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Bumblebees, Life Cycle and their role in Pollination - A Review

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ABSTRACT

Bumble bee belongs to order Hymenoptera, family Apidae and genus Bombus. Genus Bombus includes approximately 250 species found primarily in temperate and subtropical regions. Bumble bees live in society that consists of up to 400 individuals. Their colonies are annual, with only the queens who hibernate to live through the winter and starts laying eggs in the spring. These are divided in three groups; queen, workers and drones. Bumble bees are some of our most easily recognized insects and serve a vital role as pollinator of wild and cultivated plants. These are most successful pollinator due to their compatible body in the areas of inability of honeybees to work as effective pollinator under different types of floral and climatic conditions. Lack of adequate pollinators has been the major cause and concern of low productivity of various horticultural and agricultural crops. Therefore, it is necessary to evolve adaptable strategies which are simple, easy to operate and compatible with poor farmers. Hence, the important and valuable literature concerned to bumblebees, their life cycle and important role in pollination of crops is reviewed in this paper so that more and more entomologists, educated and progressive farmers can read and could start to rear, conserve and manage bumblebees artificially to a satisfactory level of population to cover pollination problem.

Keywords: bumblebee, colonies, queen, worker, drone, hibernates, compatible, pollinator, rear, conserve, manage.

INTRODUCTION

The word "bumble bee" is a compound of "bumble" + "bee" - "bumble" meaning to hum, buzz, sponger, move ineply or flounderingly. The generic name bombus, assigned by Pierse Andre Latreile in 1802, is derived from the Latin word for buzzing or humming sound. Bumble bee belong to Kingdom Animalia, phylum Arthropoda, class Insecta, order Hymenoptera, tribe Bombine, family Apidae and genus Bombus having more than 250 species in temperate, sub-temperate and sub-tropical regions. They are absent from Australia, low land India, and from most of Africa. Bumblebees usually live in temperate regions. They can survive in various habitats and on different altitudes. Majority of bumblebees inhabits forests, meadows and gardens. Generally, bumble bees live in the nests in the ground or made of piles of leaves, abandoned nests of birds or mammals.

Bumblebees live in society that consists of upto 400 individuals. They are divided in three groups; queen, workers and drones. Workers develop from the eggs during the summer. Worker bees can survive couple of months. Drones will die immediately after fertilization / mating. Queens live one year. Queen hibernates during the winter and starts laying eggs in the spring. She lays 8 to 12 eggs at a time. Young bumble bees emerge after 21 days. Bumble bees undergo complete metamorphosis through four developmental stages from the egg to adult. Eggs needs to pass larvae and pupal stages before it transforms in to adult insect. Only queen and worker bees have stingers. Besides lack of stingers, drone can be identified by size as they are the smallest type of bumble bees in the colony. Unlike the honeybees, bumblebees will not die after stinging. They can sting as much as they want. Luckily, they are not aggressive and they will sting only in self defence (Anonymous, 2015).

Bungle bees are some of our most easily recognized insects, and they serve a vital important role as pollinators of wild and cultivated plants. In the latter role, they are vital for local fruit and seed production in orchards, allotments and gardens. Entire body of bumble bee is covered with tiny hairs and alternately arranged yellow and black bands.

They have rounded body with 2 pairs of membranous wings and 3 pairs of legs. Legs are designed for gathering of pollen. They use sense of smell to detect flowers rich in nectar. Sense of smell is located on the antennas on the head. Bumble bees produce buzzing sound as a result of vibration of muscles used for flying. These muscles increase temperature of the body and facilitate gathering of pollen. They eat pollen and nectar collected from various flowers. They produce minimal amount of honey that is used as food from the young bumble bees (Keven, 1999).

Lack of adequate pollinators has been the major cause due to injudicious use of pesticides for pest control in all type of crops and concern of low productivity of various horticultural and agricultural crops. Using bumble bees and other insect pollinators for pollination in different climatic conditions is an effective alternative and can completely replace manual pollination and help in saving cost on production. In temperate conditions due to inclement weather conditions prevailing at peak flowering there is generally a low fruit set owing to inability of honeybees to work at low temperature. In such situations, bumble bees can play a pivotal role. Therefore, it is necessary to formulate and evolve suitable and adaptable strategies which are simple, easy to operate and compatible with poor farmers for meeting the pollination needs of their crops through conservation and management of pollinators such as bumble bees and other insect pollinators. Government agencies should take part in programmes related to bumble bee conservation and their utilization in pollination. Moreover, there is an urgent need to work in mission made for enterprising the bumble bee industry and its utilization in planned pollination of various crops. (Chauhan and Thakur, 2010).

MATERIALS AND METHODS

The literature related to Bumblebees, their life cycle and role in pollination from the year 1995-2015 was surfed out through sources and facilities i.e. CERA (Indian and Foreign Journals), CDROM Databases (Biological, Agricola and CAB Abstracts), Google scholar, Reference tools thesis, Books and periodicals available in the Nehru Library, Chaudhary Charan Singh Haryana Agricultural University, Hisar and the quite most relevant literature was collected, studied well and then reviewed for this article.

Life cycle

Most bumblebees are social insects. They create nests dominated by a single large fertile female (the queen) served by numerous smaller sterile females (workers). In this sense they are similar to the Honey Bee, though bumblebee colonies are smaller and less sophisticated, and never survive more than one summer (those of a Honey Bee can survive for several years). The annual life cycle kicks off with a fertilised overwintering queen emerging from hibernation, usually in March or April. Some queens may even emerge on mild winter days. Emergence time also depends on the species, with queens of the Large Garden Bumblebee and Brown-banded Carder-bee rarely emerging before May. Overwintered queens for age on spring-blossoming shrubs and other flowers, and initiate new nests. The location of those nests varies between species, with many favouring pre-existing rodent burrows and other small cavities, whilst the various carder-bees nest on the surface of the ground, often at the base of grasses and other rough herbage. The Tree Bumblebee is the only species that habitually nests well above the ground, often using bird nest boxes or roof cavities.

Left: Red-shanked Carder-bee nest, located at the base of grasses and constructed from moss; right: nest of Early Bumblebee opened up to show the untidy arrangement of wax cells.

By May, the workers of several species can be on the wing collecting pollen and nectar to build up food stores in the nests though they do not mix pollen and nectar to create honey like a Honey Bee and the wax cells are not arranged in a comb. The workers build new wax cells and feed the larvae and the queen. The queen does not normally leave the nest once it is established. Colony size varies between species and may involve several hundred workers or just a few dozen. Double-brooded species like the Early Bumblebee and Tree Bumblebee will produce males and new queens by May if not earlier.

Those new queens will then establish another nest in mid summer to bring about two nesting cycles (or 'broods') in a single year. But single-brooded bumblebees such as the Buff-tailed Bumblebee or garden bumblebees typically produce new queens in late summer, and once these have mated and built up their fat stores they find hibernation sites to overwinter in. Hibernation sites can include an assortment of sheltered holes or cavities, compost heaps, grass tussocks and so on. The males, workers and old queens do not survive the winter. Hence, bumble bees' colonies are annual, with only the queens living through the winter. Each individual of colony is divided into a number of groups, each with a specific task (Falk Steven, 2011).

At the top of the hierarchy stands the queen, who does not differ physically from the workers in some species, except from her size, which is much bigger than the size of the largest worker. The size of the queen bumblebee ranges between 20-23 mm in length with a 38-43 mm wingspan. Average size of worker bee ranges between 11 – 17 mm in length with 22 – 34 mm wing span. The male varies between 14 – 16 mm in length with 22 – 34 mm wing span. Unlike the queen and workers the male does not sting. These queens emerge from hibernation in the early spring and immediately start foraging for pollen and nectar and begin the search for a nest site. Nests are often located underground in abandoned rodent nests, or above the ground in tufts of grass, old birds' nests, or cavities in dead trees or under rock piles depending on species. After the queen finds a nest site, she constructs a few waxen pots and begins the process of provisioning these with pollen, on which she lays her eggs.

