Research Review

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# Pollination management in horticultural crops under protected conditions: a review

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**ABSTRACT**

Pollination is an essential process for almost all crops and plants, playing a vital role in ensuring a successful crop yield with improved quality of fruits, seed and produce. For several years, honeybees have been the primary pollinators in most agricultural systems under open field conditions, including greenhouses and net houses up to some extent. Honeybees, especially *Apis mellifera* and *Apis cerana indica* are highly effective pollinators in natural environments, where they are able to freely forage and access flowers. However, they may not be efficient pollinators under closed environmental conditions such as greenhouses and net houses. In large areas, honeybees have shown reluctance to work under protected structures, and this has led to a decline in pollination efficacy under these environments and conditions. As a result, research on the use of alternative pollinators like bumblebees, carpenter bees, stingless bees, syrphid flies, etc. has been conducted under different structures. Henceforth pollination management under greenhouses and net houses using alternative pollinators, have been discussed.

The greenhouses and net houses are used to protect crops from harsh environmental conditions, pests, viruses and diseases. However, these structures come with some disadvantages, such as there is no entry of insect pollinator populations. The enclosed environment of greenhouses and net houses limits the movement of pollinators, leading to decreased pollination efficacy. Honeybees, which are the most efficient and commonly used pollinators in agriculture, are reluctant to work under such conditions, and this can lead to significant losses in crop yield and quality without aided pollination management by alternative pollinators. The primary reason for this is that honeybees tend to be affected by the enclosed environment of these structures, which leads to decreased pollination efficacy. For instance, temperature and humidity inside the structures may not be optimal for the honeybees, causing them to be less active and less likely to visit flowers for pollination. The limited space inside the structures can also make it difficult for honeybees to navigate and find flowers to pollinate, (Dag, 2008).

Another reason why honeybees may not be efficient pollinators under closed environmental conditions is competition for resources. When honeybees are placed in a limited area of greenhouse or net house, they may be competing with other bees for pollen and nectar. This competition may lead to a decrease in the number of flowers visited by honeybees, resulting in lower pollination efficacy under such conditions. Furthermore, use of pesticides and other chemicals in closed environmental conditions can negatively affect the foraging behaviour of honeybees. Pesticides may alter the chemical composition of flowers, making them less attractive to honeybees. The chemicals may also make the honeybees more vulnerable to diseases and other environmental stressors.

In contrast, alternative pollinators such as bumblebees, carpenter bees, and stingless bees are better adapted to the enclosed environment of greenhouses and net houses. These bees are generally more active and able to navigate the space inside the structures more efficiently. They are also less affected by the environmental conditions and competition for resources, making them ideal for pollination under closed environmental conditions, (Singh, 2002). It is well-known fact that honeybees are highly effective pollinators in natural environments, but may not be as efficient in closed environmental conditions such as greenhouses and net houses. Alternative pollinators such as bumblebees, carpenter bees, and stingless

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bees are better adapted to these environments and may be more efficient in pollinating crops grown in protected structures, (Singh, 2002).

To counteract the problem of decreased pollination efficacy of honeybees under protected conditions, alternative pollinators have been identified as an effective solution. These alternative pollinators include bumblebees, carpenter bees, stingless bees, syrphid flies, and other species. Bumblebees, for instance, have been found to be effective pollinators under protected structures. They are known for their superior pollination efficacy, indicating that they are two to three times more efficient than honeybees. Additionally, bumblebees are not as affected by environmental conditions as honeybees, making them ideal for greenhouse and net house pollination. (Singh, 2002).

Alternative pollinators such as carpenter bees, stingless bees, and bumblebees have been found to be efficient pollinators in greenhouses and net houses. Carpenter bees and stingless bees are effective pollinators in cucurbits, while bumblebees have greater efficacy in pollinating tomatoes, cherry tomatoes and strawberries. Pollination management using these alternative pollinators is essential in ensuring optimal crop yield. It is, therefore, important for farmers to consider using these alternative pollinators in protected structures to increase pollination efficacy and improve crop yield.

