Journal of Pharmacognosy and Phytochemistry

Available online at www.phytojournal.com

E-ISSN: 2278-4136
P-ISSN: 2349-8234
www.phytojournal.com
JPP 2020; 9(3): 1328-1334
Received: 14-03-2020
Accepted: 18-04-2020

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A review on role of bumblebee pollination in fruits and vegetables

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DOI: https://doi.org/10.22271/phyto.2020.v9.i3v.11494

Abstract
Bumblebees are efficient pollinator of various fruit and vegetable crops as compare to honeybees under protected condition as well as open conditions. The cross pollination carried out by bumblebees known as myophilly. Bumblebees have tend to forage faster than honeybees, pollinate more flowers per bee, long tongue prefers flower with long corolla tube. At low temperature and low light intensities, the foraging activities of bumblebees are more efficient and cost-effective alternate to hand/manual pollination even. They are perfect pollinator of flowers of family Solanaceae because sonication is required for pollination. Now a days, the population of bumblebees is decreasing at global level due to indiscriminate use of pesticides, loss of natural habitats, mechanization in agriculture and climate changes. The conservation techniques like modification of landscape such as promoting wild flowers and creation of niches for their hibernation, survival and reproduction etc. which provide favorable conditions to increase the bumblebees abundance, foraging behavior and their efficiency. The scientists should attempts for evaluating the pollination efficiency of bumblebees to boost the production of vegetable and fruit crops.

Keywords: Bumblebees, vegetables, efficient pollinator, myophily and foraging behavior

1. Introduction

Pollination is one of the major factors responsible for good quality and high productivity of any crop. Proper pollination is necessary for the ideal fruit set and production. Pollination occurs when the flowers are receptive and transferring of pollen grains from male anther to female stigma with the help of abiotic and biotic pollen dispersal agents. The important abiotic agents are wind, water and gravity, whereas the biotic agents are insects, birds, bats and small mammals (Free, 1993) [19]. The most reliable and efficient form of pollination is through insects known as entomophilous. The entomophilous crop pollination is the important ecosystem service which is helpful to human health and global food security (Aizen *et al.*, 2009) [3]. Many insects such as honeybees, bumblebees and solitary bees are the important pollinators which are in commercial use for successful crop production (McGregor, 1976) [38]. Among them, bumblebees are the superstars of pollination also known as teddy bear of insects. Bumblebees are incredibly efficient pollinators of many commercially grown plants like red clover, cucumber, water melon, cotton, tomato, pepper, kiwifruit and strawberry effectively. Bumblebees work well in confinement and are a key component in the glasshouse production of fruit. As their large size and hairy body allows for the extremely effective collection and deposition of large quantities of pollen. The bumblebees are mostly forage the flowers as top workers and collect more pollen on their hairy body. The more pollen transferred, the better and effective pollination increases the fruit quality (number of seeds developed, improving fruit size, weight and shape), as well as the quantity (percentage of fruit set, overall number of fruit), and can be the difference between a bountiful or meagre crop. Honeybees pollinate various plants like; tomato, pepper, eggplant, melon, water melon, cucumber, straw berry, crane berry etc., but are less efficient than bumblebees (Free and Butler, 1959) [18]. Hobbs *et al.* (1961) [26] and Holm (1966) [27] found that the bumblebees are the perfect pollinator species to pollinate flowers with deep corolla. Bumblebees 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 (Wolf and Moritz, 2008) [62]. Use of bumblebees as a pollinator in pollinating crops was found cheaper (9100 pounds) than mechanical pollination (10,000 pounds) in Netherland and Belgium (Roulston and Julier, 2009) [45]. The flowers of family Solanaceae and Ericaceous plants make it difficult for bees to access their pollen. The flowers of tomatoes, potatoes, peppers, eggplants, cranberry and blueberry release pollen grains most efficiently through sonication. The bumblebees, carpenter bees and sweat bees are able to do buzz pollination by contracting their flight muscles rapidly, causing the anthers to vibrate and dislodging pollen. Honeybees are inefficient pollinators for crops whose flowers require buzz pollination because they contract their flight muscles slowly as compared to bumblebees (Averill *et al*., 2018) [6]. Bumblebees are well survive in cooler weather conditions and can forage efficiently also at ambient temperatures below 15°C (Goulson, 2010) [24]. In India, apple orchards are present in such cool weather conditions. Whereas *Apis melifera* unable to forage efficiently at this ambient temperature (Zisovich *et al*., 2012; Vicens and Bosch, 2000) [65, 58]. Almost all bumblebees also foraged over longer distance and moving between canes and rows more frequently than honeybees (Willmer *et al*., 1994) [64]. Bumblebees show high mobility within orchards, and are effective cross-pollinators, in many cases much more so than honeybees. Bumblebees are more robust than honeybees, and will pollinate in adverse weather conditions. Research has shown that when bumblebees are used in combination with honeybees, there are increases in both the quantity of seeds per fruit, and the overall yield. Farmers are becoming more interested in having alternative pollinators to ensure proper pollination for their crops.