Once hatched, the larvae develop into adults in 4–5 weeks, during which time the queen is busy gathering pollen and incubating the developing larvae. The newly emerged adults become the colony's worker force to gather pollen and nectar. The queen now stays in the nest, where her sole responsibility is to lay eggs and rear offspring. At some point, depending on the species and habitat conditions, the colony switches from producing workers to rearing the reproductive members of the colony, the new queens and the males (which are called drones). As soon as males reach adulthood they leave the colony in search of a mate, and do not return. New queens remain with the nest until they have mated and the season is over. At that time, the new queens leave the nest in search of an overwintering site. Once she finds her site, she will dig down a few centimeters, usually in soft earth, form an oval cavity, and settle in until the following spring. The remainder of the colony, including the foundress, dies off at the end of the year. (Osborne, 2006; Koppert, 2008 ; Steven Falk, 2011; and Rich Hatfield, 2012).

In India, Bombus haemorrhoidalis Smith is the only species on which rearing trials are being made due to non-availability of other bumble bee culture after summer and mid monsoon. In nature, Bumble bee, Bombus haemorrhoidalis starts its life cycle with the onset of spring when the fecundated queens come out from hibernation and start nesting in sites generally in abandoned nests of rodents and small mammals. It was observed that after locating the nesting sites (Fig.1), queens start building nests with the secretion of wax from the four pairs of wax glands present on 4-7th sternal plates of the abdomen. Initially each queen foraged for collecting food (nectar and pollen) and then laid 1-4 white rice shaped eggs in the wax cups which had been moulded by her. Sometimes she secreted a multilayered wax crest in which eggs were laid. On hatching, the crests were converted into cells. For laboratory rearing, thirty nine overwintered fecundated queens were collected to study the biology and life cycle of bumble bees during March 2013 as per earlier studies (Kirandayal and Rana, 2004; Thakur et al., 2005; Chauhan, 2011and Chauhan & Thakur, 2011). Of these, thirty two queens formed wax mounds selected and eggs were laid in them.

The eggs hatched after 1-2 days into white larvae. The egg, larval and pupal stages were found covered with wax and can be seen only when the wax coverings are opened daily for feeding by queen/workers. It means that bumble bee exhibits progressive provision. The larvae were fed daily with a mixture of pollen and nectar. After 28±4 days of wax secretion, workers emerged. The colour of abdomen of newly emerged workers was covered with white and orange bands on dorsal side (Fig.2) which later on changes to yellow and orange bands (Fig. 2). Ventrally, they were black. After 3-7 days of emergence, the workers under took all the duties of the nest which was earlier done by the queen such as nest building, feeding of larvae, protection of nest and brood etc., except egg-laying. After this, the queen did not leave the nest. Young workers helped in building of egg cups, honey pots, pollen pots and feeding of larvae (Fig. 2). In this manner, 10-15 brood batches (Fig. 3a) were laid by the queen till the onset of winter totaling up to 150-200 workers. During the last week of May 15.62% colonies laid, had in them queen and drone brood (Fig 3b). Drones were located serendipitously while cleaning the colonies. Bees were kept in the plastic vials for cleaning of debris from the colonies. In some vials mating was observed. When these bees were examined it was found that some bees had round abdomen without sting apparatus having longer antennae, especially flagellum part was longer than other bees. Similar observations were recorded in other developing colonies. Thus drones do not bear sting and have round abdomen while queens have pointed ovipositor which develop into sting. Workers were also found bearing sting with reduced ovaries compared to queens. The life span of a drone from emergence was 44-49 days while workers lived for 40-56 days under laboratory conditions.

When the daughter queens and drones emerged during last week of May, they started mating after 6-8 days of emergence. Mating was usually noted during the day outside the nest both under laboratory (Fig.4a) and natural conditions (Fig.4b). When daughter queens and drones were kept for mating under laboratory conditions (in transparent plastic vials), their mating behavior studies reflected single to multiple mating. Multiple mating was observed in queens. The maximum number of drones was recorded as 3 drones mated with a single queen. The mating time varied from 15-43 min. Drones were always found ready to escape when colonies were opened for regular examination and feeding while workers and queens did not try to escape from the nest. Even if they ventured out, bees returned back into the nest and attended the brood. Six mated daughter-queens were kept in the wooden boxes in the incubator and fed with pollen and sucrose (50%). After 14-32 days, three of them initiated nest building. Sixteen to twenty one workers emerged in one colony while in the second colony only one worker emerged. No worker emerged in the third colony. It is for the first time in the country that rearing bumble bees till second generation was realised. The possible reason for the cessation of brooding in second generation colonies might be due to partial mating.

In nature, drones leave the nest forever after 2-7 days of emergence. Queens do not leave the mother nest and continue foraging even after mating. The mated queen’s forage for nectar and pollen, their size increased due to fat stores in the body which help them in successful overwintering. With the end of autumn, new queens searched for hibernaculums to ibernate/overwinter or remain in the nest for group overwintering. In winter, worker bees die with the old queen while the daughter queens hibernate in groups in the same nest or separately by searching new/fresh hibernaculums. These daughter queens come out of hibernation in the next spring and the life cycle continues year after year. (Chauhan et al., 2013)

Fig.1: Bumble bee nest

Fig. 2: Newly emerged workers and ‘honey and pollen’ pots

Fig. 3a: Brood batches

Fig. 3b: Developing colony showing drones, queen and workers

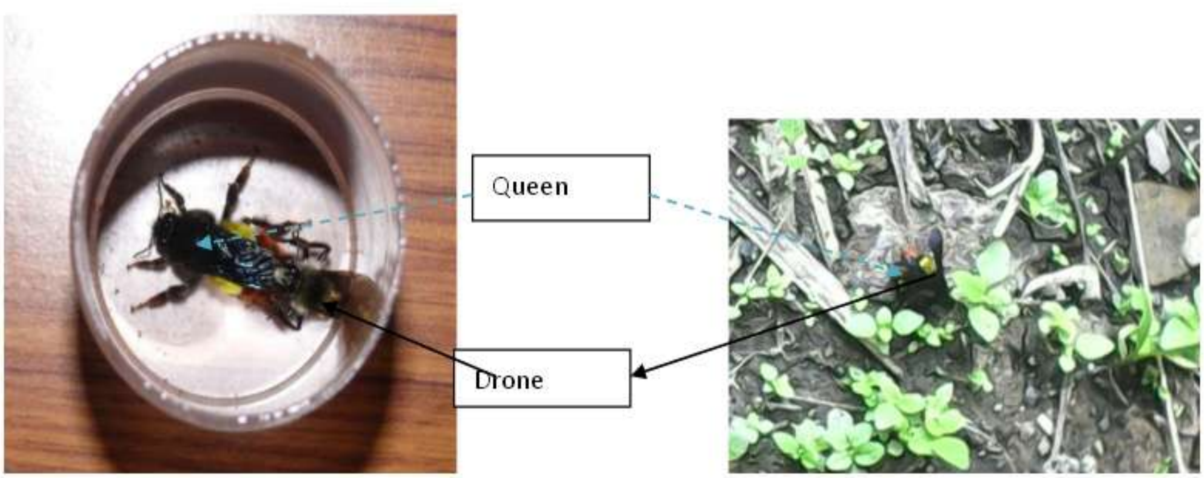

Fig .4 a Mating under laboratory condition

Fig. 4b Mating under natural conditions

The Cuckoo bumblebee lifecycle

Cuckoo bumblebees are a group of related species that are descended from 'true' or 'social' bumblebees. However, cuckoo bumblebees, like their namesake the cuckoo bird, use the nest of true bumblebees to raise their own offspring. They have large, queen like females and smaller males, but no worker and queen. The females are more heavily armoured than queen bumblebees and have simple hind legs that lack the pollen collecting apparatus found in social bumblebees.