**Honeybees as pollinators for protected conditions**

Muskmelon being monoecious, bear both the staminate (male) and pistillate (female) flowers separately in a ratio of 18:1. A pistillate flower produced 4.34 - fold higher dry nectar sugar (DNS) (0.909 mg/flower) than staminate flower (0.209 mg/ flower). Maximum DNS production was found in hand pollinated flowers which might be due to stimulation of nectar situation. While minimum DNS was observed in situations devoid of bee pollination floats and stimuli, moderate quantity was found in all other bee pollination treatments. In staminate flowers, minimum DNS was produced in flowers devoid of pollination (0.186 mg/flower) and its provision though various modes significantly increased DNS production, the highest in enclosure where hand-pollination and colony permanently inside treatment were 0.219 and 0.215 mg/flower, respectively. Maximum DNS was produced in flowers at 0700h (0.307 mg/flower), declined at 1000h (0.184 mg/flower), again increased at 1300h (0.201 mg/flower) and lowest at 1600h (0.145 mg/flower). Pistillate flowers also exhibited similar pattern of DNS production in different treatments (maximum DNS production by flowers was in hand pollination (0.945 mg/flower) probably due to stimulation of nectar secretion and minimum in without bee pollination plots (WBP) (0.829 mg/flower) in absence of stimuli, but was moderate (0.915-0.29 mg/ flower) in all other bee pollination treatments. However, the diurnal pattern differed with higher DNS at early 0700h (0.944 mg/flower), peaked at 1000h (0.976 mg) followed by a gradual decline from 1300h (0.871 mg) to 1600 h (0.844 mg/flower).

Minimum fruit weight was observed in WBP plots (248.61 g), which improved in open pollination (290.12 g), hand pollination (320.51 g), and colony with addition of one brood frame @ 10-day interval (433.33 g). The highest fruits were obtained when colony with dual entrance (486.66 g) and colony placed regularly inside (496.77 g). Similarly, results were obtained for other fruit quality parameters including seed number, TSS and acidity. Pollination was also the most critical input for fruit set and its further development. In WBP plots, lack of pollination resulted in lowest fruit yields (29.83 q/ha) while exposure to various floral visitors in open pollination condition improved yields significantly (47.38 q/ ha). Moreover, ensuring pollination increased yields further to 1666.66 q/ha.

Further pollination input by addition of one brood frame to bee colony @ 10-day interval yielded 207.99 tonnes/ha. Maximum yield was obtained from treatment where bee colony was permanently kept inside enclosures (397.80 q/ha), followed by colony with dual entrance (364.99 q/ha) (AICRP on HB&P, 2020-21).

Pollination studies in muskmelon under polyhouse conditions using *Apis mellifera* and hand - pollinations were conducted at PAU, Ludhiana during summer season of 2021. In various muskmelon varieties/lines *viz.* Chand, Punjab Sharda (CY 2012-21), GG 551, MM 964, CT 2015-35 and CY 2012-01 the foraging intensity varied from 1.0 to 2.0 bees/$m^2$/2 mins. The forging rate varied from 0.6 to 2.1 flowers/ 2 min. *Apis mellifera* was found to be highly efficient for perfect pollination of muskmelon crop (AICRP HB&P, 2021-22).

*Apis mellifera* colonies placed inside polyhouse having capsicum crop showed highest darting behavior during the first 3 days which reduced thereafter. Normal colony activity started only 8 days after placement of colonies. Mean intensity of bees foraging on capsicum flowers was very low (0.34 bee/m row length/2 min). Only 5.51 per cent bees were foraging for pollen. Fruit setting in *Apis mellifera* crop was 4.5 per cent more than the crop excluded from bees. (AICRP on HB&P, 2020-21).

**Alternative pollinators for protected conditions**

High productivity with quality produce of any crop depends upon many factors and pollination is one of them. The most reliable and efficient form of pollination is through insects. Wild and managed bees are well documented as effective pollinators of global crops of economic importance. Non-bee pollinators include flies, beetles, moths, butterflies, wasps, ants, birds, and bats. Many insects such as honeybees, bumble bees, leaf cutter bees and solitary bees are important pollinators which are in commercial use (McGregor, 1976). Bumble bees were selected as efficient pollinators of greenhouse (Corbet *et al*., 1988). Under tropical and subtropical ecologies, we have Xylocopid bees facilitating buzz pollination. Five species of stingless bees (*Tetragonula iridipennis*, *Lophotrigona canifrons*, *Lepidotrigona ventralis*, *Tetragonula laeviceps* and *Lepidotrigona arciferal*) have been collected and maintained at the SASRD, Nagaland centre. The different stingless bees were evaluated for their pollination efficiency under protected condition.