2. Role of bumblebees in fruit crop production

2.1 **Blueberry:** The major growing areas of high-bush blueberries (*Vaccinium* spp.) are Canadian provinces and several U.S. states. The buzz-pollination is highly necessary for flowers of blueberries so bumblebees are primary pollinator for berry production. Honeybees are less effective because lack of buzz-pollination character (Buchmann, 1983 and Free, 1993) [7, 19]. Several research groups have investigated the dependence of blueberry production on wild bees. Cane and Payne (1988) [9] used the four species of wild bumblebees (*Bombus* spp.) and the anthophorine *Habropoda laboriosa* that buzz-pollinate high-bush blueberry fields in Alabama and Georgia. Honeybees from colonies at field borders were found to carry little or no blueberry pollen. Five colonies of bumblebees, *B. Impatiens*, per hectare of low bush blueberry produced yields equal to using 7.5 honey bee colonies per hectare, despite the significantly greater size of honey bee colonies (Stubbs and Drummond, 2001) [51].

2.2 **Cranberry:** The bees are rarely appears in large amounts on the cranberry plantations because flowers of cranberry are poor source of nectar and pollen grains (Marucci, 1967) [36]. Some specific varieties are greatly responsible toward the bumblebee pollination. The bumblebees are more efficient foragers than honeybees on cranberry flowers because they are capable of buzz-pollination. Bumblebees hang on to the flower and buzz it by vibrating their muscles that control flight. The pollen in the flower is actively shaken loose and released onto the bee and the bee then grooms the pollen grains onto her hind legs. After visiting many flowers to collect pollen, she will have accumulated a large ball of pollen on each hind leg, and will have cross-pollinated the flowers along the way. Honeybees are not able to buzz pollinate. They gather pollen passively by rubbing up against the anthers as they visit the flowers. They also collect large balls of pollen on each hind leg as they cross-pollinate, but they are not nearly as efficient in collecting the pollen from each flower as are bumblebees (Spivak, 2000) [49]. The berry quality (size) of Bergman' variety of blueberry was increased by bumblebee pollination as compared to honeybee pollination (Tikuma and Liepniece, 2013) [55].