The female (there is no queen) cuckoo bumblebee enters the nest of the true bumblebee, and often hides in the nest debris for a while. Eventually, the cuckoo female may kill the social bumblebee queen, and lay her own eggs in the nest. The worker bumblebees will then unwittingly raise the offspring of the cuckoo bumblebee, without realising that they are not related to them. The cuckoo bumblebees become adult bumblebees that leave the nest and mate with others of the same species, before the females go into hibernation (Anonymous, 2016).

Fig 5

Role in pollination

Bumble bees are some of our most easily recognized insects, and they serve a vital important role as pollinators of wild and cultivated plants. In the latter role, they are vital for local fruit and seed production in orchards, allotments and gardens. They help to pollinate apples, pears, plums, raspberries and important crops including Oil-seed Rape, Mustard, Pea and Broad Bean (Keven, 1999). Most other floral visitor drink nectar and therefore the movement of pollen from flower to flower is purely incidental. Bees collect pollen to feed their young, they move pollen from flower to flower without any intension of cross pollination. This behavior makes them very effective pollinator (Kremen et al., 2002). Their large body size allows bumble bees to be active when temperatures are cool (such as dawn or dusk). Combined with the ability to forage in low light levels, this characteristic makes them significant pollinators in northern latitudes and in high elevation ecosystems (Goulson et al. 2008).

In general, bumble bees forage on a diverse group of plants, though individual species preferences in plants vary due to differences in tongue length. Some species have long tongues and preferentially forage on plants such as penstemon and beebalm that have longer corolla tubes. Species with short tongues forage on flowers with an open structure, such as sunflower and prairie coneflower. In addition, short-tongued bumble bees will engage in "nectar robbing" from flowers with a long corolla tube by biting holes at the base of the corolla and drinking the nectar from the outside of the flower. This practice is called nectar robbing because the bee does not touch the anthers when accessing the nectar, thus taking the reward without contributing to the plant's pollination needs (Potts et al. 2009).

Bumble bees are important pollinators of high-value agricultural crops such as blueberries, cranberries, and clover. They are also the exclusive pollinator of greenhouse (restrict areas) crops such as tomatoes and peppers. They have the ability to buzz pollinate which can not be accomplished by honey bees. This makes the community of bumble bees second only to the honey bee as the top insect contributors to the global economy. Bumble bees are mostly attracted by blue and violet flowers. They cannot see red but can see UV light. They are still active at relatively low temperatures (around 10^{o}C) and

low light intensity levels. Even strong wind and drizzle will not keep them from doing their job. (Goulson, 2010; Rich Hatfield, 2012).
Goulson et al.1998 reported that Foraging bumblebees avoid flowers already visited by conspecifics or by other bumblebee species. Honey bees, Apis mellifera, use short-lived repellent scent marks to distinguish and reject flowers that have recently been visited by themselves or by siblings, and so save time that would otherwise be spent in probing empty flowers. Conversely, both honey bees and bumblebees, Bombus spp., can mark rewarding flowers with scent marks that promote probing by conspecifics. They examined detection of recently visited flowers in a mixed community of bumblebees foraging on comfrey, Symphytum officinale, in southern England. When foraging among inflorescences on a plant, three abundant species of Bombus probed fewer inflorescences more than once than would be expected from random foraging. Bees frequently encountered inflorescences but departed without probing them for nectar. Examination of the incidence of such rejections in the two most common species, B. terrestris and B. pascuorum, revealed that the low incidence of multiple probing visits was due to two factors: bees both foraged systematically and selectively rejected inflorescences that they had previously visited. When presented with inflorescences of known history, bees selectively rejected those that had been recently visited by themselves or by conspecifics compared with randomly selected inflorescences. They were also able to distinguish inflorescences that had been visited by other Bombus species. Bees were unable to distinguish and reject inflorescences from which the nectar had been removed artificially. It was conclude that these Bombus species are probably using scent marks left by previous visitors as shown in figure 6 and table I.

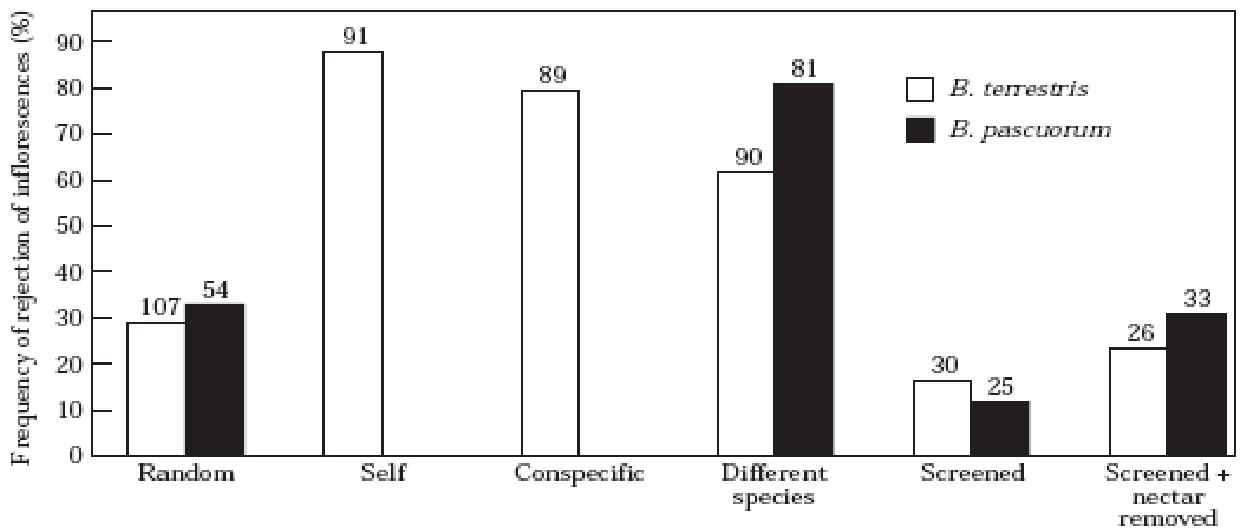

Figure 6. Frequency of rejection of inflorescences when presented to foraging bumblebees, according to the history of the inflorescence; random: chosen at random from the area in which the bees were foraging; self: previously visited by the same bee; conspecific: previously visited by a conspecific; different species: previously visited by a different species of Bombus; screened: inflorescence screened from insect visitors for 1 h; screened+nectar removed: as previous treatment but nectar removed from flower before presentation. Sample sizes above the bars refer to the number of trials. The frequency of rejection of inflorescences by B. pascuorum was not examined for the categories ‘self’ or ‘conspecific’.