Bumble bees are larger, more robust and furrier than honeybees. Their capacity to forage at low temperature and low light intensities makes them an important pollinator under protected conditions. Therefore, bumble bees are being used as pollinators of tomatoes, peppers, blue berries, cucumber and egg plants under protected conditions in many countries such as the Netherland, Belgium, France and Israel since 1988. Bumble bees are well adapted in confined greenhouse conditions as they do not fly against windows since other bees are less likely to forage outside the glasshouse even when windows are opened (Delplane, 1996). However, only the group of long tongued bees can be used for pollination, as short tongued bees are reported to pierce the corolla (cause infection through tear) and rob nectar without facilitating pollination. In narrow corolla tube with deep nectarines, bumble bees owing to large size are unable to enter into the flowers. One more disadvantage is that being annual in nature and farmers need to buy colonies afresh every year and bumble bees are not available to the crops blooming in winter. However, diversity would provide added advantage though restricted to tropical areas of India. The large diversity of 48 bumble bees species existing in India must be exploited through mass rearing the most commonly adapted species in the niche area towards its commercialization for customized renting-hiring service for farmers resorting to protected cultivation, during summer, monsoon and autumn seasons (AICRP on HB & P, 2012-17)

The studies in Capsicum crop under protected conditions by using indigenous bumble bees (*B. haemorrohoidalis),* conducted at YSPUHF, Solan, during 2021 recorded the average activity, 0.4, 0.53, 0.57, 0.37 and 0.23 bumble bees/five minutes during 0600-0700h, 1200-1300, 1500-1600h and 1800-1900h, respectively. The activity of incoming bumble bees initiated at 0600h to late evening. Utilization of laboratory reared *Bombus haemorrohoidalis* colony was found suitable for bell pepper grown under polyhouse conditions for efficient pollination (AICRP on HB&P, 2021-22).

**Foraging behavior of bumble bees and honeybees on Strawberry (*Fragaria ananassa*)**

The experiment was laid out in a randomized block design with four treatments, viz. cage with *B. haemorrohoidalis* colony, cage with *A. mellifera* colony, control (cage with pollinators) and open pollination. Laboratory reared *B. haemorrohoidalis* colony was utilized for pollination of strawberry cv. Sweet Charlie during April-May, and their role in pollination of strawberry grown under protected conditions and influence on bio-physical parameters of strawberry in comparison to open pollination and control was undertaken during the year 2020. There was maximum fruit set in cage with *A. Mellifera* colony (89.81%) which was at par with fruit set in cage having *B. haemorrohoidalis* colony (87.16%). The minimum fruit setting was recorded in the control i.e. cage without pollinators (78.96%) which was at par with open/natural pollination (80.80%). The fruit weight of strawberry cage with *B. haemorrohoidalis* pollination was at par with open/natural pollination.

Fruit weight of strawberry was maximum (14.26 g) in cage with *B. haemorrohoidalis* colony which was at par with fruit weight with *A. Mellifera* pollination (14.02 g), followed by fruit weight in open pollination

(10.87 g) which was at par with fruit weight in the control, i.e. cage without pollinators (10.54 g). (AICRP on HB&P, 2020-21).

The tomato hybrid (Lakshmi) seedlings were planted in pots on 3rd October, 2020 and the plants were maintained with proper irrigation and fertilizer application in insectary at TNAU, Coimbatore. During flower initiation phase, pots were shifted to insect proof net poly house in Insectary on 27th November, 2020. One strong stingless bee colony of *Tetragonula iridipennis* was placed inside the poly house and the plants were observed regularly for bee visitation and foraging activity of stingless bees. Initially, for few days no bee activity was observed in tomato flowers. Hence, bee colony was fed sugar syrup mixed with tomato pollen for inducing foraging. But, even during the peak flowering phase of tomato, no bee foraging activity was observed in the polyhouse. So, stingless bee colonies become gradually weakened. Hence, the study revealed that the tomato flowers are not preferred by stingless bee, *Tetragonula iridipennis* for rewards collection. The tomato flowers produce sticky pollen with poricidal anthers which require buzz pollination or scraping behaviour in bees to collect pollen from flowers. The most commercialized stingless bees species of Brazil, viz., *Melipona bicolor* and *Nannatrigona testaceicornis* were employed successfully for pollination of cherry tomatoes under protected cultivation. Whereas, another common stingless bee species *Paratamona helleri*, was found not foraging on tomato flowers (AICRP on HB&P, 2020-21).

