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Role of pollinators in vegetable seed production

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Abstract
This paper reviews a role of pollinator's in vegetable seed production and commercial production of large numbers of colonies for the pollination. The pollination phase has a significant impact on final seed yield and quality. The most reliable and efficient form of pollination is through insects. Though butterflies, moths, beetles, thrips, birds play a role in pollination, honey bees are the ideal pollinators. Many insects such as honey bees (*Apis mellifera, A. cerana),* bumble bees (*Bombus haemorrhoidalis, B. terrestris*) and flies are the important pollinators which are in commercial use. Low seed yield due to inadequate pollination is often faced as a major problem in vegetable seed production. There is a need to ensure pollination by conserving the pollinators and attracting them towards the crop land. The pollination potential and economic importance of the effect of honeybees on these vegetables is still need to be established.

Keywords: Bees, pollination, pollinators, seed, quality, vegetables

1. Introduction
Vegetables are important constituents of Indian agriculture and nutritional security due to their short duration, high yield, nutritional richness, economic viability and ability to generate on-farm and off-farm employment. Our country is blessed with diverse agro-climates with distinct seasons, making it possible to grow wide array of vegetables. India is the largest producer of vegetables after China in the world. Vegetables are vital sources of proteins, vitamins, minerals, dietary fibers, micronutrients, antioxidants and phytochemicals in our daily diet. Apart from nutrition, they also contain a wide array of potential phyto-chemicals like anticarcinogenic principles and anti-oxidants (e.g. flavonoids, glucosinolates and isothyocynates). India is rich in biodiversity of vegetables and is the primary/secondary center of origin of many vegetables. It produces 163 million tonnes of vegetables from an area of 9.39 million hectare. To improve the productivity of any crop, use of quality seeds is essential. The seed replacement rate in varieties of important vegetables varies from 42 per cent in leafy vegetables to 99 per cent in tomato, the overall replacement of the seed being nearly 80 per cent (Mishra, 1998) [1]. Some of these crops require insect pollination to produce a crop, such as pumpkin, squash, cucumber and swedes. Some of the major seed vegetable crops grown in India include carrots, cauliflower, cabbage, broccoli, cucumber and beetroot. Pollination and fertilization are the important events in seed development and maturation. Pollination also benefits society by increasing food security and improving livelihoods. The successful production of any crop in terms of good quality and high productivity depends upon many factors and pollination is one of them. Pollinators enhance the reproduction and genetic diversity of around 80% of the plant species. Inadequate pollination is caused by several factors and the most important of which includes the lack of adequate number and diversity of pollinators. This can be achieved only through planned honeybee pollination, owing to the fact that honeybees are the only pollinators which we can managed. Role of pollinator in vegetable seed production has been discussed in the present review.

2. Pollinators and Pollination services
Pollination is one of the most important mechanisms in the maintenance and promotion of biodiversity and in general, life on Earth. Pollinators strongly influence ecological relationships, ecosystems conservation and stability, genetic variation in the plant community, floral diversity, specialization and evolution. Pollinators are extremely diverse, with more than 20,000 pollinating bee species and numerous other insect and vertebrate pollinators.

More than half of plant species are self-incompatible or dioecious and completely dependent on biotic pollination (McGregor, 1976) [2]. These plants are critical for the continued functioning of ecosystems as they provide food, form habitats and provide other resources for a wide range of species. In India, mostly honey bees are used for the pollination of various agricultural and horticultural crops but in western countries like Netherland, Europe and USA. Bumble bees are widely used for the pollination of many crops both in open and protected conditions (Delplane, 1995) [3]. The potential value of bumblebees as pollinating insects in agriculture has been recognized for a long time. Because their tongues are longer than those of honeybees, bumblebees are much better at pollinating flowers with deep corollas. Some pollinators also use flowers as brood sites (Sabara and Winston (2003); Hembry and Althoff 2016) [4, 5]. The degree of ecological dependence of these animals on the flowers ranges from completely obligate, as in species that use particular flowers as brood sites or sources of food, to facultative, as in species that have generalist diets that include some food from flowers.

