Chapter 10
Pollination Behavior of Cotton Crop and Its Management

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Abstract Cotton is the most important non-food crop in the world producing natural fiber, edible oil, and seed cake. Approximately 249 million bales of cotton were produced worldwide in 2017. The United States, China, and India are the major cotton-producing countries in the world. Brazil is emphasizing on organic farming of cotton utilizing the natural services of insect pollinators for pollination and natural enemies for cotton pest management. Cotton products are obtained from its fruit (bolls) for lint and seed which takes place after pollination. Although cotton is commonly known as a self-pollinating crop, it is often cross-pollinated with 5–50% cross-pollination by natural mechanism of out-cross pollination. Insects are important natural pollinators, foraging cotton crop due to the presence of floral and extrafloral nectaries. Three main pollinating insect species, namely, *Allograpta exotica* (Diptera), *Apis mellifera*, and *Melissodes tepaneca* (Hymenoptera), have been reported as effective pollinators in cotton agroecosystems with 12% increase in fiber weight and 17% increase in number of seeds in insect-pollinated cotton crops than conventional cotton. Climate change, pesticide use, and agronomic practices are the main reasons for the decline of pollinators in cotton-growing areas. Pollination efficacy and pollinator diversity can be increased by manipulating the habitat for conservation of pollinators, reducing pesticide use, and maintaining natural flora near cotton-growing areas for alternate pollen source to pollinators for better cotton yield and quality. Small farmers can earn extra income if they get engaged in land use management to improve pollination services.

Keywords Cotton · Pollination · Cotton pollinators · Cotton hybridization · Organic farming

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Abbreviations

A.m	*Apis mellifera*
BB	Bumble bees
BE	Bees excluded
BP	Bee pollination
C	Cross-pollination
CE	Cross-pollination essential
H	Hand pollination
IE	All insects excluded
INM	Integrated nutrient management
IPM	Integrated pest management
IWM	Integrated weed management
OP	Open pollination
S	Self-pollination
TI	Tiny insects permitted
USDA	United States Department of Agriculture

10.1 Introduction

Cotton is an important fiber crop known as the most used natural fiber in the world (Cusser et al. 2016). It is known as the major component of textile industry with total supply of approximately 248.63 million bales all over the world in 2017 (Johnson et al. 2018). The USDA annual report showed the United States, China, and India as major producers of cotton. The last 40 years of agricultural development shows that the yield and production per unit area is increasing but not in a sustainable manner. It has been observed that the genetic diversity is capable of playing an important role in crop yield and quality improvements which occurs through the Mendelian variation from the wild crop species. Genetic diversity is more in cross-pollinated crops (apples, grapes, plums, pears, raspberries, blackberries, strawberries, runner beans, pumpkins, daffodils, tulips, lavender) than self-pollinated crops (peas, wheat, barley, oats, rice, potatoes, apricots, and peaches). Scientists are dealing with new technologies for improving the production of crops, especially oilseed and fiber crops, but Mendelian variation is not so far concerned by most. Often, cross-pollinated crops like tobacco, maize, and cotton have a brighter scope for higher production yields (Dastagiri et al. 2013) than that of self-pollinated plots. Cotton flower anatomy supports cross-pollination in addition to the self-pollination mechanism as it has many stamens around a five-lobed pistil in the center which releases the pollens.

Agriculture and natural ecosystems have great concern for declining pollinators in the developed world like North America and Europe. The economic and ecosystem losses due to declining pollinators are detrimental for these regions but are considered less detrimental for developing areas like South Africa and Pakistan.

Fig. 10.1 A bee visiting a cotton flower dusted with pollen

Pollinators decline in developing countries due to reduction of crop yield, increase in food prices, reduction of food quality, decrease in micronutrient availability through natural resources, and serious threat to honey production industry (Gallai et al. 2009; Potts et al. 2010).