**Impact of stingless bee pollination on cucumber**

The results revealed that the highest yield/plant were observed under stingless bee pollination (SBP) treatment, followed by open pollination (OP) and pollinator exclusion (PE) during both the seasons. Highest infestation on fruit fly was observed in open pollination which resulted in 45-55 % fruit damage which might be a probable reason for low yield under OP. In PE, fruits were shriveled and stunted which had negatively influenced the quality of fruit and yield.

Most of the observed bees were side workers (78%), land on the petals and proceed towards the reproductive part (stamen or stigma), while the rest of the foragers (22 % were top workers), land directly on the top of stamen or stigma. Foraging rate was highest (6.80 male flowers 5min$^{-1}$) during the time of initiation of foraging (0800-0900h), while maximum foraging intensity was recorded as 4.40 bees male flower$^{-1}$ 10 min$^{-1}$ during 1000-1100 h. Maximum time spent by pollen collectors per male flower was recorded as 44.20 sec during 1200-1300 h of the day during which maximum pollen grains were recorded from the body of bees. Irrespective of time period, stingless bee spent significantly more time on female flower compared to that of male flowers in respective time intervals.

The diurnal activity of a colony assessed in terms of total number of incoming and outgoing foragers at hive entrance revealed that their number increases with the ascent of the day, reaches a maximum during 1300-1400 h (67.00 and 58.00 numbers of incoming and ongoing foragers respectively) and then decreases thereafter. Weekly observations showed that the pollen and nectar foraging activity of stingless bees varies in a day with the peak period during 1200-1400 h. A significant positive correlation was observed between relative humidity and number of incoming foragers (r=-0.68).

There was significant increase in per cent fruit setting in stingless bee pollinated crop (76%) compared to hand pollinated one (54%) whereas the qualitative yield parameters like per cent malformed fruit, length and diameter of fruits were statistically on par. With regard to quantitative yield parameters, significantly higher single fruit weight, number of seeds per fruit and germination per cent (2DAS) (685.00 g, 344.10 seeds/fruit and 90.60% respectively) were recorded from the stingless bee pollinated crop than that of the control crop (555.00 g, 210.90 seeds/fruit and 63.00 % respectively). Higher yield was observed in augmented pollination (5.09 kg m$^{-2}$) compared to hand-pollination (3.16 kg m$^{-2}$), Apart from this, bee assisted pollination was economically feasible with a B:C ratio of 1.23 than that of the hand pollinated one (0.67). Thus, augmentative pollination with stingless bee under protected cultivation has increased the yield of salad cucumber both in terms of quantity (61% yield increase) and quality in protected cultivation, (AICRP on HB&P, 2020-21).

Pollination studies in bitter gourd conducted at DRPCAU, Samastipur, Bihar, under protected conditions by using carpenter bees (*Xylocopa fenistrata)* showed minimum fruit yield under pollinator exclusion treatment (PE), 72.10 g, whereas maximum fruit yield was recorded under carpenter bees pollinated treatment. It clearly shows that carpenter bees can be the most efficient pollinator for different cucurbitaceous vegetables under protected environment. (AICRP HB&P, 2021-22). Carpenter bees are also efficient pollinators under protected structures. They are known for their larger size, and this allows them to carry more pollen from one flower to another. Moreover, they are active pollinators, and their large size ensures that they are not affected by the wind, which can be a problem for smaller pollinators such as honeybees.(Singh, 2022).

Stingless bees, which are commonly found in tropical regions, have also been identified as effective pollinators under greenhouses and net houses. These bees are small, and their size allows them to move around easily under the enclosed environment. They are also known for their ability to pollinate a variety of crops, making them versatile pollinators.

Beneficial insects provide pollination and biological control in natural and manmade settings. Those ecosystem services (ES) are especially important for high value fruits and vegetables, including those grown under greenhouse conditions. The hoverfly *Eupeodscorollae* (Diptera: Syrphidae) delivers both ES, given that its larvae prey upon aphid pests and its adults pollinate crops. In this study, we investigated this dual role of *E. corollae* in three insect-pollinated and aphis affected horticultural crops, *i.e.* tomato, melon and strawberry in greenhouses in Hebei province (China). Overall, our work shows how augmentative releases of laboratory-reared hoverflies, *E. corolla,* can enhance yield of multiple horticultural crops while securing effective, non-chemical control of resident aphis pests, (Li *et al.*, 2023).