Development of insect pollinators is considered as one of the cheapest and eco-friendly approaches in maximizing the yield of cross pollinated crops. Bees, flies, butterflies, moths, wasps, beetles, thrips and some other insect orders encompass the majority of pollinating species. Vertebrate pollinators include bats, non-flying mammals (several species of monkey, lemur, rodents, tree squirrel, coati, olingo and kinkajou) and birds (hummingbirds, sunbirds, honeycreepers and some parrot species). Among the insects, hymenopterans (largest and diversified assemblages of beneficial insects) are highly evolved and constitute the most important group of pollinating insect. Diptera are probably the second most common order of flower visitors and pollinators today (after Hymenoptera). Flies (Diptera) are among the most common insects that visit flowers, and their association with flowers has a long history. Flies are also considered to be primitive pollinators of the earliest flowering plants with their suctorial or lapping mouthparts (Kevan and Baker, 1983) [6]. Over 75 per cent of the food and medicinal plants that benefit mankind and 90 per cent of all flowering plants rely on pollination by animals to produce healthy seeds and fruits. Honeybees are critically important for crop pollination worldwide, as it is assumed to contribute 80% of insect pollination. A well-pollinated flower will contain more seeds, with an enhanced capacity to germinate, leading to bigger and better-shaped fruit (Ken *et al*., 2012) [7].

Honeybee plays important role in sustainable agriculture and is sometimes major source of income to the farmers, especially to the small farmers. Approximately 70% of the tropical crop species depend on pollinators for optimum yields. The economic value of such pollinated crops in India is 726 million. Of the total pollination activities, over 80 per cent is performed by insects and bees contribute nearly 80 per cent of the total insect pollination, and therefore, they are considered as best pollinators. According to an estimate there are at least 30,000 species of bees in the world. In India , out of the 160 million hectares of the cropped area, more than 55 million is under bee dependent crops. India is endowed with the greatest biodiversity as far as honey bee species are concerned. Out of the seven *Apis species* six (*A. cerana, A. florea, A. dorsata, A. andreniformis, A. laboriosa, A. koschevnikovi*) are indigenous to India and *A. mellifera* has been introduced in to our country (Thakur *et al*., 2016) [8].

Table 1: State-wise details of Bee species in India

S. No.	Region	Species	Honey Production Area
1.	North	*Apis mellifera* *Apis cerana*	Delhi, U. P., Haryana, Punjab, H.P. Uttra khand & J & K.
2.	South	*Apis cerana*	A.P., Karnataka, Kerala, T.N., Pondicherry.
3.	East	*Apis mellifera* *Apis cerana*	Bihar &W.B. Orissa, All North-east States, Chhattisgarh, & Jharkhand.
4.	West	*Apis mellifera* *Apis cerana*	Rajasthan. Gujarat, Maharashtra, M.P., Goa.

(Alam *et al*., 2014) [9]

3. Bumble bees (*Bombus terrestris*)

In some crops, Bombus workers can be the main pollinator or can be used to complement honey bees. Bumble bees are active at temperatures from 10 °C, and even below, to 30 °C. They function best at temperatures between 15 and 25 °C and are extensively used for pollination in greenhouses. In numerous countries, several bumblebees' species (major ones are *Bombus terrestris* and *B. haemorrhoidali)* are used for tomato pollination in greenhouses; in 2004, 40,000 ha of tomato crops were pollinated, with a crop value of e 12,000 million. The growers benefit from bumblebee pollination because of lower production costs, increased yields, and improved fruit quality (Velthuis and Doorn, 2006) [10]. These large bees buzz the flowers through vibration of the thoracic muscles, which causes a large number of pollen grains to be released onto the stigma. Bumblebees are more efficient and reliable pollinators of greenhouse crops helping in fruit production of high quality due to their high speed of pollination, buzzing behaviour and efficiency at low temperature and sunlight (Paydas *et al*., 2000) [11]. Use of insect pollination within greenhouse, especially bumblebees gave cost effective and attractive substitute of manual pollination (Velthuis and van Doorn, 2006) [10]. An external and internal environmental condition along with foraging efficiency of bumblebees has impact on required pollination of tomato cultivation. Activity of bumblebees foraging was important to serve as successful pollinators under these greenhouse conditions when compared with honeybees (Wolf and Moritz, 2008) [12]. They have better adaptive qualities for pollen and nectar collection near their hives and preference increases in small patches with flower abundance (Sheikh *et al*., 2014) [13]. The foraging behaviour of pollinators can influence their efficiency in pollinating a particular plant species and understanding of foraging behavior of pollinators can help in pollination management. Activity of bumblebees foraging was important to serve as successful pollinators under these greenhouse conditions when compared with honeybees. Bumblebees can fly and pollinate flowers under cool conditions due to their better thermoregulatory abilities (Corbet, 1996) [14]. They have better adaptive qualities for pollen and nectar collection near their hives and preference increases in small patches with flower abundance (Sowig, 1989; Sheikh *et al*., 2014) [15, 16].