2.3 **Kiwifruit:** Kiwifruit is dioecious plant means they have male and female flowers on different plants and flowers are present at the basal end of the shoot (Ferguson, 1990) [17]. Wearing (1983) [60] conducted an experiment on kiwifruit pollination with increasing bumblebees density. He observed that fruit size increased with increasing number of bumblebees, there was no clear relationship with seed number, which is the true end product of pollination. He also observed that 900 viable pollen grains were found on the stigma after a bumblebees visit. The flowers of kiwifruit, *A. deliciosa*, are buzz pollinated. Its pollen grains are activated by vibration in a manner that depended on the degree of hydration of the pollen grains in an anther (Corbet *et al*., 1988; King and Lengoc, 1993 and King and Ferguson, 1994) [12, 31, 30]. Bumblebees collected seven times more viable pollen and the production was higher when population of the bumblebees increased on the flowers (Ferguson and Pusch, 1991) [16]. Pomeroy and Fisher (2002) [44] reported that bumblebee pollination can increase the fruit quality in kiwi by visiting in large numbers and transfer more amount of pollen to the female flowers and hence the quality of fruits is improved. Due to lower production cost, increased yields and improved fruit quality in many vegetable, fruits and seed crops by bumblebee pollination, the growers benefit (Velthius and Doorn, 2006) [56]. The honeybees are more abundant and visited more kiwi flowers per time but bumblebees are more efficient on a per-visit basis (Minarro and Twizell, 2014) [39]. The bumblebee workers contact 45 per cent of the stigmas and bumblebee queen contact 68 per cent of the stigmas while honeybees contact 25 per cent of the stigmas during one flower visit (Anonymous, 2020) [5]. The buzz pollination helps in higher fruit set (79.43%), longer fruits (59.56 mm/fruits), higher fruit breadth (40.58 mm/fruit), heavier fruits (68.14 g/fruit), higher total fruit yield (8.14 kg/vine), higher healthy fruits (94.60%), higher seed number (560.13 seeds/fruit) and test weight (1.67 g/1000 seed) in kiwifruit and accounted an increase of 46.05, 41.53, 37.00, 180, 191.75, 107.33, 25.34 and 57.54 per cent, respectively over control. The chemical parameters *viz*. TSS, TSS/acidity ratio, total sugars, reducing sugars and non-reducing sugars of kiwifruits have significantly effected buzz pollination (Nayak *et al*., 2018) [40] so it is better mode of pollination next to hand-pollination.

2.4 **Strawberry:** The bumblebees are very beneficial for pollinating certain varieties of strawberries in greenhouses. The yield per plant was over 30 per cent higher in the bumblebee pollinated plants than in the control plants (Paydas *et al*., 2000) [42]. Bumblebees ranked second place after honeybee in strawberries pollination. They increase 60 per cent fruit formation over the control. The bumblebee pollinated strawberry produced no malformed berries and bigger sized fruits as compare to other pollination techniques (Zaitoun *et al*., 2006) [64]. The row of strawberries pollinated by buzz pollination produced more well-shaped fruit and the total marketable fruit production was double compared to the control row (Dimou *et al*., 2008) [13].

2.5 **Almond:** Marques *et al.* (2019) [35] reported that fruit set was significantly higher in the almond fields where *B. terrestris* had been introduced than in the control plots.

This increased production resulted in a positive economic balance for the farmer. Moreover, bumblebees showed to prefer trees in a southwest orientation that were close to their colony. In order to improve its management and obtain the highest possible almond production, it is important to understand the activity and behaviour of this pollinator.

2.6 Apple: Most of the apple cultivars are self-incompatible (Goldway *et al.*, 2007) [22]. The most important insect pollinator of apple is *Apis mellifera*. But the major problem with apple pollination is that honeybees activity on apple flowers is not always efficient. They collect both nectar and pollen from the flower, but not necessarily at the same time (Mayer, 1984) [37]. The bumblebees collect more pollen instead of nectar. The large body size and ability to forage in severe cool temperature conditions makes alternative pollinator of apple pollination. The *Apis mellifera* and *Bombus* spp. removed similar amounts of pollen from apple flowers during single visits to four cultivars of apples but *Bombus* deposited more pollen on stigmas (Thomson and Goodell, 2001) [54]. The fruit set has significantly increased with an increasing number of flower visitations of different pollinators to different apple varieties. The *Episyrphus balteatus* resulted in significantly lower fruit set than *Bombus terrestris* and *Osmia bicornis*. The seed set increased with increasing visit numbers and *E. balteatus* resulted in significantly fewer seeds per apple compared with *B. terrestris* (Garratt *et al.*, 2016) [21]. The bumblebees are effective in apple cultivar like ‘Gala’ because this cultivar suffers from insufficient number of seeds per fruit. The addition of bumblebees increased the numbers of pollinators and foraging activity of honeybees in the early morning hours and cool weather conditions. The number of seeds and fruit size also increased with the addition of bumblebees (Sapir *et al.*, 2017) [46].