Syrphid flies have also shown great potential as alternative pollinators under greenhouses and net houses. These flies are not as commonly used as other alternative pollinators, but they have been found to be effective pollinators in certain crops. They are attracted to flowers, and their movement from one flower to another ensures pollination, (AICRP on HB&P, 2020-21). It clearly indicates that honeybees (*Apis mellifera*) are most efficient and effective pollinator for taking maximum yield with highest quality of fruits as compared to other pollinators under open field conditions but *Apis mellifera* and *A. cerana indica* cannot work efficiently under protected conditions due to availability of limited area for foraging mostly with high level of humidity and temperature. For effective foraging activity of honeybees (*Apis mellifera*), the greenhouses must be bigger in size and well ventilated, particularly during high temperature conditions in tropical regions, (Singh, 2022). The results of various research centers in India and abroad indicate that bumblebees are the most efficient and effective pollinators for producing highest fruit yield with quality produce even under adverse climatic conditions in tomato and cherry tomato under protected environmental conditions. One can also use electric vibrators or speed regulated air blowers for pollination of greenhouse tomatoes, but under the adverse climatic conditions this is not efficient and effective method and the efficiency under such conditions can be achieved only with combination with bumblebees, (Singh, 2002). It may also be concluded that stingless bees (*T. irdipennis*) is the most suitable and efficient pollinator for the cucurbitaceous vegetable crops under greenhouses and net houses because of their limited foraging range (200-300 m) and low height of flight and small size. Stingless bees can also perform efficient pollination in capsicum and chilli under protected conditions although for these crops no aided pollination is usually required but stingless bees can improve the yield and quality in both these crops (Singh B, 2022).

Similarly, Carpenter bees (*Xylocopa fenistrata*) have been found efficient pollinator for most of the cucurbitaceous vegetable crops but their efficiency for pollination of tomato crop under protected conditions is yet to be established through ongoing investigation and research. In conclusion, alternative pollinators are essential in ensuring effective pollination under greenhouses and net houses. Bumblebees, carpenter bees, stingless bees, and syrphid flies, among others, have been identified as ideal pollinators in these environments. These pollinators are not affected by the enclosed environment and are more efficient than honeybees. Pollination management under greenhouses and net houses using alternative pollinators is essential in ensuring successful crop yield and should be encouraged. Pollination is a crucial process for most crops, including cucurbits and tomatoes. In greenhouses and net houses, the movement of pollinators can be limited, leading to decreased pollination efficacy. Honeybees, which are the most commonly used pollinators, have shown reluctance to work under protected structures, leading to the need for alternative pollinators. Among alternative pollinators, carpenter bees and stingless bees have been found to be efficient pollinators in cucurbits, while bumblebees have shown greater efficacy in pollinating tomatoes.

Cucurbits are a diverse group of crops that include cucumbers, melons, and squashes. These crops are known to have low fruit set due to inadequate pollination, leading to decreased crop yield. Carpenter bees, which are large bees, have been found to be efficient pollinators in cucurbits. They are active pollinators, and their large size allows them to carry more pollen from one flower to another. Moreover, they are not affected by environmental conditions and can easily move around under the enclosed environment of greenhouses and net houses. Stingless bees have also been found to be effective pollinators in cucurbits. These bees are small and can move around easily, ensuring effective pollination.

## CONCLUSION

In conclusion, alternative pollinators such as carpenter bees, stingless bees, and bumblebees have been found to be efficient pollinators in greenhouses and net houses. Carpenter bees and stingless bees are effective pollinators of cucurbits, while bumblebees have greater efficacy in pollinating tomatoes, cherry tomatoes and strawberries. Pollination management using these alternative pollinators is essential in ensuring optimal crop yield. It is, therefore, important for farmers to consider using these alternative pollinators in protected structures to increase pollination efficacy and improve crop yield. There is urgent need of more focused research on pollination management under different protected structures since the area under protected cultivation is on increasing trend in different regions of the country.

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