4. Flies

Flies can only be used as managed pollinators in enclosures. In some hybrid seed production, where one or both parental lines produce too little pollen or nectar or if the parental lines are not attractive to bees, flies may provide a valuable alternative as pollinators. Another way to use flies as pollinators is in very small cages that contain a few flowers or a limited surface for colonies of managed eusocial pollinators such as honey bees or bumble bees. The main dispersal method for flies is at the pupal stage when the flies emerge, following an incubation period in the field. The adult flies will search mainly for nectar in the flower and thus come into contact with the pollen. This pollen is not packed or collected by the flies, and therefore remains available for pollination when the fly visits another flower to collect its nectar. Prior to using flies, one needs to check the local registration requirements and use only products that are permitted in the country/state where the crop is grown. *Lucilia* spp. blow flies (Calliphoridae) have been used with the following crops: cauliflower, cabbage, oilseed rape (*Brassica napus*), carrot, onion, leek (*Allium porrum*), and asparagus (*Asparagus officinalis*). Their optimal temperature range for foraging is 18-28 °C. *Lucilia* blow flies are not endemic and their importation is not permitted, an alternative is the house fly (*Musca domestica*), which is raised in many countries for its maggots, used as bait for fishing. Where there is no commercial production of house flies, a box with chicken manure can be placed under a source of water (irrigation drip for example) that keeps the substrate wet but not flooded. Flies will propagate and increase the fly population. Priti and Sihag (1998) [17] reported 20 insect species of flower visitors of *Daucus carota*, of them 6 species are dipteran. In another study Sihag (1986) [18] observed that, among the insect visitors of carrot, flies are the second most efficient pollinator after bees. Goyal *et al*., (1989) [19] reported 71 insect species belonging to 31 families and 8 orders on carrot bloom in Himachal Pradesh. During this study flies have also proved themselves as dominant pollinators after the bees. An enormous work has been done on crops of Himachal Pradesh. Mishra and Kumar (1993) [20] reported a number of dipteran species of the genus *Musca, Orthellia* (Family Muscidae); *Eristalis, Scaeva. Sphaerophoria, Episyrphus, Ischiodon. Meanostoma* (Family Syrphidae) are common visitors of mustard. In a study of pollinator efficiency, flower visitors of onion revealed that, numerically the species strength of Diptera is more than Hymenoptera (Priti, 1998) [21]. Kumar *et al*., (1985) [22] stated that the Diptera are the predominant pollinators after Hymenoptera in onion at Himachal.

5. Wild Pollinators

The most important wild pollinators are wild bees. Insects other than bees are often recorded visiting flowers of commercial crops, but in general they lack the necessary behavioural pattern for efficient and consistent pollen transfer (such as switching between male fertile and male sterile lines). Nevertheless, the existence of wild bees can contribute to pollination service by increasing the number of efficient pollinators visiting flowers and by enhancing the pollination effectiveness of managed pollinators (Greenleaf & Kremen 2006) [23]. Improving the conditions for wild pollinators, such as keeping the wild bloom next to the fields and reducing pesticide use, may contribute to improved pollination service for seed crops. Care must; however, be taken not to create an abundance of competitive forage during the pollination period, as this can limit the effective pollination.

6. Pollinators value in Vegetable seed production

Vegetable crops require insect pollination for qualitative and quantitative seed productions. The pollination requirements for vegetable species grown for seed vary widely and depend on pollination mechanism of plant viz., self or cross-pollination to facilitate seed set. In general, irrigation of the pollinated crop impacts nectar production. Adequate watering during pollination period is important for pollinator visits. Due to peculiar environmental conditions, Himachal Pradesh is known for production of temperate vegetable seeds. Typically, temperate vegetables are those which require vernalisation of their vegetative stage below 7.2 ^{0}C for several weeks. Hence, Cabbage, Brussels sprouts, European carrot, turnip and radish are some vegetables whose seed can only be produced in zones where such conditions are prevalent. Technology for the seed production of all these vegetables have been standardised at IARI, Katrain and Vegetable Research Station, Kalpa of Dr YS Parmar UHF, Solan. In many vegetable crops, such as onion (*Allium cepa*), carrot (*Daucus carota*), cabbage (*Brassica oleracea*), cauliflower (*B. oleracea*), cucumber and radish (*Raphanus sativus*) etc pollination is performed mainly by honey bees (*Apis* sp. and bumble bee) and also dependent on insect pollination (Thakur *et al*., 2016) [8] (Table 2.).