2.7 Raspberry: Raspberry is a absolutely delicious plant and blooms are self-pollinating. About 90-95 per cent of pollination depends on bees. Among bees, bumblebees are substantially more important as pollinators of raspberries than honeybees, especially as raspberries though moderately self-fertile may exhibit metaxenia. Willmer *et al.* (1994) [64] experimented that the behaviour and activity patterns of *A. mellifera* and five species of *Bombus* were examined in relation to climatic variables and nectar quality on three varieties of unsprayed cultivated raspberry (*Rubus idaeus*) in eastern Scotland. They found that bodies of *Bombus* carried more pollen than *A. mellifera* also deposited more pollen on raspberry stigmas, with *B. lapidarius* and *B. terrestris* being particularly effective and also being the most abundant species.

Table 1: List of fruits pollinated by bumblebees

S. No.	Common name	Scientific name	Commercial product of pollination
1.	Almond	*Prunus dulcis, Prunus amygdalus*	Nut
2.	Apple	*Malus domestica*	Fruit
3.	Apricot	*Prunus armeniaca*	Fruit
4.	Avocado	*Persea americana*	Fruit
5.	Watermelon	*Citrullus lanatus*	Fruit
6.	Blackberry	*Rubus spp.*	Fruit
7.	Blueberry	*Vaccinium angustifolium*	Fruit
8.	Cashew	*Anacardium occidentale*	Nut
9.	Cranberry	*Vaccinium subg. oxycoccus*	Fruit
10.	Cucumber	*Cucumis sativus*	Fruit
11.	Guava	*Psidium guajava*	Fruit
12.	Kiwifruit	*Actinidia deliciosa*	Fruit
13.	Orange	*Citrus sinensis*	Fruit
14.	Passion fruit	*Passiflora edulis*	Fruit
15.	Peach, nectarine	*Prunus persica*	Fruit
16.	Pear	*Pyrus communis*	Fruit
17.	Plum	*Prunus domestica*	Fruit
18.	Raspberry	*Rubus idaeus*	Fruit
19.	Strawberry	*Fragaria × ananassa*	Fruit
20.	Sweet cherry	*Prunus avium*	Fruit

(Klein *et al.*, 2007)

2.7 Pear: Many research works are conducting on the effect of adding bumblebees to the honeybee colonies in pear orchards. Bumblebee pollination increase the per cent fruit set, fruit size and fruit yield because buzz pollination responsible to large increase in seed numbers per fruit of pear (Calzoni and Speranza, 1996; Zisovich *et al.*, 2012) [8, 65]. Smessaert *et al.* (2017) [48] observed that fruit set and fruit quality parameters (length, width, weight, firmness, soluble solids content, acid content and the number of seeds) of 'Conference' pears and 'Jonagold' apples were increased in orchards supplemented with bumblebee hives. They also observed that a higher acid content and a lower soluble solids content were recorded, when bumblebee hives placed close to pear trees whereas, in the apple orchard no differences were found in fruit quality and quantity among distances from the bumblebee hives.

2.8 Avocado: The studies show that bumblebees are ten times more efficient in performing close pollination (within cultivar) and at least 20 times more efficient at cross-pollination than honeybees in avocados (Ish-Am *et al.*, 1996) [28]. The pollination rates were higher in the bumblebee treatment plots than in the honeybee treatment and in the control plots of avocado (Ish-Am *et al.*, 1998) [29]. They also found that the average yield of 'Ettinger' cultivar of avocado increased by 66 per cent in the bumblebee treatment plots as compared to the control

3. Role of bumblebees in vegetable production

Insect pollinators provide an important service in several vegetable crops. Usually managed honeybees (*Apis mellifera* L.) are used to enhance pollination, fruit set and crop yield of many vegetables. Recently, the population of managed honeybees declines due to indiscriminate use of chemicals and climate change. Instead of managed honeybees, bumblebees are important pollinator of vegetable crops under protected condition. Bumblebees could serve as a backup pollinator for honeybees to pollinate cucumber, watermelon and possibly other vine crops grown in either open or greenhouse conditions (Stanghellini *et al.*, 1997) [50].