Table I. Chi-square comparisons (with Yates’ correction) of the proportion of inflorescences rejected by foraging bees to assess whether bees are able to distinguish between inflorescences that have been recently visited versus inflorescences chosen at random (df=1)

	Test bee	
Inflorescence	**B. terrestris**	**B. pascuorum**
Visited by same bee versus random	37.6**	-
Visited by conspecific versus random	25.1**	-
Visited by other species versus random	9.1*	18.6**

***P<0.01; **P<0.001.**

Dogterom et al 1998reported about pollination of greenhouse tomatoes by the North American Bombus vosnesenskii (Hymenoptera: Apidae) and compared bumble bee pollination with no pollination, manual pollination, and manual plus bumble bee pollination and found that Bumble bee-pollinated fowers produced larger fruit than non-bumble bee-pollinated flowers. Fruit shape was not affected by bumble bee pollination. Results show that B. vosnesenskii is an effective pollinator of tomatoes in greenhouses as shown in Table 2.

Table 2. Comparison of mean 6 SE weight, seed count, fruit height, and roundness per plant for 4 treatments; no pollination, manual pollination, bumble bee pollination, and bumble bees plus manual pollination.

Yield and quality	No Pollination (n = 12)[a]	Manual (n = 11)	Bumble bees (n = 12)	Bumble bees plus manual (n = 12)
Weight, g	149.9 ± 6.8a	159.1 ± 7.0a	188.4 ± 4.5b	181.0 ± 6.0b
Seed (Count)	165.2 ± 8.4a	213.1 ± 11.9b	277.8 ± 10.1c	279.5 ± 9.2c
Height, mm	55.5 ± 0.7a	56.7 ± 0.7a	60.6 ± 0.4b	61.0 ± 1.0b
Max diam, mm	70.1 ± 1.2a	71.6 ± 1.2ab	76.0 ± 0.7c	74.3 ± 0.8cb
Roundness[b]	1.056 ± .005a	1.059 ± 0.05a	1.054 ± .004a	1.050 ±.004a

Means in the same row followed by different letters are significantly different at the $P < 0.05$ level as determined by 2-way ANOVA, followed by the Duncan multiple comparison test.
[a]Number in brackets indicates the number of plants per treatment.
[b]Fruit roundness is measured by the ratio of maximum diameter to minimum diameter.

Stanghellini et al. (1998) compared the effectiveness of bumble bees, Bombus impatiens Cresson, and honey bees, Apis mellifera L., on the pollination of cucumber, Cucumis sativus L., and watermelon, Citrullus lanatus (Thunb.) Matsum. & Nakai, under field conditions. Comparisons were based on fruit abortion rates and seed set as influenced by bee type (honey bee or bumble bee) and the number of bee visits to treatment flowers(1,6,12 and 18 bee visits), plus two controls: a no visit treatment and an open pollinated (unrestricted visitation) treatment. For both crops, an increased number of bee visits had a strong positive effect on fruit and seed set. All cucumber and watermelon flowers bagged to prevent insect visitation aborted, demonstrating the need for active transfer of pollen between staminate and pistillate flowers. Bumble bee visited flowers consistently had lower abortion rates and higher seed sets in the cucumber and watermelon studies than did honey bee- visited flowers when compared at the same bee visitation level. Only slight differences in fruit abortion rates were detected between bee types in the watermelon study. However, abortion rates for bumble bee-visited flowers were consistently less than those for honey bee-visited flowers when compared at equal bee visitation levels, with one exception at the 12 bee visit level. As the number of honey bee colonies continues to decline due to parasitic mite pests and based on the data obtained, we conclude that bumble bees have a great potential to serve as a supplemental pollinator for cucumbers, watermelons, and possibly other vine crops, when honey bees available for rental are in limited supply.

Table 3. Sample size, percent fruit abortion and mean seed set for eight bee-pollination treatments and two controls for cucumber cultivars and one watermelon cultivar.

Bee type	Visits (no.)	Cucumber						Watermelon		
		Calypso			Dasher II			Royal Jubilee		
		Sample size[z]	Fruit abortion[Y] (%)	Mean Seed set	Sample size[z]	Fruit abortion[Y] (%)	Mean Seed set	Sample size[z]	Fruit abortion[Y] (%)	Mean Seed set
No-visit control	…	0[x]	100*	0*	0[x]	100*	0*	0[x]	100.0*	0*
Honey bee	1	8	60*	175*	9	55*	126*	16	73.3*	171*
Bumble bee	1	10	50*	259*	10	50*	164*	27	55.0*	235*
Honey bee	6	11	45*	250*	12	40*	192*	28	53.3	217*
Bumble bee	6	16	320*	291*	14	30*	220	29	51.7	251*
Honey	12	15	25*	386	16	20*	197*	31	48.3	233*

bee										
Bumbl e bee	12	15	25*	416	16	20*	216	30	50.0	287
Honey bee	18	16	20*	254*	18	10	197	30	50.0	279
Bumbl e bee	18	17	15*	430	18	10	240	33	45.0	322
Open-pollinated control		19	5	430	18	10	243	34	43.3	305

Sample size was the number of fruit reaching maturity based on 20fruit possible for both cucumber cultivars(10 flowers per replication; 2 replications in 1995) and on 60 for watermelon (10 flowers per replication; 4 replications in 1995, 2 replications in 1996). Treatment means per fruit across replications for cucumber and across years and replications for watermelon. All flowers not receiving bee visitation aborted. Percent fruit abortion and mean seed set comparisions between treatments and the open pollinated control within the same column were significant at P<0.05.

Saeed and Known 2003 evaluated the effect of temperature on the foraging activity of Bombus terrestris L. (Hymenoptera: Apidae) on greenhouse hot pepper (Capsicum annuum L.).The bumble bee Bombus terrestris L. is an effective pollinator in the cultivation of greenhouse hot pepper Capsicum annuum L. Data indicates that colony traffic and foraging activity was highest at 25.7°C in greenhouse, whereas at 32.7°C, the foraging activity and colony traffic decreased 69.7 and 40.0%, respectively. By increasing the number of larvae and workers, the colony traffic and foraging activity also increased, respectively. Moderate temperature in the morning probably facilitates the overall activity of bees in a greenhouse. The data indicates that bumble bee pollination increased the fruit mass and number of seeds by 27.2 and 47.8%, respectively, compared to that of the control. These significant results substantiate the effectiveness of bumble bees in the pollination of pepper grown in greenhouses as shown in table 4 and figure 7.

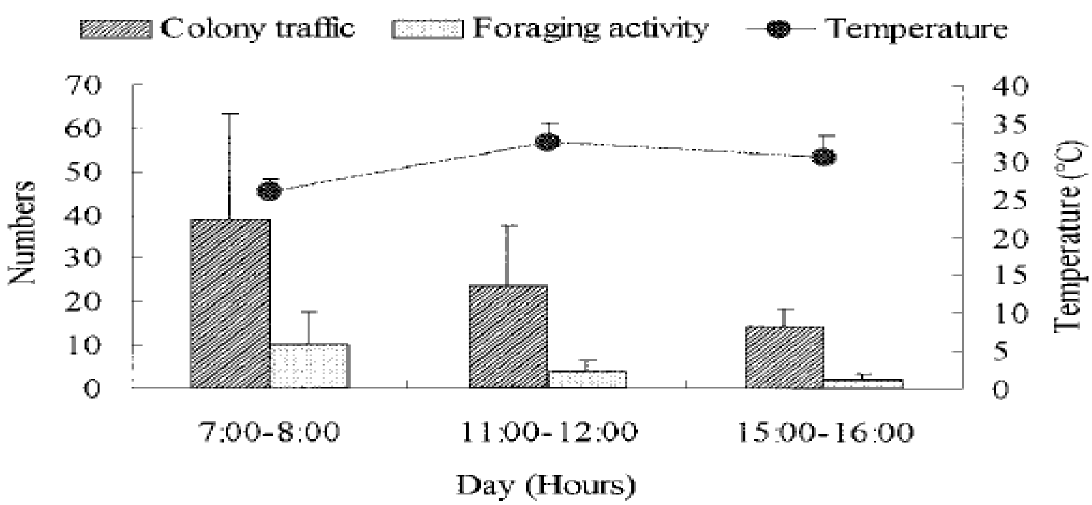

Fig. 7. Effect of average temperature on colony traffic per hour and foraging activity per unit time of day in hot pepper greenhouse (p,0.05).