Brassica spp. flowers usually produce ample nectar and therefore the hives should be supplied without sugar syrup. Brassica spp. can be pollinated by honey bees, bumble bees and flies. The diversified Brassica family contains over 3500 species in 300 genera of which most of them are important to the diet and economic welfare of people throughout the world (Wills, 1973) [24]. Brassica vegetables like broccoli, *Brassica oleracea* var. *italica* Plenck, Chinese cabbage, *B. rapa pekinensis* (Lour.) Hanelt., Kohlrabi, *B. oleracea* var. *gongylodes* L. etc. are grown in the Indian Himalayas during cropping season and also in off seasons under protected /polyhouse conditions. This transformation from subsistence agriculture to commercial agriculture possesses new challenges for improving the productivity and quality of vegetables (Pratap, 1999) [25]. Duran *et al*., (2010) [26] stated that an increase in yield of 50.34% in honey bee introduced field of *Brassica napus* with that of plots without bees. Sushil *et al*., (2013) [27] reported that more number of bees (*Apis mellifera*) were found visiting broccoli crop under net house condition (6.05 bees/plant) followed by kohlrabi (5.35 bees/plants) and Chinese cabbage (5.05 bees/plant). Bees spent more time in Chinese cabbage flower (6.92 sec) while it was 6.50 sec in broccoli and 5.54 sec in kohlrabi. Bees in the open conditions were found to spend less time in a flower as compared to the net house conditions. Planned honeybee pollination was found to inflict maximum impact on the seed production of broccoli with an increase in seed yield of 29.2 per cent. The net profit was also more in case of broccoli, which was calculated to be 1324.60$ per ha in honeybee pollinated broccoli crop when compared to the natural pollinated crop.

Cucumber, melon and squash have male and female/hermaphrodite flowers on the same plant. Both flower types produce nectar, while only the male and hermaphrodite flowers produce pollen. Visits by bees can be determined by the presence of pollen grains on the stigma of the female/hermaphrodite flower. Because the cucumber and especially the squash flower produce ample nectar, the beehives are provided without sugar syrup. These crops can be pollinated by honey bees and bumble bees. Walters and Taylor (2006) [28] study on honey bee (*Apis mellifera* L.) impact on seed set, fruit set, and yield of jack-o-lantern (*Cucurbita pepo* L.), large-sized (*C. maxima* Duch.), and processing pumpkins (*C. moschata* Duch. ex Poir.) under field conditions. There were sufficient natural pollinators (including bumblebees (*Bombus* spp.), carpenter bees (*Xylocopa* spp.), honey bees, and squash bees (*Peponapis pruinosa* Say) provided. Honey bee pollination resulted in larger-sized fruit, increasing individual fruit size of all but small-sized pumpkins (<0.5 kg). Individual pumpkin fruit weights of the *Cucurbita pepo*, *C. moschata*, and *C. maxima* cultivars evaluated increased by about, 26%, 70%, and 78%, respectively, when honey bee colonies were included. Natural pollination was insufficient to stimulate maximum fruit size development and seed number and seed weight per fruit.

In Onion, the stamens in each floret dehisce a few days before the stigmas become receptive. Florets of onion produce nectar and pollen. Bees collect onion nectar, but very rarely collect onion pollen under Israeli conditions, and therefore the hive should be supplied without sugar solution, and in enclosures they should be provided with additional pollen supply. Onion can be pollinated by honey bees and flies. Chandel *et al*., (2002) [29] conducted experiment on the abundance of different natural pollinators and on the effect of bee pollination on quantity and quality of onion seed (var. Nasik Red) under sub-temperate conditions of Himachal Pradesh situated at an altitude of 1200 m above mean sea level. Two colonies each of *Apis mellifera* and *A. cerana* were introduced into the crop ecosystem. Besides, a natural nest of *A. dorsata*, *A. florea* and syrphids (*Episyrphus balteatus*, *Metasyrphus conferator* and *M. corollae*) were also visiting the crop. *A. dorsata* proved to be the dominant visitor (7.4 bees/m^2/2 minutes) and most efficient pollinator covering on an average 7.5 flowers/umbel/visit during peak hours of their foraging activity (1200-1400 hrs) compared with *A. cerana* (5.4 flower/umbel/visit). *Apis florea* and *A. mellifera* visited onion flowers least and ranked fourth and fifth overall in visiting frequency. *Apis dorsata* had the maximum foraging period (0630-1855 hrs) followed by *A. cerana* (0645-1830 hrs) and *A. mellifera* had the least foraging period (0725-1820 hrs) on onion seed crop. Induced bee pollination increased seed yield by 2.5 times and produced on an average 971 seeds per umbel compared to 406 in the control. The seeds from induced pollination field resulted in 90 per cent germination compared to 69.5 per cent germination from the control.