Brazil is focusing on organic cotton production and emphasizing the cotton pollination through insect pollinators for increase in yield, lint quality, and oil contents (Araujo et al. 2012). Cotton crop has shown positive output in organic production system especially in the presence of more pollinators as compared with no or less pollinators in conventional cotton production programs. There was 14% and 17% weight increase of fiber and number of seeds, respectively, in cotton fields with natural cross-pollination as compared with fields that were lacking bees (Dutra et al. 2012). Farmers must favor the pollinators by managing their conservation and increasing bee flora and natural vegetation. Dutra et al. (2012) revealed that by increasing the nearby vegetation of cotton field, bee visitation on cotton flowers may increase from 0.45 bees/h which is inadequate to increase production (Fig. 10.1). A maximum of 27% production increase has been observed near vegetation field increasing the bee diversity and frequency. Four bee species were the major visiting pollinators of cotton crop with greater output in diverse pollinator visitation than a single bee species (Araujo et al. 2012). Small farm holders can adopt organic farming of cotton crop and increase the pollinators by reducing the use of pesticides and chemicals. However, only a few varieties were studied for efficacy of pollinators, while a lot of work is desired to attain sustainable high yields. Better economic achievements are possible under pollinator-friendly cotton production technology.

10.2 Mode of Cotton Plant Pollination

Cotton belongs to angiosperms, and the transfer or placement of pollens from anther (male flower part) to stigma (female flower part) of the same flower or the other flower is called pollination. After this transfer, pollen germinates through the pollen tube and fertilizes the egg. Artificial breeding programs are common for artificial selection to produce new high yielding cultivars. Cotton is commonly known as a self-pollinated crop, but pollinators have also been observed on cotton flowers if it is near cross-pollinated crop boundary and included in often cross-pollinated crop (McGregor 1976). The details are given below.

10.2.1 Self-Pollination

The transfer of pollen from anther to stigma of the same flower is called self-pollination. This process is a basic feature of bisexual flowers, e.g., cotton which is considered as a self-pollinated crop by many ecologists (Free 1970; Rhodes 2002). However, cross-pollination is also possible in such self-pollinated crops. In cotton, self-pollination is responsible for less genetic diversity due to which artificial breeding programs are adopted. In the past, self-pollination for cotton breeding was adopted just due to the myth that natural crossing is responsible for hybridization of seed stock.

10.2.2 Cross-Pollination

Cross-pollination is the transfer of pollen from the flower of one plant to the stigma of the flower of other plant. There exist different modes of cross-pollination like wind, water, mammals, birds, arthropods, etc. Cotton crop is pollinated by insect pollinators mainly wasp, flies, butterflies, moths, and bees which provides them nectar and pollen as a reward. Self-pollination also occurs in cross-pollinated crops from 5% to 10%. Mostly cross-pollinated crops include maize, millets, sunflower, sesame, alfalfa, and castor. In earlier days, cotton was not considered to be cross-pollinated.

10.2.3 Often Cross-Pollination

Often cross-pollinated crops include millets, safflower, cotton, pigeon pea, etc. In these crops, self-pollination is the basic phenomenon, but cross-pollination also occurs from 5% to 50%, so they are named as often cross-pollinated crops. These

crops are intermediate between cross- and self-pollinated crops due to their genetic architecture. Cross-pollination is adopted by plants to maintain genetic diversity.

Insects are considered as potential cotton crop pollinators among the natural crossing agents. Honeybee, *Apis mellifera*, was identified to be the most effective pollinator of cotton crop, and bumblebees (*Bombus* species) were identified as frequently visiting pollinators with pollen loads (Meade 1918). Birds are also sometimes attracted to flowers and cause pollen transfer when collecting the nectar as their food requirement (Dellinger et al. 2014; Armbruster 2011; Proctor et al. 1996). Food reward is not always on active sexual parts of the flower as it can occur on non-sexual parts of plants like in cotton plant where nectaries are present on the back side of the leaves (Simpson and Neff 1981).

10.3 Biodiversity of Cotton Crop Pollinators

Cotton belongs to Malvaceae family which has almost thirty-two *Gossypium* species like Deccan hemp, okra, cotton, etc. These species have large size flowers and nectaries other than flowers to attract pollinators. Pollinator biodiversity is important for cotton crop in an area as most visiting flower insects are not good pollinators, e.g., European honeybee (Vaissiere et al. 1984). Many pollinators have been reported from different communities, but all are not effective cotton pollinators. The area, climate, surrounding environment, pollen, and nectar flow of that area may alter the situation. Mostly cotton pollinators are reported from the class Insecta. Hymenoptera and Diptera are the orders having most of the cotton pollinators. Three main species *Allograpta exotica* (Diptera), *Apis mellifera*, and *Melissodes tepaneca* (Hymenoptera) were reported as effective pollinators in cotton agroecosystems. They have a great variation in their life history which makes them adjustable to agriculture land use change.