Table 4. Comparison of pepper yield between pollinated with bee and without bee (control)

Treatments	Control	Bumble bee pollinated	Increase (%)	P value
Number of seeds per fruit	81.6	156.3	47.8	P<0.01
Length of fruit (cm)	15.6	16.2	3.8	P>0.05
Width of fruit (cm)	4.4	4.5	2.2	P>0.05
Mass per fruit (g)	8.0	11.0	27.2	P<0.01
Mass per 20 seeds (g)	0.11	0.09	-14.0	P>0.05

Shivanna et al. (2007) studied that Amomum subulatum Roxb. (family Zingiberaceae) is the large cardamom of commerce cultivated in tropical wet evergreen forests of the Eastern Himalayas of India, Nepal and Bhutan. This study seeks to identify floral visitors and pollinators, examine floral adaptations for pollination and evaluate pollination efficiency. Studies were carried out in two flowering seasons (2005, 2006) in a 6 ha plantation located adjacent to a degraded reserve forest in the Sikkim part of the Himalayas. Only two flower visitor species, a bumble-bee (Bombus haemorrhoidalis Smith) and a honey bee species (Apis cerana F.) were recorded. The bumble bee was the effective and only pollinator, but A. cerana was the pollen robber. Major flower adaptations for pollination by the bumble bee are the length of the nectar tube, which is not accessible to short tongued bees and a narrow passage in the fresh flower between the anther-stigma column and the labellum. The narrow passage forces the bumble bee to push the anther-stigma column to enter the flower, which brings the body of the bumble bee in contact with the anther and the stigma, and effects pollination. A. cerana does not come in contact with the stigma during pollen foraging and hence is unable to bring about pollination. Thus, structural features of the flower of A. subulatum differentiate the pollinator and the pollen robber. Pollination efficiency in the plantation was low due to the low population density of wild native pollinator, B. haemorrhoidalis as shown in figure 8.

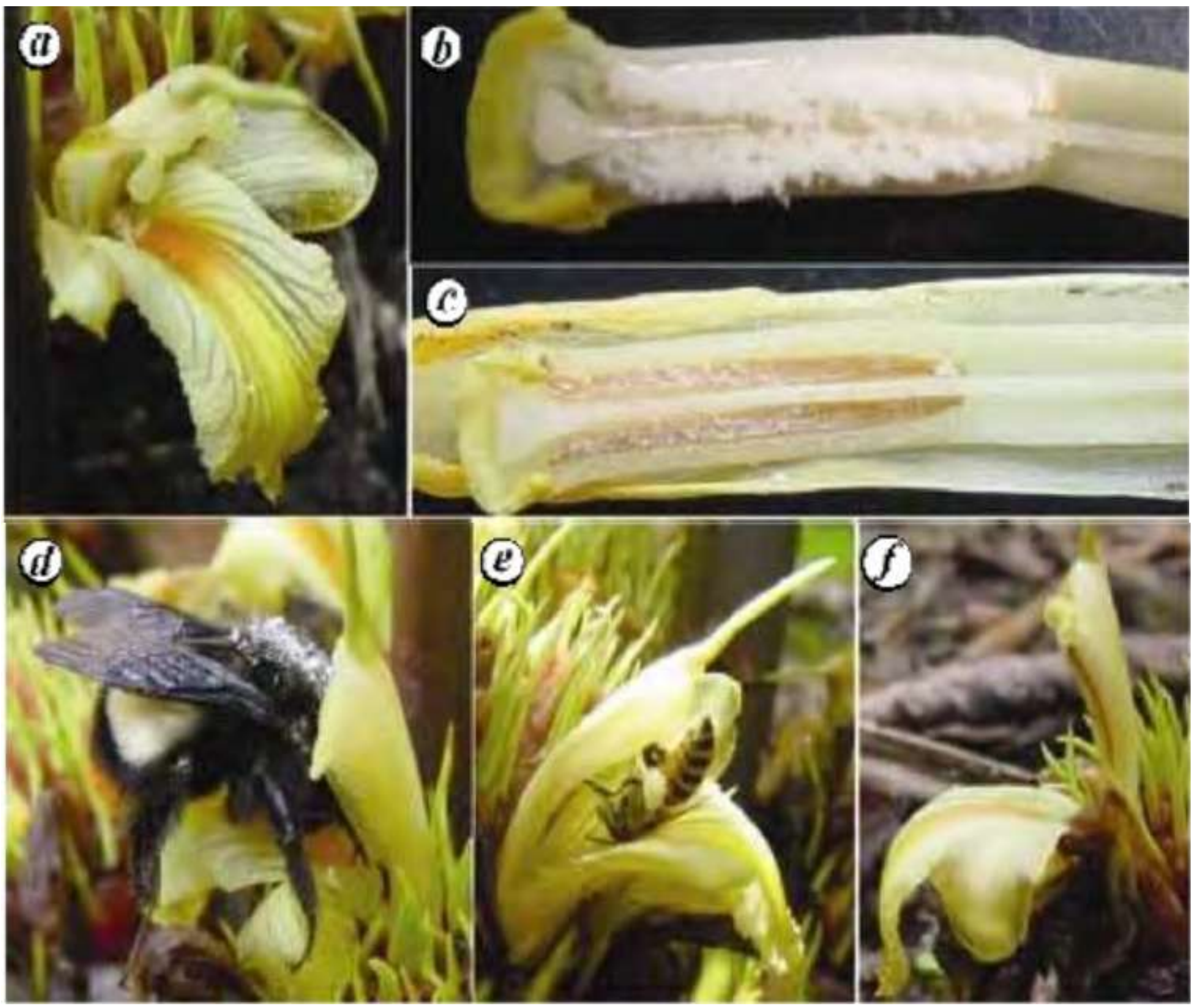

Figure 8. a. An individual flower of Amomum subukatum. b. Anther-stigma column photographed from the lower side before honey bee visit to show massive amount of pollen on the anther. The hood is also seen on the tip (left). c. Similar to (b). but photographed at 12.00 h after repeated visits by the honey bee. There is hardly any pollen left on the anther. A petal is seen below the anther-stigma column. d. The bumble bee. Bombus haemorrhoidalis engaged in foraging nector from the flower. Pollen load on its body is apparent. e. The honey bee. Apis cerana collecting pollen from the flower. One of the pollen baskets is clearly seen. The distance between the anther-stigma column and the labellum is narrow. f. A flower photographed at 14.00 h to show significant increase in the distance between the anther-stigma column and labellum.

Muljar et al.2010 conducted an experiment to study the effect of the field size on the abundance of bumble bees in Estonia. The data was collected from 66 farms located in different regions of the country. Bumble bees were counted along the field transect of each farm. The relationship between field size and number of bumble bees present was calculated. It was found that a negative correlation between the field size and the abundance of bumble bees: as the field area increased the number of bees decreased as shown in figure 9.