In Carrot**,** the stamens in each flower and umbel ripen a few days before the stigma becomes receptive, such that cross-pollination occurs more often than self-pollination. The flower produces nectar as well as pollen. Nevertheless, the nectar and pollen produced by the carrot flower is not always sufficient for optimal colony development. For this reason, sugar syrup and pollen are supplied for the development of bumble bee colonies. Carrots can be pollinated by honey bees, bumble bees and flies. It has been reported that more than 95% crossing occurs in the field (Thompson, 1962) [30]. Insect pollinators were proved to be essential for commercial seed production (Hawthorn *et al*., 1960) [31] as 85% increase in yield was obtained with honeybees' pollination. Pankratova (1964) [32] found that plots visited by insects produced 15 times more number of seeds and ten times more weight of seed as compared to that of plants covered with muslin cloth. Whitaker *et al*., (1970) [33] reported that for large scale production of seeds, where male sterile plants are used, there is a need for pollinating agents for maximum cross-pollination. Syrphids, *Musca* spp. and honeybees seemed to be the most important flower visitors in carrot (Singh 1983, Mishra *et al*., 1993, Abrol 1997) [34-36]. In open pollinated plots, 85-90% Dipterous visitors and 7.7-10.9% *Apis florea* were observed (Sinha and Chakrabacti 1992) [37], resulting in 25-33% higher seed yield. Sharma and Sharma (1968) [38] found that houseflies were more prominent and more active than honeybees in the pollination of carrot in Kalpa Valley, India.

Table 2: Vegetable crops dependent upon pollinators

Crops	Pollinators / Visitors
Tomato	Honey bees, Wild bees, halictid bee (*Augochloropsis ignita* Smith), bumble bees (*Examalopsis glubosa*),
Watermelon	Honey Bees, bumble Bee, and different species of bees (*Apis mellifera* L., *Halictus* spp. *Augochlorella gratiosa* Smith, *Agapostemon splendens* Lepeletier, and *Augochloropsis caerulea, Apis Cerana, A. Florea, Melipona* spp. and *Tigona iridipennis*)
Pumpkin and squash	Honey bee, wildbees (*Peponapsis* spp. and *Zenoglossa* spp), cucumber beetles (*Diabrotica* spp.), scarab beetles, meloid beetles, flies and moths.
Muskmelon	Honey bees, ants and thrips.
Carrot	Flies and Bees. Most of the species of visitors were in the superfamily Apoidea, or the Ichneumonidae, Psammocharidae (Pompilidae), Sphecidae, and Vespidae families of the Hymenoptera, and the Bombyliidae, Sarcophagidae, Stratiomyidae, Syrphidae, and Tachinidae families of the Diptera.
Bitter gourd	Small bees
Beet	Thrips, syrphid fly, honey bees, solitary bees and hemipteran insects
Coriander, Cucumber, and Asparagas	Honey bees.
Brinjal	Bumble bees, carpenter bees and honey bees
Lettuce	Honey bee, flies, wild bees and butterflies.
Okra	Honey bees and bumble bees.
Onion	Flies, honey bees, small syrphid flies, halictid bees and drone flies
Peppers	Honey bees and other bees.
Parsnip	Honey bee, other bees, beetles and dung flies.
Beans	*Apisdorsata* spp., *A. florea, Trigona* spp. and bumble bees.
Scarlet runner bean	Honey bee and bumble bee
Cole crops	Honey bees, wild bees, and flies. Bees of the family Andrenidae, Megachilidae, and Nomadidae more important than

	honey bees in the pollination of cabbage (Bombus, psithyrus and wild bees).
Field beans	Honey bee and short toungue bumble bee and carpenter bee
Cowpea	Bumble bees
Lima bean	Honey bee, bumble bee and thrips