FAO (2018) issued a list of cotton crop pollinators effective in cotton seed production programs. Some of the main pollinators visiting cotton flower are *Megachile monticola*, *Apis dorsata*, *Xylocopa* species, *Anthophora confusa*, *A. quadrifasciata*, and scoliid wasps. *Apis florea* is also reported to visit the cotton flowers but seems to be a less effective pollinator due to its small size. *Halictus* species, *Andrena ilerda*, *Nomia* species, *Coelioxys* species, *Nomada* species, *Xylocopa* species, and *Pithitis smaragdula* have also been reported in Pakistan and India as cotton pollinators. *Scolia* and *Xylocopa pubescens* have been reported in Egypt pollinating the cotton flowers. In North America, the bodies of *Melissodes* (solitary bees) and *Elis plumipes* (scoliid wasps) were found dusted with cotton pollens when constantly visiting cotton flowers. Carpenter bees and bumblebees are the most effective cotton pollinators in the United States because of their floral nectary visiting behavior and touching stigma and stamens while foraging. Foraging frequency of bumblebee was 1.2 flowers/plant, and there were 2750 maximum flowers potentially visited by the bumblebees.

Pollinators may have different habitats and can adjust according to their life history in different agroecosystems. *Melissodes tepaneca*, a solitary bee, lives in underground soil nest. In contrast, *A.m* is living in complex social nests above the ground (Michener 2007). Both of these bees are distance specific in their foraging and are the best central flower foragers. Some foraging insects are not central flower visitors like a native hoverfly (*A. exotica*), while some may forage through landscapes to fulfill their nectar and pollen requirements like *Allograpta* adults, which help in controlling aphid on crops through their developing larvae (Bugg 2008). Many factors can be in force for affection of pollinator's abundance and diversity. Landscape nature and complexity have a strong relationship with the diversity of foraging insects (Gaines-Day and Gratton 2016; Steffan-Dewenter et al. 2002; Petersen et al. 2013). The reason may be the different food (pollen and nectaries), nesting space, environment, specific interaction with flowering host needs, etc., for different foraging insects (Brown and Paxton 2009).

Diversity of pollinator in cotton crop resulted in a total of 841 foraging insects belonging to 52 species of four insect orders, Hymenoptera, Diptera, Lepidoptera, and Coleoptera with 37, 5, 7, and 3 species, respectively (Roubik 1995). The maximum number of specimens was of solitary bee (*M. tepaneca*) sharing 21% of the total specimens and the European honey bee (*A. mellifera*) having 19% share followed by the syrphid fly (*Allograpta exotica*) with 16% share. The remaining 15% of the pollinator specimens were from different nine species of insect order Hymenoptera. Birds have also been reported on cotton crop visiting for nectar. Passerines and hummingbirds are nectar lovers and mostly visit the flowers for sugar preference (Cronk and Ojeda 2008).

10.4 Importance and Scope of Insect Pollination in Cotton Cultivation

Cotton breeding and cotton seed production are greatly affected by natural cross-pollination. Earlier studies showed that insects are the main source of cross-pollination in cotton playing their role for enhancement of cotton yield as shown in Table 10.1. Some of the important factors have been discussed below.

10.4.1 Seed Production Technology

Seeds are produced when ovaries from female plants and pollens from male plants meet. There is a natural mechanism of self-pollination in cotton, but for cross-pollination, insects play their role in cotton crop. Insect-pollinated cotton has shown 17% increase of seeds/boll, while comparing different pollination means including BE, BP, C, CE, H, IE, TI, OP, and S (Pires et al. 2014). In different

Table 10.1 Pollinating species and their benefits to cotton crop under different ecological zones