3.1 Tomato: Tomato (*Solanum lycopersicum* Mill) is a main crop that pollinated by bumblebee pollination under protected condition. The buzz-pollination of tomato done by four native species of Japanese bumblebees (*Bombus hypocrita hypocrita* P., *B. ignitus* S., *B. ardens ardens* S., and *B. diversus diversus* S.). A high (84-100%) fruiting rate and almost no puffy fruit (0-7%) resulted from pollination by the Japanese bumblebees. Larger fruits and maximum seed content are produced from bumblebees-pollinated flowers as compare to non-bumblebees-pollinated flowers of greenhouse tomatoes (Dogterom *et al.*, 1998) [14]. The bumblebees pollinated fruits contained more number of seeds and heavier weight of 1000 seed as compared to tomato crop without bumblebees pollination (Vergara and Buendia, 2012; Yankit *et al.*, 2016) [57, 63].

3.2 Eggplant: Brinjal belongs to family Solanaceae and its flowers are self-fertile. The brinjal flowers require vibration for pollen release. Wind can be sufficient to pollinate brinjal flowers in open conditions, but polyhouse grown plants require pollination by other means, such as bumblebees. Bumblebees are perfect to release the pollen from the anther efficiently. Brinjal flowers do not produce nectar. So bumblebees can be use with honeybees for brinjal pollination. The bumblebee pollinated eggplants gives higher yield (25%), fruit size (14% in weight and 7% in length) and four times higher number of seeds per fruit than vibration under unheated plastic houses (Abak *et al.,* 2000) [2]. Al-Abbadi (2009) [4] reported that the fruit set percentages for eggplant were 66, 59, 52 and 30 per cent, for the two honeybees nuclei, one honeybees nuclei, bumblebees and control treatments, respectively. He found that *Bombus terrestris* L perform as good pollinator after *Apis mellifera* L. in the fruit set, fruit weight and length parameters of brinjal.

3.3 Cucumber: Honeybees have in recent years used to pollinate crops such as squash, cucumbers and melons due to the large number of bees per hive. Honeybees tend to go down rows whereas bumblebees tend to go across rows or are more erratic in their foraging (Mader *et al.*, 2010) [34]. Thakur *et al.* (2010) [53] studied that higher fruit set (4.08 kg/plant) was obtained in bumblebee pollinated cucumber as compare to control (no insect pollination). They found that bumblebee pollinated cucumbers produced more healthy fruits (83.62%), fruit length (20.75 cm), fruit diameter (11.01 cm), fruit weight (413.62 g), number of seeds/fruit (422) and 1000-seed weight (31.50 g) and less crooked fruits (16.18%) over control. Their study revealed that 22 per cent increase in monitory returns from bumblebee pollinated crop at the cost: benefit ratio of 1:2.02. The bumblebee pollinated cucumbers produced good quality fruits over control (without pollinators) (Chauhan, 2011) [10].

3.4 Chili: The bumblebee (*Bombus terrestris* L.) is an effective pollinator in the cultivation of greenhouse hot pepper (*Capscum annuum* L.). The colony traffic and foraging activity of bumblebees were 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. The bumblebee pollination increased the fruit mass and number of seeds by 27.2 and 47.8%, respectively, compared to that of the control (Kwon and Saeed, 2003) [33]. Shipp *et al.* (1994) [47] observed that effect of bumblebees as pollinators was significant ($P< 0.05$) for fruit weight, fruit width, fruit volume, pericarp volume, seed weight and days from fruit set to harvest in 'Plutona' cultivar of sweet pepper. Bee pollination improved fruit grade and increase the average pepper yield (4.0%), weight of fruit (10.0%), diameter of fruit (6.0%) and the number of seeds (12.5%) as compare to the control in greenhouse trials. Similarly, in commercial greenhouses the average early and total yields increased 29.6% and 22.4%; and fruit weight, diameter, volume and flesh thickness were also positively influenced (Abak *et al.*, 1997) [1]. The bumblebees increase the number of fruits per plant (3.77%), fruit weight (g) (24.60%), fruit length (cm) (13.51%), fruit breadth (cm) (21.52%), healthy fruits (23.84%), seed number (113.64%), 1000 seed weight (g) (5.44%) and fruit yield per m^2 (kg) (89.42%) in bell pepper over control (Thakur, 2018)[52].