(Thamburaj and Singh 2001) [39]

Abak *et al.*, (2000) [40] conducted an experiment on eggplants grown in unheated plastic houses and observed that bumble bee's activity on eggplants was increased between 9:00 and 11:00 a.m., the peek activity was observed between 10:00 and 11:00 a.m. then decreases gradually and they stopped between 13:00 and 14:00 p.m. They started foraging again in the afternoon between 15:00 and 18:00 p.m. Spivak (2000) [41] found that bumble bees are more efficient foragers than honey bees on cranberry flowers because they are capable of buzz-pollination. Bumble bees hang on to the flower and buzz it by vibrating their muscles that control flight. Bumble bees are the most efficient pollinators not only for the wild plants, but also for pollination services, used in both outdoor and greenhouse horticulture and orchards. Sanz and Serrano (2006) [42] recorded the bumble bee activity on sweet pepper to determine the fruit quality in greenhouse and found that there is an increase in the seed set per fruit. They recorded 49.8% and 40.7% more seed set than the control (27.5% and 25.71%) in two varieties. Vergara and Buendia (2012) [43] reported more number of seeds in tomato pollinated by *B. Ephippiatus* (201.00) and (183.94) as compared to control (139.03 and 59.63, respectively) grown inside polyhouse. Similar results were reported by Ahmad *et al.*, (2015) [44] in bumble bee pollination (126 seeds/fruit) as compared to manual pollination (102 seeds/fruit). Yankit *et al.*, (2018) [45] reported that bumble bee pollination of tomato cultivar (Solan Lalima) grown inside polyhouse resulted in increased number of fruits per cluster (6.76 fruits/cluster), number of fruits (75.80 fruits/plant), fruit length (5.16cm), fruit breadth (5.75cm), fruit weight (93.87g), fruit yield (12.7kg/m2) and healthy fruits (90.33%). Reduction in number of misshapen fruits (9.8%), number of seeds (102.95 seeds/fruit), 1000 seed weight (6.32gm) over control crop was also observed in bumble bee pollinated crop. Bumble bee pollination accounted per cent increase in number of fruits per plant, healthy fruits, fruit length, fruit breadth, fruit weight, fruit yield, number of seeds and 1000 seed weight by 38.41, 21.94, 46.45, 50.82, 57.66, 64.79, 78.54 and 78.80 per cent, respectively.

7. Pollination under Protected condition

A small colony (nucleus) may be introduced in closed environments with a surface area of less than 500 m^2. The adult and brood populations of such beehives should be lower than those in open fields (around 5 bee frames, 3 containing brood). Colonies should be moved during the day as the old foragers will not get accustomed to their new environment and will die outside the hive following its installation. By leaving the majority of foragers at the original apiary, new foragers will start to forage in the confined environment while old ones will return to the colonies left in place by the beekeeper to host them. With some crops, such as onion, cucumber (*Cucumis sativus*) and melon (*Cucumis melo*), honey bees generally not collect pollen. Therefore, the pollen stores inside the beehives should be checked frequently (at least every 2 weeks). In the case of pollen deficiency, pollen supplements or substitutes should be supplied. There should always be free space for honey gathering. There should always be drinking water available for the bees. The most highly recommended method is a vessel with water containing floating elements or a clean burlap that is dipped in the water so that bees can stand while drinking. Avoid using greenhouse covers that absorb or diffuse the UV part of the spectrum (wavelengths ~320-380 nm).

8. Conclusion

Cross-pollination by insects is considered as one of the effective and cheapest method for triggering the crop yield both qualitatively and quantitatively. Insect pollinators enhance the yield and provide uniform and early pod setting. Pollination by bumblebees has shifted the growers to adopt biocontrol methods for crop protection to reduce the usage of toxic pesticides is a positive step for our environment and economy. A realistic way to ensure pollinator conservation is to promote and enhance its value to society. During last few decades, the population of pollinators is declining due to use of toxic agrochemicals, loss of natural habitats and climate change at worldwide. We can improve the health of bumblebees and other pollinators by use of nontoxic chemicals and in-situ conservation of natural habitats. Improving the health of bees and other pollinators is a necessity. Without pollinators, we can't enjoy the natural habitats and food also.