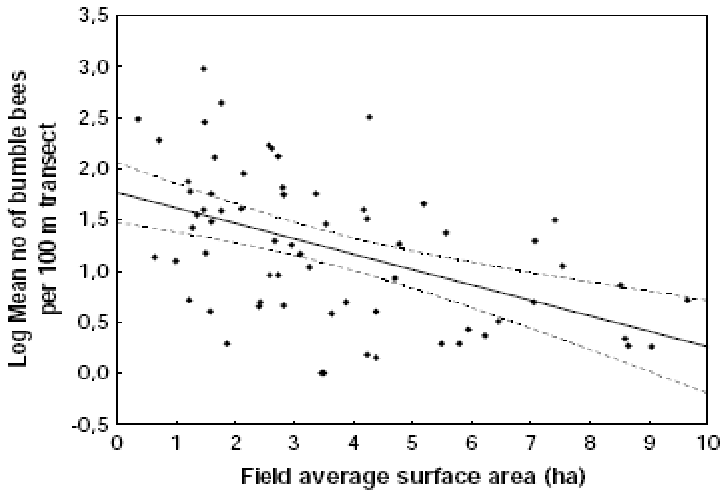

Figure 9. The number of bumble bees per 100 m transect depending on the field size monitored in Estonia in 2007.

Deka et al.2011 observed the New record of bumble bee, Bombus breviceps Smith as a pollinator of large cardamom. Large cardamom (Amomum subulatum Roxb.) belonging to the family Zingiberaceae is essentially a cross-pollinated crop due to the heterostylic nature of its flowers, though they are selffertile. Effective cross pollination occurs with the help of bumble bees due to their compatible body size within the cavity of the floral tube (corolla), bringing the upper part of the thorax in contact with the stigma and anther of the flower. The thorax carries the pollen from distant flowers. Here, they report the bumble bee Bombus breviceps Smith as an effective pollinator of large cardamom during the initial flowering period at different altitudes of cultivation (Figure 10, table 5 and table 6).

Figure 10. a, Full view of Bombus breviceps. The size and abdominal colouration are important taxonomic characters. **b**, B. breviceps entering the floral cavity and collecting honey. The thorax of the bee which carries pollen from distant flowers is seen touching the stigma. **c**, B. breviceps visiting flowers of ornamental plants grown in the vicinity of a large cardamom plantation.

Table 5. Bee species visiting large cardamom flowers as recorded at various altitudes of cultivation

Altitude (m amsl)	Flowering period	Pollinators recorded	Period of occurrence of pollinators
High (> 1515)	May-July	Bombus breviceps Bombus haemarrhoidalis Apis spp.	Initial flowering period Mid and late flowering period Throughout the flowering period
Mid (970-1515)	April-June	B. breviceps B. haemarrhoidalis Apis spp.	Initial flowering period Mid and late flowering period Throughout the flowering period

Low (<970)	March-May	B. breviceps B. haemarrhoidalis Apis spp.	Initial flowering period Mid and late flowering period Throughout the flowering period

Table 6. Comparative morphometry of Bombus breviceps and Bombus haemorrhoidalis

	B. breviceps		B. haemorrhoidalis	
Appendage	**Length (mm)**	**With (mm)**	**Length (mm)**	**Width (mm)**
Head	8.2 (7.2-9.4)	6.5 (6.2-6.7)	6.1 (5.0-7.2)	4.5 (4.2-5.1)
Thorax	8.6 (7.5-9.4)	9.7 (9.4-10.2)	5.6 (5.3-6.2)	6.1 (6.0-6.3)
Abdomen	17.1 (16.9-17.4)	10.4 (9.0-11.5)	9.3 (8.4-10.3)	5.6 (5.2-5.9)
Forewing	23.2 (22.2-24.0)	7.3 (7.1-7.6)	12.5 (12.0-13.2)	4.6 (4.5-4.9)
Hindwing	15.4 (14.9-16.2)	4.5 (4.2-5.1)	9.2 (8.5-9.7)	2.2 (2.1-2.4)
Foreleg	17.1 (15.9-18.2)	1.4 (1.2-1.6)	10.3 (9.2-11.5)	1.3 (1.2-1.4)
Midleg	21.0 (19.4-22.3)	1.8 (1.4-2.5)	10.4 (9.6-11.4)	1.9 (1.7-2.3)
Hindleg	31.2 (30.0-32.2)	2.6 (2.3-3.1)	13.4 (12.6-14.2)	2.0 (1.7-2.6)
Antenna	6.5 (5.9-7.1)	0.06 (0.05-0.07)	4.7 (4.5-5.1)	0.04 (0.03-0.04)
Proboscis	15.2 (14.3-16.2)	-	14.4 (13.6-15.1)	

Vergara et al. 2012 reported about the pollination of greenhouse tomatoes by the Mexican Bumble bee bombus ephippiatus (hymenoptera: apidae) The Mexican native bumblebee Bombus ephippiatus Say, was evaluated as a potential pollinator of greenhouse tomatoes (Solanum lycopersicon L.). The experiments were performed at San Andrés Cholula, Puebla, Mexico, from June to December, 2004 in two 1000 m2 greenhouses planted with tomatoes of the cultivar Mallory (Hazera ®). For the experiments, they used two colonies of Bombus ephippiatus , reared in the laboratory from queens captured in the field. Four treatments were applied to 20 study plants: pollination by bumble bees, manual pollination, pollination by mechanical vibration and no pollination (bagged flowers, no vibration). They measured percentage of flowers visited by bumble bees, number of seeds per fruit, maturing time, sugar content, fruit weight and fruit shape. All available flowers were visited by bumblebees, as measured by the degree of anther cone bruising. The number of seeds per fruit was higher for bumble bee pollinated plants as compared with plants pollinated mechanically or not pollinated and was not significantly different between hand-pollinated and bumble bee pollinated plants. Maturation time was significantly longer and sugar content, fresh weight and seed count were significantly higher for bumblebee pollinated flowers than for flowers pollinated manually or with no supplemental pollination, but did not differ with flowers pollinated mechanically as indicated in table 7.

Table 7. Comparison of five measures of tomato quality recorded from four pollination treatment groups.

Treatment (n = 20)	**Ripening Time (Days)**	**Fresh weight (g)**	**% sugars**	**Number of seeds/fruit**	**Roundness**
Pollination by bumble	55.45 ± 18.7a	62.60 ± 23.7a	4.97 ± 1.8a	201.00 ± 80.5a	0.81 ± 0.06a
Mechanical Pollination	49.76 ± 18.6a	60.84 ± 22.9a	4.93 ± 1.9a	159.32 ± 31.1b	0.81 ± 0.03a
Manual Pollination	49.71 ± 19.6a	59.36 ± 22.2b	5.79 ± 3.1b	153.28 ± 25.3b	0.80 ± 0.05a
No supplemental Pollination	46.50 ± 17.3b	57.72 ± 21.5b	4.70 ± 1.7c	139.03 ± 60.1b	0.88 ± 0.07a

Average ± S.E. of the response variables. Means followed by the same letter in any given column are not significantly different from one another (Tukey's HSD. $P<0.05$)

Drummond (2012) used the commercial bumble bee, Bombus impatiens Cresson, in Maine for pollination of lowbush blueberry since the late 1990s. Studies conducted in 1995–1998 and published in 2001 showed that B. impatiens was a good pollinator of lowbush blueberry. Stocking density was estimated at 3/4–1 quad (set of four, 250-bee colonies) per acre. Subsequent research reported here has shown that on an individual bee basis, B. impatiens is 2.5 times more efficient per floral visit in placing pollen on the stigma. Foraging behavior suggests that bumble bees may be more consistent at producing outcrossing among clones than honey bees, although individual honey bees are more likely to be floral constant than bumble bees. By 2004, some blueberry growers questioned the efficacy of commercial bumble bees. To address these concerns, a three-year validation experiment was conducted from 2005–2007. Seven to nine isolated individual small blueberry fields (2–25 acres) were selected each year to compare bumble bees with honey bees or no commercial pollinators (n = 3 to 5 fields per treatment) It was verified that 2.5 quads/ha was a suitable stocking density and did not differ in pollination level from 7.5–10 honey bee hives per ha. A central place foraging behavior could not be demonstrated with bumble bees in these smaller fields. It was established that as the foraging force of bumble bees increased, which varied between hives and fields, better fruit set resulted as shown in table 8 and figure 10