Ecological zone/ country	Pollinating species	Insect order	Economic benefit	Ecological benefit	Reference/ source
India	Honeybees (*Apis mellifera*)	Hymenoptera	Increase the boll setting per plant	Maintenance of bee fauna	Santhy et al. (2008)
South Texas	*Apis mellifera* *Allograpta exotica*	Hymenoptera Diptera	Increased seed-cotton weight by 18%	Conservation of pollinators	Cusser et al. (2016)
Asia	*Apis dorsata*, *Xylocopa*, *Anthophora confusa*	Hymenoptera	27–30% extra boll retention (fruit set)	Conservation of pollinators	FAO (2018)
Brazil	Honeybees (*Apis mellifera*)	Hymenoptera	Increase cotton quality	0.25% dependence on pollination	Giannini et al. (2015)
West Africa	Honeybee (*Apis mellifera*), twenty-six wild bee species and four species of wasps	Hymenoptera	33–43% more cotton weight	Enhanced germination rate	Stein et al. (2017)
China	*Bombus ignites* and *Apis mellifera*	Hymenoptera	Increased cotton production	Risk of gene flow	Yan et al. (2015)

studies, it is proved that abundance and richness of bees near organic farms (with nearby natural vegetation and without pesticides) play an important role in seed production as compared with conventional farms (less vegetative diversity and use of pesticides). Pollinators are helpful to increase the number of seeds and fiber weight.

10.4.2 Yield Improvement

Cotton is capable of producing good yield in conventional agriculture depending on self-pollination, but the yield can be improved by adopting pollinator management practices by cross-pollination. As a result of insect pollination, large boll size was produced resulting in high cotton yield and creating more profits for the farmers (Cusser et al. 2016). Cotton yield increased up to 12% by maintaining pollinator communities on cotton farms (Pires et al. 2014).

10.4.3 Oil and Lint Quality

Insect pollination increased the quality and yield by improving oil contents and lint quality in fiber crops. If there is loss in number of seed per boll due to lack of pollination, reduction in cake production and oil occurred (Silva 2007). Cotton pollinated by foraging insects showed at least 10% fiber production increase along with betterment in oil contents (Klein et al. 2007).

10.4.4 Survival of Beehives

The purpose of honeybee visitation in cotton field is not always to maximize the cotton crop production but the important pollen source for managed *A.m* colonies near cotton fields. One hectare of cotton can support two to three hives for honey production along with increase of cotton crop yield (Cusser et al. 2016). In summer, exact season of cotton flowering in Indo-Pak region can support honey bee farmers. There is natural attraction for honey bees to visit cotton flowers from at least 8.5 miles away to get their pollen (Minkov 1956).

10.5 Challenges of Cotton Crop-Pollination

Different pollinators have quite different life history with variable efficacy in different regions depending on land management cultural practices and chemical used for pest control and so on. Some devastating factors affecting the pollinator's diversity in cotton are discussed below.

10.5.1 Climate Change

Plant-pollinator mismatch is resulting due to the phenological changes in the environment. Changing climate is affecting a lot of plant and pollinator species potentially damaging their interactive benefits. Timing of flowering plants hosting bumblebees has shifted earlier, but their activities are not. In this way, overall pollen chain and flowering plant seasoning is disturbing these pollinators. They are dying due to starvation as there are no pollens, and crop yields have decreased due to a decline in pollinator's diversity established for long period of evolutionary process (Hughes 2000; Parmesan and Yohe 2003).

This important phenomenon of climate change has affected the foraging activity of general pollinators by altering their body physiology. Different sized pollinating insects have shown different responses to increased stress. Pollinators bigger in size

can better perform through their thermoregulatory system as compared to smaller ones (Bishop and Armbruster 1999). Mostly pollinators decrease their activity in summer with increasing temperature beyond the limits, e.g., *A.m* stops its activity when the temperature is above 40 °C (Cooper et al. 1985). These studies showed that cotton, a summer crop, will greatly face decline in pollinator's activity.

10.5.2 Farm Management and Pesticide Use

Ground nesting bees (*Melissodes*) can be destroyed through deep plowing which is common practice in cotton cultivation areas. *Apis* and *Allograpta* species, however, are not disturbed through such plowing practices (Shuler et al. 2005). Application of poisonous pesticides for pests and disease management in crops is limiting the activity of pollinators in cotton crop. Pesticides on cotton crop may affect larval development of *Allograpta* flies in addition to killing the honey bees and flying insects (Moens et al. 2011). Intensity of cultural practices used at farms negatively affects their diversity (Adger et al. 2002; Kehoe et al. 2015; Roulston and Goodell 2011). Intensively managed cotton farms are deficient in beneficial insects (pollinators, predators, and parasitoids) resulting in increased pest management cost in addition to decreased pollination activity. Ecosystem services reduce, and input cost of production is increased. Yield and its quality also reduced due to reduction of these natural farmer friends (Kevan et al. 1990).

