that radish flowers attracted wide variety of insects belonging to 5 orders, 10 families, 12 genera and 16 species. Of all these insects, honeybees *Apis dorsata*, *A. mellifera*, *A. cerana,* and *A. florea* were the dominant flower visitors and comprised more than 83.71% of the total flower visiting insects. Their abundance was in the order: *A. cerana*>*A. mellifera*>*A. dorsata*>*A. florea*. The other important insects frequenting radish flowers were *Andrena* spp., *Xylocopa fenestrata*, *X. pubescens, Musca* sp., and *Syrphus* sp.; the latter group of insects mostly collected nectar and frequented at interrupted hours and were not considered as dependable pollinators. The detailed

Table 1. Insect visitors and their percentage proportion on radish flowers during March–April 2015

Order	Family	Species	Percentage composition	Total
Hymenoptera	Apidae	*Apis cerana*	35.25	83.71
		A. dorsata	19.41	
		A. florea	5.76	
		A. mellifera	23.29	
	Anthophoridae	*Xylocopa aestuans*	1.48	2.13
		X. fenestrata	0.65	
	Halictidae	*Halictus* spp.	0.60	0.60
	Andrenidae	*Andrena* spp.	1.62	1.62
	Formicidae	*Camponotus compressus*	0.84	0.84
Diptera	Muscidae	*Musca* spp.	2.07	2.07
	Syrphidae	*Eristalis* spp.	2.51	6.48
		Metasyrphus corollae	2.82	
		Episyrphus balteatus	1.15	
Lepidoptera	Lycaenidae	*Horage* spp.	0.32	0.32
Coleoptera	Coccinellidae	*Coccinella septumpunctata*	0.83	0.83
Thysanoptera	Thripidae	*Thrips*	1.40	1.40

Fig. 1. Insect pollinators on radish. (A) observation by senior author, (B) *Apis florea*, (C) *A. dorsata*, and (D) *A. mellifera*.

Table 2. Seasonal incidence of different pollinators on radish in relation to weather parameters

Observation days after flowering	Number of pollinators					Weather parameters							
	A. florea	*A. dorsata*	*A. cerana*	*A. mellifera*	Others	Max T	Min T	RH1	RH2	WS	SS	RF	EV
4	0.53	1.61	2.67	2.21	1.46	24.4	12.2	90	52	2.6	4.5	4.0	1.2
8	0.36	1.88	3.41	2.55	1.75	23.7	10.5	95	59	2.4	3.3	7.0	1.1
12	0.45	2.28	4.77	2.45	1.90	22.4	15.5	73	72	4.7	0.5	10.6	0.8
16	1.21	2.79	5.51	2.73	1.97	15.5	12.8	93	93	2.1	0.0	0.0	0.4
20	0.55	1.92	2.70	2.62	1.70	14.4	12.4	95	86	2.7	0.0	3.0	0.0

Max T - maximum temperature, Min T - minimum temperature, RH1 - relative humidity morning, RH2 - relative humidity evening, WS - wind speed, SS - sunshine hours, RF - rainfall, EV - evaporation

investigations were, therefore, carried out on honeybees which frequented radish flowers in large numbers throughout the day and were anatomically suited for pollen collection.

2. Seasonal abundance of pollinators on radish flowers

The data presented in Table 2 shows the seasonal abundance pattern of honey bees *Apis dorsata*, *Apis mellifera*, *Apis cerana*, *Apis florea* and other flower visitors in relation to abiotic factors such as Max T, Min T, morning and evening relative humidity, wind speed, sunshine, rainfall and evaporation at biweekly intervals during the entire flowering periods for five different days commencing from 0800 to 1800 hours at hourly interval. The data recorded during different hours was pooled to obtain observation for each day. The data in general revealed that activity of honey bees increased with temperature and sunshine and decreased with relative humidity, wind speed, rainfall and evaporation. However the species differences in the population dynamics of bees were evident of all the honey bees *Apis cerana* was most abundant followed by *Apis mellifera* > *Apis dorsata* > *Apis florea*. The influence on the population dynamics of bees as maximum population of all the bee species were observed after 12 days of flowering.

3. Correlation coefficient (r) between bee activity and weather parameters

Analysis of data (Table 3) revealed that foraging population of *Apis florea* correlated significantly and positively with maximum temperature and sunshine hours but was negatively correlated with relative humidity, wind speed and rainfall. Similarly, population of *Apis dorsata* was highly correlated with maximum temperature and minimum temperature and had a high significant positive correlation of 0.535 and 0.412, respectively. However the population was negatively correlated with evening relative humidity and rainfall and have no significant relation with morning relative humidity, wind speed and sunshine hours. In case of *Apis cerana*, the population was highly significant and positively correlated with maximum temperature, minimum temperature and sunshine hours but was negatively correlated with relative humidity, wind speed and rainfall. Same trend was observed for *Apis mellifera* and other pollinators. This clearly reveals that all the four species of honeybees and other pollinators varied in their response to climatic conditions prevailing at a unit time.