9. References

1. Mishra RC. Beekeeping in the changing agricultural scenario for rural upliftment. In: Prespective in Indian Apiculture (G S Gatoria, Y Singh and H S Jhajj, eds). H. S. Offset Printer, Daryagunj, New Delhi. 1998, 15-19.
2. McGregor SE. Insect pollination of cultivated crop plants. Agriculture Handbook. Academic Press, London. 1976, 496.
3. Delplane KS. Bumble beekeeping: queen starter box. American Bee Journal. 1995; 133:743-745.
4. Sabara HA, Winston ML. Managing honey bees (Hymenoptera: Apidae) for greenhouse tomato pollination, Journal of Economical Entomology. 2003; 96:547-554.
5. Hembry DH, Althoff DM. Diversification and coevolution in brood pollination mutualisms: Windows into the role of biotic interactions in generating biological diversity. American Journal of Botany. 2016; 103:1783-1792.
6. Kevan PG, Baker HG. Insects as flower visitors and pollinators. Annual Review of Entomology. 1983; 28:407-445.
7. Ken T, Marma A, Munawar MS, Partap T, Partap U, Phartiyal P. Value of insect pollinators to Himalayan agricultural economies. International Centre for Integrated Mountain Development (ICIMOD), 2012.
8. Thakur RK, Sehgal M, Chakrabarty PK. Pollinator and IPM: An interface in different agro climatic zones of India. ICAR Press, New Delhi. 2016, 1-4.
9. Alam P, Katiyar A, Sachan AK. Beekeeping of Indigenous Honeybees, Honey Production Practices and Policy Option for Their Conservation. Trends in Biosciences. 2014; 7(7):586-591.
10. Velthuis HHW, Van Doorn A. A century of advances in