10.6 Future Scope of Cotton Crop Pollination Management

Natural and human-managed terrestrial ecosystems are basically based on pollination which is critical to fulfill the human requirements of food and clothing. The process of pollination is connecting wild ecosystem with human-managed agroecosystems. Pollinators and pollinated crops have a strong symbiotic relationship with each other. As the coming era is focusing on organic farming which should be chemical-free for mankind, there is intense need to overcome low yield problems of our cotton crop utilizing natural services. Some important steps are discussed below which can extend the relationship between cotton and pollinators in favor of mankind.

10.6.1 Conservation of Pollinators

Pollinator communities have greatly been influenced by the human activities in cotton-producing regions. Provision of diversified natural habitat on local and regional levels will increase their diversity and the pollination activity (Garibaldi

et al. 2013). It is already discussed that the increasing distance between natural habitat and cotton fields will reduce the foraging activity of pollinators. Natural habitats will play their role to conserve them during harsh environmental condition, and plant-pollinator relationship will be stronger, and richness of species will be increased in that area (Sih and Baltus 1987).

10.6.2 Target-Oriented Pesticides

Techniques for pest management in cotton crop have changed over time. In earlier days, the use of broad-spectrum pesticides was common which has been replaced with selective ones with comparative less toxicity to beneficial insects including pollinators. However, it is still dangerous to move a beehive near cotton crop because of a large number of pesticide applications in a short period of time (Goodwin 2012). The following steps can save the pollinators while increasing the cotton yield:

- Delay of the first foliar pesticide application as much possible to benefit from pollinators and other beneficial insects.
- Minimum pesticide uses on cotton crop in flowering season.
- Awareness program for pollinator safety and nonchemical pest management techniques through seminars and electronic, print, and social media.
- Use of selective safer pesticides with plant- and animal-based rather than broad-spectrum chemicals.
- Molecular insecticides safe for non-target animals.
- In case of spray, proper and early warning to beekeepers in nearby areas.

10.6.3 Ecological Intensification

Agricultural approaches should be modified to promote ecological pest management and the pollinators. These approaches include integrated pest management (IPM), integrated nutrient management (INM), integrated weed management (IWM), precision farming, and plant breeding that are good for the humanity and least disturbing to the surrounding environment. Research should focus on improving the crop and pollinator interaction while minimizing the loss caused by other pests. These are some points which may be helpful for ecologically promoting the pollinator in cotton crop.

- Maximizing the natural resources utilization like wild flowers and native bees to improve crop yield and generate income.
- Maintenance of natural habitat like oak wood lands and shrub lands around the cotton farms to boost cotton crop by strengthening pollinator communities and increasing diversity.

- Plantation of wild flower rows between the cotton crops to provide food and shelter to the pollinators. Farmers can also utilize economic crops and vegetables like okra, sunflower, and melons to increase diversity.
- Reduction in tillage practices especially nearby area of cotton crop can enhance the soil-nesting pollinators, and ultimately better pollination service will be provided.
- Farming of wild flowers and flowering plants other than cotton fields by all citizens will increase natural flora and pollinator's diversity.

These small ecological developments can change our environment and increase our cotton production with minimum use of chemicals. The coming generations may compete for their pesticide-free food and clothing by our adoption to these small steps.

10.7 Conclusion

Cotton is often a cross-pollinated crop with potential to increase fiber yield, number of seeds, oil contents, and lint quality in the presence of wild bees and foraging insects. Insects belonging to order Hymenoptera are potential cotton pollinators, e.g., *Apis mellifera* and *Xylocopa* species that visit the cotton flowers are found abundant. The out-cross cotton crop has improved its yield factor as compared with the self-pollinated crop. The decline of pollinators is observed due to injudicious pesticide use and climate change including many other factors like loss of habitat and deep plowing of land. Farmers can achieve 18% extra seed production by adopting some small steps. Pollinator diversity can be enhanced by managing land use practices, reduced use of pesticides, and intercropping of wild flowers or other pollen sources, e.g., okra, sunflower, and sesame in our cotton crop. Cotton farmers should be trained regarding the benefits of pollinators and their importance for mankind. Convincing conventional farmers to utilize natural pollination services of nature to increase cotton yield under pollinator-friendly conditions can work when they will observe their benefits.

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