4. Impact of pollination treatments on seed yield of radish

The data presented in Table 4 revealed that hand pollination resulted in significantly higher siliquae per plant than those excluded from insect visits. The caged plants on an average had 482.30 siliquae per plant whereas those left for open pollination resulted in 754.05 siliquae per plant. Open pollination was found to be superior to both the treatments as the number of siliquae produced was much higher 754.05. Similarly, Seeds/20 Siliquae, 1000 seed weight, Seed yield per plant, Seed yield per plot and Seed germination (%) was significantly higher

Table 3. Correlation coefficient matrix between bee pollinators and weather parameters

S. No.	Name of the pollinator	Correlation coefficient (r) with						
		Max T	Min T	RH1	RH2	WS	S.S	RF
1.	*A. florea*	0.312*	0.191	−0.240*	−0.706**	−0.435**	0.221*	−0.767**
2.	*A. dorsata*	0.535**	0.412**	−0.178	−0.421**	−0.035	0.123	−0.276
3.	*A. cerana*	0.433**	0.304*	−0.396**	−0.521**	−0.221*	0.342**	−0.132
4.	*A. mellifera*	0.572**	0.504**	−0.352**	−0.442**	−0.120	0.432**	−0.027
5.	Others	0.233*	0.204*	−0.312*	−0.221*	−0.234*	0.342**	−0.034

*Correlation is significant at the 0.05 level (2-tailed).
**Correlation is significant at the 0.01 level (2-tailed).

Table 4. Effect of pollination on yield parameters of mustard

Treatments	Siliqua per plant	Seeds/ 20 Siliquae	1000 seed weight	Seed yield per plant (g)	Seed germination (%)	Folds increase in seed yield over control	Percentage increase in seed yield over control
Hand pollination	615.93	112.68	12.63	45.20	92.90	1.27	78.00
Open pollination	754.05	124.77	13.37	56.10	95.33	1.56	63.00
Self pollination	482.30	89.39	10.82	25.71	82.46		
Mean	617.42	108.94	12.27	42.33	90.23		
Sem ±	1.99	0.98	0.36	0.66	1.54		
CD	7.81	3.85	1.37	2.60	6.07		
CV	1.23	1.56	2.24	2.15	2.97		

in bee pollinated plots compared to open pollination and self pollination. Open pollination and hand pollination resulted in 118 and 76 per cent enhanced seed yield in radish as compared to control.

DISCUSSION

The radish is an important vegetable crop highly dependent on pollinating insects for cross pollination and seed production. The results obtained are discussed under heads.

1. Diversity of insect pollinators on radish flowers

Radish flowers attracted wide variety of insects belonging to 5 orders, 10 families, 12 genera and 16 species. Among all the flower visiting insects, honeybees were most abundant comprising more than 83 per cent of the total flower visiting insects. The other visitors included *Andrena* spp., *Xylocopa fenestrata*, *X. pubescens, Musca* sp., and *Syrphus* sp.; which frequented at interrupted hours in few numbers. Similar results were obtained by Muhammad *et al*. (1973) who reported that honey bees comprised 77 to 94 per cent of pollinators of radish. Among the honey bees, *A. dorsata* was the highest (41%) followed by *Apis cerana* (F.) (32%) and *A. florea* (F.) (21%). However, in Egypt, Hussein and Abdel-Aal (1982) reported the solitary bees (*Amegilla* spp., *Halictus* spp., *Nomia* spp., *Nomiodes* spp., *Megachile* spp., and *Prosopis* spp.) as main flower visitors (85 per cent) and honeybees (15 per cent). Uma and Verma (1994) reported *A. cerana* as important pollinator of radish flowers. Verma and Phogat (1994) reported that the foraging activity of *A. cerana*, *A. dorsata*, *A. florea* and other insects were found on radish from morning to evening with peak foraging activity of *A. cerana*, *A. dorsata*, *A. florea* and others between 0800 to 1000 hr, respectively and activity declined thereafter. Rush *et al*. (1995) reported that pollen removal by pollinators in wild radish (*Raphanus raphanistrum* L.) was extremely high with a minimum of 84 per cent of pollen produced was removed in one hour. Pollen removal increased with increasing number of visits by honey bees and small native bees, but increased numbers of syrphid fly visits had no effect.