TABLE 8: Measures of Pollination over Three Years in Lowbush Blueberry Fields Supplemented with Honey Bees, Bumble Bees, or Not Supplemented with Commercial Bees (Measures within Parentheses are Standard Errors of the Mean)

Main effects[1]	Fruit set[2]	Mature berries[3]	Berry weight4	Viable seeds
Year				
2005	0.291 b (0.059)	0.246 b (0.055)	0.345 a (0.020)	29.34 b (3.42)
2006	0.539 a (0.058)	0.445 a (0.054)	0.259 b (0.019)	21.67 a (2.97)
2007	0.496 ab (0.059)	0.421 a (0.055)	0.329 ab (0.020)	27.34 ab (3.20)
Bee tmt				
Honey bee	0.584 a (0.044)	0.450 a (0.042)	0.326 ab (0.015)	26.77 a (3.34)
Bumble bee	0.514 a (0.041)	0.461 a (0.039)	0.346 a (0.014)	28.32 a (3.27)
Wild bees only	0.282 b (0.061)	0.249 b (0.056)	0.264 b (0.027)	27.65 a (3.16)

1. Main effects of univariate analyses of variance with year, bee treatment main effects, and a year × bee treatment interaction. Letters associated with mean levels within a pollination measure for the year effect or bee treatment effect reflect Tukey post-hoc multiple comparisons (α = 0.05).
2. Initial proportion fruit set, calculated as ratio of set to initial flowers per stem.
3. Mature berries are the proportion of berries at harvest to initial flowers per stem.
4. Berry weight is represented in grams per berry.
5. Viable seeds are the number of darkly pigmented, developed plump seeds within mature fruit.

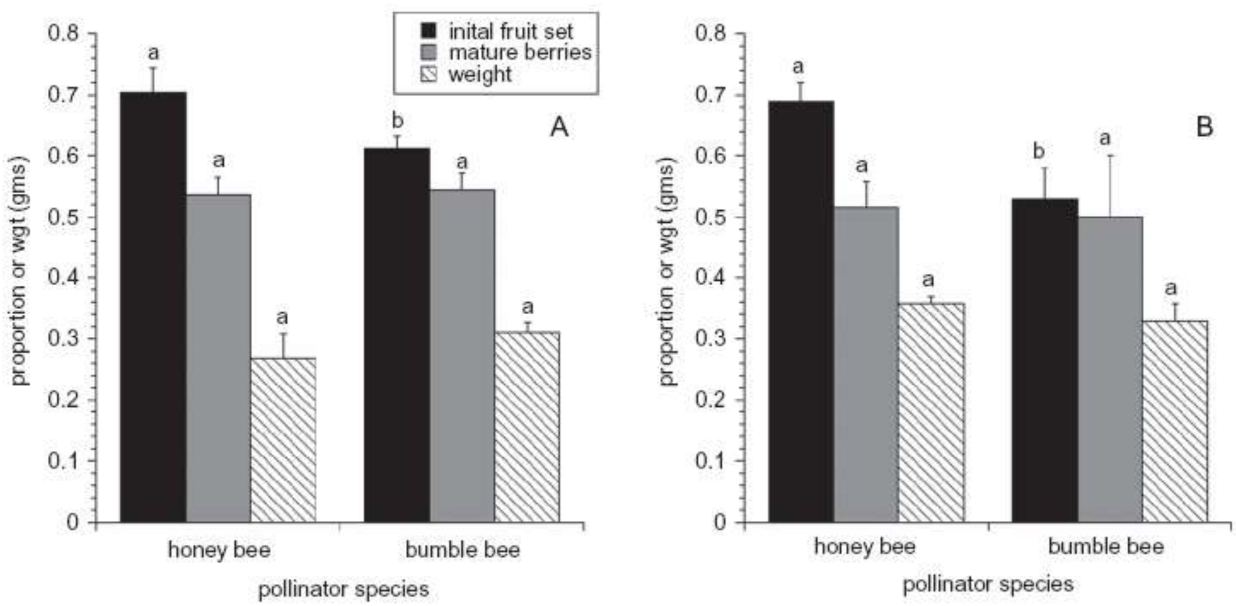

Fig. 10. Three measures of pollination for 2006 (A) and 2007 (B). The same letters for a given pollination measure within a year denote means that are not significantly different (α = 0.05).

Rao and Strange (2012) examined the foraging behavior of bumble bee workers in natural habitats, whereas agricultural landscapes, which can provide insights on flight distances to fragmented patches of bloom, have received limited attention. In particular, information on worker flight distances to crops blooming several months after nests have been established is invaluable. Here, they examined foraging patterns of Bombus vosnesenskii Radoszkowski in late-season blooming clover in the agricultural dominated Willamette Valley in Oregon. Workers from 10 fields collected over 2 yr were assigned to full sibling families (colonies) by using eight microsatellite loci. With estimation of numbers of unseen species, we inferred the presence of 189 colonies from 433 bees genotyped in year 1, and 144 from 296 genotyped the next year. Worker foraging distance was estimated to be at least 11.6 km, half the distance between the most remote fields visited by the same colonies. Numbers of nests contributing workers to each field ranged from 15 to 163. Overall, 165 (50%) colonies foraged in two or more fields, and thus used common resources within the landscape. Estimates of average nest densities in the landscape each year ranged from 0.76/km2 to 22.16/km2, and highlighted the influences of various study parameters incorporated into the calculation including sample size, distances between sites, and analytical tools used to estimate unsampled individuals. Based on the results, bumble bees can fly long distances, and this could facilitate their survival in fragmented agricultural landscapes. This has important implications for the scale of habitat management in bumble bee conservation programs.

Strange et al. 2015 compared two western, Bombus huntii Greene and Bombus vosnesenskii Radoszkowski, and one eastern species, Bombus impatiens Cresson, for their efficacy as pollinators of greenhouse-grown tomatoes. In two experiments, colonies were placed in greenhouses and compared with control plants that received no supplemental pollination. In the first experiment, seed set was significantly increased with B. huntii pollination in one variety of cherry tomatoes. In the second experiment comparing all three bumble bee species, fruit weight was an average of 25.2 g heavier per fruit pollinated by bees versus the control, and the number of days to harvest was 2.9 d shorter for bee pollinated fruit. In some rounds of pollination, differences were found among bumble bee species, but these were inconsistent across replicates and not statistically significant overall. Additionally, fruit weight was shown to be highly correlated to fruit diameter and seed set in all tests and, thus, is shown to be a reliable metric for assessing pollination in future studies. These results suggest that commercialization of western bumble bees is a viable alternative to the current practices of moving of nonnative bees into western North America to pollinate tomatoes.