Table 2: List of vegetables pollinated by bumblebees

S. No.	Common name	Scientific name	Commercial product of pollination
1.	Tomato	*Solanum lycopersicum Mill*	Fruit
2.	Broad bean	*Vicia faba*	Seed
3.	Chilli pepper	*Capsicum annuum*	Fruit
4.	Cowpea	*Vigna unguiculata*	Seed
5.	Eggplant	*Solanum melongena*	Fruit
6.	Potato	*Solanum tuberosum*	Fruit
7.	Scarlet runner bean	*Phaseolus coccineus*	Seed
8.	Pumpkin	*Cucurbita pepo*	Fruit
9.	Cucumber	*Cucumis sativus*	Fruit
10.	Alfalfa/ Lucerne	*Medicago sativa L.*	Seed

(Klein *et al.*, 2007) [32]

3.5 Pumpkin: The bumblebees can be used in the open field of oil pumpkin (*Cucurbita pepo* L. subsp. pepo var. styriaca GREB.) and can lead to a general improvement in pollination, as bumblebees visit four to five times more flowers in a minute and foraged at adverse weather, even during rain (Fuchs, 2004) [20]. Petersen *et al*. (2013) [43] compare pumpkin yield, *A. mellifera* flower visitation frequency and *B. impatiens* flower visitation frequency between treatments. Results revealed that supplementing pumpkin fields with either *A. mellifera* or *B. impatiens* hives did not increase their visitation to pumpkin flowers or fruit yield compared with those that were not supplemented. Fruit yield increased as the frequency of flower visits by *A. mellifera* and *B. impatiens* increased in 2011 and 2012, respectively. These results suggest that supplementation with managed bees may not improve pumpkin production and that *A. mellifera* and *B. impatiens* are important pollinators of pumpkin in our system.

4. Foraging behavior of bumblebees

Bumblebees are eusocial hymenopteran insect. The foraging behavior of bumblebees are complex. The foraging range and flights are variable and dependent on species and environmental factors. They are able to forage up to 1-2 km from their colony with a ground speed of 54km/h (Osborne *et al*., 1999; Walther-Hellwig and Frankl, 2000; Dramstad *et al*., 2003) [41, 59, 15]. Bumblebees have tendency of flower constancy and able to identify the flower recently visited by other bees through detection of electric field (Clarke *et al*., 2013) [11] and identify flowers through temperature of flowers (Harrap *et al*., 2017) [25]. Sapir *et al.* (2017) [46] most interestingly, the bumblebees also changed the behavior of the honeybees, thereby increasing their pollination efficiency. This was due to the honeybees increasing their mobility between rows and hence cross-pollination and the proportion of their flower visits as top workers. Furthermore, the bumblebees beat their wings 130 times per second. Buzz pollination is a main character of bumblebees where they produce vibration with flight muscles and thus pollen dislodge from anthers. Bumblebees deposit their marking pheromone after visiting flowers which deters themselves from visiting that flower until the scent degrades (Goulson *et al*., 1998) [23]. The bumblebees's activity 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. (Abak *et al.*, 2000 and Chauhan, 2011) [2, 10].

5. Conclusion

Bumblebees are superstar pollinator of many fruit and vegetable crops and have ability to pollinate flowers under windy and low temperature conditions. Qualitative fruits are produced by bumblebees pollinated crops because they are able to transfer pollen grains in sufficient amount and quickly. In addition, bumblebees are able to do buzz pollination that helpful for solanaceaus crops because these crops require vibration for pollination. During last few decades, the population of bumblebees and other pollinators are decreasing due to use of toxic agrochemicals, loss of natural habitats and climate change at worldwide. Ergo, we should know that life is not possible without insect pollinators. We can improve the health of bumblebees and other pollinators by use of non-toxic chemicals and in-situ conservation of natural habitats.

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