bumble bee domestication and the economic and environmental aspects of its commercialization for pollination. Apidologie. 2006; 37(4):421-451.
11. Paydas S, Eti S, Kaftanoglu O, Yasa E, Derin K. Effect of pollination of strawberries grown in plastic greenhouse by bumblebees on the yield and quality of the fruits. Acta Horticulturae. 2000; 513:443-451.
12. Wolf S, Moritz RFA. Foraging distance in *Bombus terrestris* L. (Hymenoptera: Apidae). Apidologie. 2008; 39:419-427.
13. Sheik UAA, Ahmad M, Imran M, Nasir M, Saeed S, Bodlah I. Distribution of bumble bee, *Bombus haemorrhoidalis* Smith, and its association with Flora in Lower Northern Pakistan. Pakistan Journal Zoology. 2014; 46(4):1045-1051.
14. Corbet SA. Why bumble bees are special? In: Bumble bees for pleasure and profit (ed. A. Matheson, Cardiff). IBRA. 1996, 1-11.
15. Sowig P. Effects of flowering plant's patch size on species composition of pollinator communities, foraging strategies, and resource partitioning in bumblebees (Hymenoptera: Apidae). Oecologia. 1989; 78:550-558.
16. Sheik UAA, Ahmad M, Imran M, Nasir M, Saeed S, Bodlah I. Distribution of bumble bee, *Bombus haemorrhoidalis* Smith, and its association with Flora in Lower Northern Pakistan. Pakistan Journal Zoology. 2014; 46(4):1045-1051.
17. Priti, Sihag RC. Diversity, visitation frequency, foraging behaviour and pollinating efficiency of different insect pollinators visiting carrot, *Daucus carota* L. var. Hc-1 blossoms. Indian Bee Journal. 1998; 59(4):1-8.
18. Sihag RC. Insect pollination increases seed production in cruciferous and umbelliferous crops. Journal of Apiculture Research. 1986; 25(2):121-126.
19. Goyal NP, Singh M, Kandoria JL. Role of insect pollination in seed production of carrot. *Daucus carota* Linn., Indian Bee Journal. 1989; 51(3):89-93.
20. Mishra RC, Kumar J. Status of research in Pollination biology in Himachal Pradesh. Proc. Int. Symp. Polln. Trop., (eds.) G.K. Veeresh *et al*., Pub. IUSSI-Indian Chapter. 1993, 279-295.
21. Priti. Abundance and pollination efficiency of insect visitors of onion bloom. Indian Bee Journal. 1998; 60(2):75-78.
22. Kumar J, Misra RC, Gupta JK. The effect of mode of pollination on *Allium* species with observation on insects as pollinators, Journal of Apicultural Research. 1985; 24(1):62-66.
23. Greenleaf SS, Kremen C. Wild bees enhance honey bees' pollination of hybrid sunflower. Proc. Natl. Acad. Sci. USA. 2006; 103:13890-13895.
24. Wills JC. A dictionary of the Flowering Plants and Ferns. Eight editions. Cambridge University Press, Cambridge. 1973, 1245.
25. Pratap T. Sustainable land management in marginal mountain areas of the Himalayan region. Mountain Research and Development. 1999; 19:251-260.
26. Duran XA, Ulloa RB, Carrillo JA, Contreras JL, Bastidas MY. Evaluation of yield component traits of honeybee pollinated (*Apis mellifera* L.) rapeseed canola (*Brassica napus* L.). Journal of Agricultural Research. 2010; 70:309-314.
27. Sushil SN, Stanley J, Hedau NK, Bhatt JC. Enhancing Seed Production of Three Brassica Vegetables by Honey Bee Pollination in North-western Himalayas of India, Universal Journal of Agricultural Research. 2013; 1(3):49-53.
28. Walters S, Taylor BH. Effects of Honey bee Pollination on Pumpkin Fruit and Seed Yield. Hort Science. 2006; 41(2):370-373.
29. Chandel RS, Thakur RK, Bhardwaj NR, Pathania N. Onion Seed Crop Pollination: a missing dimension in mountain Horticulture, Acta Horticulturae. 2002; 631:79-86.
30. Thompson DJ. "Natural cross pollination in carrots", Proceedings of the American Society for Horticultural Science. 1962; 20:212-219.
31. Hawthorn RL, Bohart GE, Toole EH, Nye WP, Levin MD. "Carrot seed production as affected by insect pollination", Bulletin Utah Agricultural Experiment Station. 1960; 422:18.
32. Pankratova EP. "Data on the biology of blossoming and pollination of carrots", Dokl. TSKhA, 1964; 36:118-123.
33. Whitaker TW, Sherf AF, Lange WH. "Carrot production in United States", U.S. Department of Agriculture, Handbook. 1970; 375:37.
34. Singh M. "Role of insect pollination in seed production of carrot, *Daucus carota* Linn." Thesis Abstract of Punjab Agriculture University, Ludhiana, India, 1983; 9:327-328.
35. Mishra RC, Kumar T, Veeresh GK, Shaankar RU, Ganeshaiah KN. "Status of research in pollination biology in Himachal Pradesh", Proceeding International Symposium Pollination in Tropics, August 8-13, India. 1993, 279-295.
36. Abrol DP. "Impact of insect pollination on carrot seed production", Insect Environment, 1997; 3:61.
37. Sinha SH, Chakrabacti AK. "Insect pollination in carrot seed crop", Seed Research, 1992; 20:37-40.
38. Sharma PL, Sharma B. "Insect pollination in carrot crop", Indian Journal of Horticulture, 1968; 25:216.
39. Thamburaj S, Singh N. Textbook of vegetables, Tuber crops and spices. New Delhi: Indian Council of Agricultural Research, 2001.
40. Abak K, Ozdogan AO, Dasgan HY, Derin K, Kaftanoglu O. Effectiveness of bumblebees as pollinators for eggplants grown in unheated greenhouses. Acta Horticulturae. 2000; 514:197-204.
41. Spivak M. What can you do to improve craneberrypollina tion.http://www.library.wisc.edu/guides/agnic/cranbery/proceedings/2000/whaspi.pdf?
42. Sanz JMG, Serrano AR. Quality fruit improvement in sweet pepper culture by bumble bee pollination. Scientia Horticulturae. 2006; 110(2):160-166.
43. Vergara CH, Buendia-Fonseca P. Pollination of greenhouse tomatoes by the Mexican bumblebee *Bombus ephippiatus* (Hymenoptera: Apidae). Journal of Pollination Ecology. 2012; 7(4):27-30.
44. Ahmad M, Bodlah I, Sheikh K, Aziz MA. Pollination and foraging potential of European bumble bee, *Bombus terrestris* (Hymenoptera: Apidae) on tomato Crop under greenhouse system. Pakistan Journal Zoology. 2015; 47(5):1279-1285.
45. Yankit P, Rana K, Sharma HK, Thakur M, Thakur RK. Effect of Bumble Bee Pollination on Quality and Yield of Tomato (*Solanum lycopersicum* Mill.) Grown Under Protected Conditions. International Journal Current Microbiology Applied Sciences. 2018; 7(01):257-263.