Table 9: Average fruit weight, fruit diameter, and number of seeds produced in tomatoes pollinated by B. huntii versus an unpollinated control in a greenhouse pollination experiment

Round	Variety	Treatment	Fruits	Average weight (g)	Pole-pole diameter (mm)	Equatorial diameter (mm)	Number of seeds
1	Favorita	huntii	76	14.92 ± 4.45	28.47 ± 4.96	N/A	66.12 ± 38.85*
	Favorita	control	82	14.02 ± 4.57	29.56 ± 8.88	N/A	45.63 ± 49.76*
	Sungold	huntii	43	16.39 ± 8.63	25.00 ± 10.93	N/A	53.02 ± 41.47
	Sungold	control	49	13.75 ± 6.05	25.03 ± 8.47	N/A	65.00 ± 47.04
2	Favorita	huntii	100	15.03 ± 5.63	29.4 ± 3.33	28.81±3.41d	54.8 ± 37.09*
	Favorita	control	119	11.92 ± 4.69	26.29 ± 4.57	26.31± 4.35d	23.97±35.22*
	Sungold	huntii	70	15.82 ± 6.89	27.38 ± 5.36	29.23 ± 5.70	65.66 ± 37.76
	Sungold	control	36	19.31 ± 11.84	29.16 ± 6.40	31.32 ± 6.61	51.36 ± 40.19

Values that are followed by a symbol are significantly different than values that share the same symbol at the P<0.05 level.

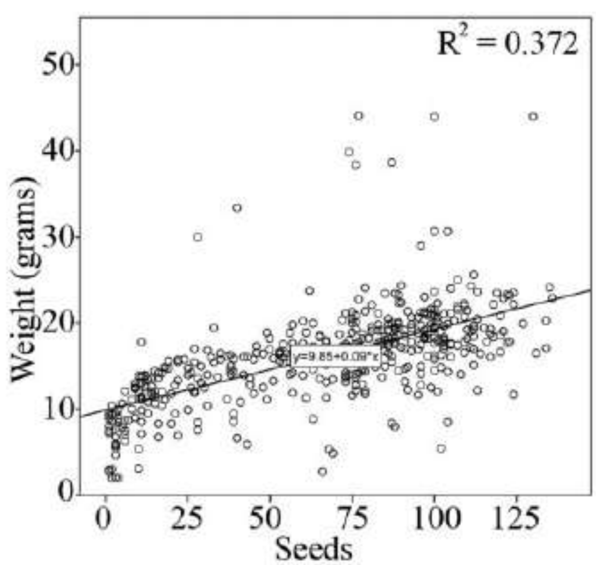

Fig. 11. Correlation of the number of seeds in cherry tomato fruit to fruit weight. The correlation was significant at the P<0.05 level.

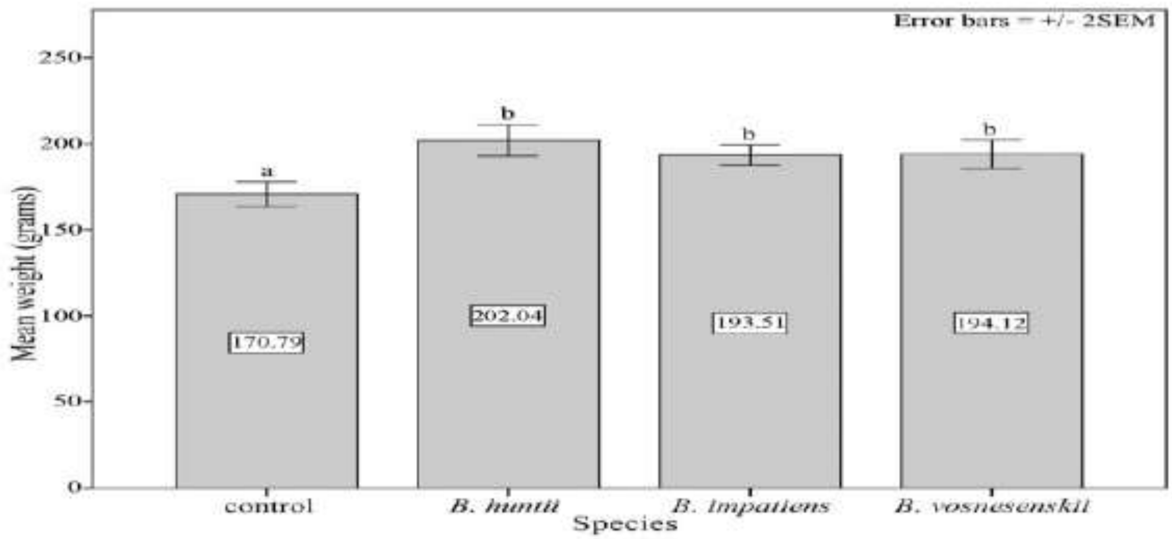

Fig. 12: Mean weight in grams of tomatoes receiving pollination by three species of bumble bee and ambient air movement (control) in greenhouse trials. Values are averaged across all four rounds of the experiment. Significance is at the P<0.05 level, and bars with the same letter are not significantly different from each other

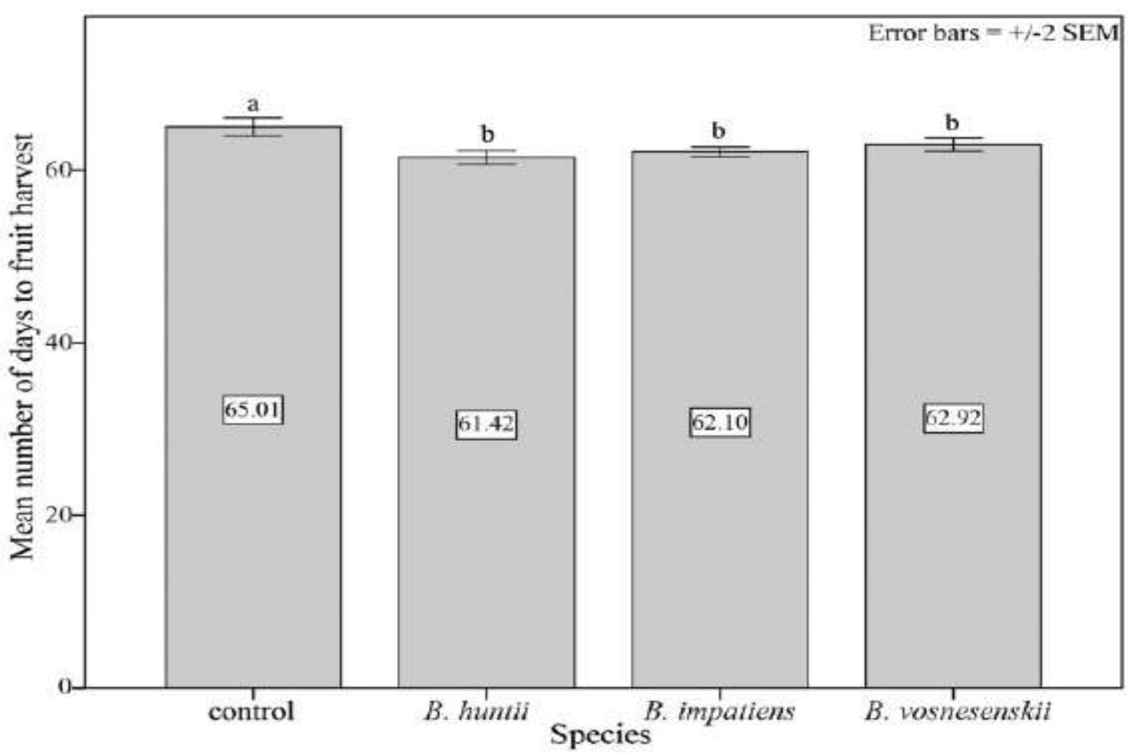

Fig.13: Mean number of days to the harvest of ripe fruit from the introduction of bumble bees to the flowers. Three bumble bee species were compared with a control that received only ambient air movement. Significance is at the P<0.05 level, and bars with the same letter are not significantly different.

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