2. Seasonal abundance of pollinators on radish flowers

The observation on seasonal abundance pattern of bees in relation to weather factors revealed that (Table 2) activity of honey bees increased with temperature and sunshine and decreased with relative humidity, wind speed, rainfall and evaporation. However, the species differences in the population dynamics of bees were evident. Of all the honey bees species, *Apis cerana* was most abundant followed by *Apis mellifera* > *Apis dorsata* > *Apis florea*. The influence of flowering seasonality on the population dynamics of bees was evident as maximum population of all the bee species were observed after 12 days of flowering. Similar results were obtained by Uma and Verma (1994) who made observations on *A. cerana* foraging on radish flowers from 0640 to 1839 hr with peak foraging between 1100 and 1400 hr. In general, population of foraging bees increases with increase in bloom density when availability of flowers and obtainable reward is more.

3. Correlation coefficient (r) between bee activity and weather parameters

Correlation analysis between foraging bees and weather factors (Table 3) revealed that foraging population of *Apis florea* correlated significantly and positively with maximum temperature and sunshine hours but was negatively correlated with relative humidity, wind speed and rainfall. Similarly, population of *Apis dorsata* was highly correlated with maximum temperature and minimum temperature and had a high significant positive correlation of 0.535 and 0.412, respectively. However, the population was negatively correlated with evening relative humidity and rainfall, and had no significant relation with morning relative humidity, wind speed and sunshine hours. In case of *Apis cerana*, the population was highly significant and positively correlated with maximum temperature, minimum temperature and sunshine hours but was negatively correlated with relative humidity, wind speed and rainfall. Same trend was observed for *Apis mellifera* and other pollinators. This clearly reveals that all the four species of honeybees and other pollinators varied in their responses to climatic conditions prevailing at a unit time.

In general, each bee pollinator has specific ecological threshold for foraging activity which differ inter and intra specifically depending upon the level of adaptation of a given species in an environment (Burill and Dietz, 1981; Abrol and Kapil, 1986). The bee activity increased with temperature but was not affected by relative humidity and vapour pressure. Nunez (1977) found that in case of *Apis mellifera*, morning activity was related to nectar flow and in the evening, it was correlated with the photoperiod. Iwama (1977) found that the interaction between temperature and light intensity was responsible for the flight activity of *Tetragonisca angustica*. Abrol and Kapil (1986) found that light intensity and solar radiations were important factors controlling flight activity of *Megachile lanata*.

4. Impact of pollination treatments on seed yield of radish

The data presented in Table 4 revealed that hand pollination resulted in significantly higher siliquae per plant than those excluded from insect visits. The caged plants on an average had 448.94 siliquae per plant whereas those left for open pollination resulted in 769.05 siliquae per plant. Open pollination was found to be superior to both the treatments as the number of siliquae produced was much higher 944.54. Similarly, Seeds/20 Siliquae, 1000 seed weight, Seed yield per plant, Seed yield per plot and Seed germination (%) was significantly higher in bee pollinated plots compared to open pollination and self pollination. Open pollination and hand pollination resulted in 118 and 76 per cent enhanced seed yield in radish as compared to control. In several earlier studies, open pollination and bee pollination has been reported to significanty enhance seed yiels in radish. For example, Olsson (1952) recorded flower set of 64.7 per cent of cauliflower with 2.46 seeds per pod and 1.75 gram per pod with bees excluded plots whereas bees included plots these values were increased to 95.3, 4.08 and 2.69, respectively.

Uma and Verma (1994) reported that pod set per plant (44.9%), number of seeds per pod (42.3%), 1000 seeds weight (44.5 g) and germination rate (72.7%) were significantly high in bee pollinated radish plants over open-pollination. There was no pod set in control plot.

Priti *et al.* (2001) reported that fruit set was 81 per cent and 56.55 per cent, siliqua length 13.2 and 6.8 cm, number of seeds per pod was 8.6 and 4.8 and seed weight 1.5 and 0.9 grams in bee pollinated and self pollinated radish, respectively. Kapila *et al.* (2002) reported that open pollinated plants of radish and greater number of grains per siliqua, seed yield per plant, 100 seed weight, seed set than the caged plants, indicating the positive effects of insect pollination on seed production and quality.

5. Summary and conclusion

The above findings clearly establish that insect pollination not only enhances seed yield but improves the quality as well. Radishes are self-incompatible plants that require cross-pollination, making pollinators crucial. The availability of sufficient pollinators available under natural conditions may vary in different locations. Such studies on pollinator diversity and abundance are helpful to supplement the areas with managed colonies of honeybee for obtaining optimum yields in terms of seed quantity, weight, and harvest, Conserving and enhancing native pollinators - especially the bees - can promote the radish productivity. Furthermore, findings of current study can be widespread over large geographical range as *A. dorsata* and many specioes of bees are distributed widely across India, Pakistan, Oman, Sri Lanka, Iran, Afghanistan, Indonesia, Philippines, and southern China (Akratanakul, 1990). Further studies should focus other hundreds of native pollinators for their pollination potential coupled with basic investigations on their life cycle and biology e.g. nesting biology and host plant range.

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