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A review on the role of beekeeping in economy and agriculture through bee diversity and bee-pollinated crops

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Abstract
Pollination by animals play important role in the production and quality of grown crops. Honey bees can be used for this purpose by farmers to gain dual benefits by apiculture and agriculture, as honey bees are the best-known pollinator. For this purpose, information from available literature must be combined to tabulate plant species that can be grown by farmers with honey bee culture. Total 53 research articles review papers and web-references related to honey bee diversity and their pollinated plants at the International, National, and State level, from duration 1990-2020 were explored to prepare a reference library for apiculturists that can be utilized in agricultural productions. Different plants like Mango, Litchi, Citrus, Papaya, Guava, Banana, Pomegranate, Ber, Custard apple, Apple, Almonds, Eggplant, Cucumber, Onion, Mustard, Groundnut, etc. are pollinated by honey bees. The government of India and various agencies provide funds to increase apiculture, this information must reach local farmers so that they can use their land for the sweet revolution with the green revolution at the same time.

Keywords: honey bees, apiculture, pollination, agriculture, sweet revolution

Introduction
Plants and pollinators have bilateral relations which play a crucial role in the maintenance of all components of the ecosystem and prevent them from disintegration. Most of the angiosperms are pollinated by animals in different zones of the earth, animal pollinates 78% and 94% of plant proportion in the temperate and tropical zone, respectively (Ollerton *et al.*, 2011) [34]. According to Mohapatra *et al.*, (2003) [3], more than half of the total known plant species depend on insects for competent pollination. Bees (especially eusocial bees) the member of order Hymenoptera are the most common vectors worldwide for pollination as reported by Mitra and Banerjee (2007) [28]. Moreover, genus *Apis* which includes honey bees has been reported as the best pollinator due to its foraging behavior by Corlett 2004; Keng-lou James hung *et al.*, (2018) [9]. The pollination role of honey bees is used to enhance agricultural production by combining apiculture and agriculture, thus occupational beekeeping is now playing a remarkable role in crop pollination and productivity. Countries like Ethiopia and US have close relation of beekeeping and crop production, with apple crop (Bareke, Addi and Wakjira, 2018) and almond crop (Degrandi-Hoffman *et al*. 2019) [12]. Ethiopia produces approximately 43384000 kg of crude honey annually which is 23.5 % and 2.35 % of Africa and the world's honey (MoARD, 2007). The almond crop is valued at $2.2 billion and gives an estimated $21.5 billion rise to the California economy, as well as 104,000 jobs in various sectors (Sumner *et al*. 2016).
Occupational beekeeping requires less time and effort and can be done as a complementary activity with full-time agriculture, sericulture, lac culture, and animal farming. In addition, bee products, also increase crop production and quality of fruits. It requires only flowers and a little knowledge of bees and their hive management. Short training or practice can make it possible for any person who cannot do hard work due to age factors or physical disabilities. Moreover, beekeeping can utilize geographical areas where no other economic activity is possible (Nuru 2007; Guyo and Legesse 2015) [33, 17]. It is also helpful to generate awareness about nature, the relation of pollinators with plants, and the requirement of natural vegetation for honey and other products. This motivates local farmers and native populations to maintain and restore the natural ecosystem by understanding the interdependence between plants, animals, and the economy (JAICAF, 2009) [20].
Traditional agriculture occupation has the contribution of 13.9% in Indian GDP and it gives employment to 54.6% of the working population. However, the Indian agriculture sector faces various challenges like poverty, lack of advanced techniques, instruments, education, and an uncertain environment. The economic, natural, and agricultural conditions of India are suitable for combining beekeeping to increase pollination, crop quality, and quantity. Beekeeping also provides extra economic benefits by providing honey, bee wax, royal jelly, propolis, bee pollen. It is cost-effective and products like honey and beeswax we get may have high international market values (Dafar, A. 2018) [11]. Various government plans-projects, investment policies are regularly made to improve agriculture production and its share in the Indian economy (Wagh and Dongre, 2016) [49]. Considering

the importance of beekeeping as part of the country's Integrated Farming System, the government has approved an Rs. 500 crore allocations for the National Beekeeping & Honey Mission (NBHM) for three years (2020-21 to 2022-23) as a part of the Atma Nirbhar Bharat scheme. NBHM seeks to promote and develop scientific beekeeping throughout the country to achieve the goal of the 'Sweet Revolution,' which is being implemented through the National Bee Board (NBB, 2020) [31]. Therefore, in the present review available literature is explored to document honey bee diversity at various levels (global, national, and state) with be pollinated crops that can be used for a combined approach of beekeeping and horticulture-agriculture purpose.

Honey Bee Diversity

Global level: (Srinivasan, 2004; ZSI, 2020) [45] - Honey Bees belong to the family Apidae of superfamily Apoidea, which is included in order Hymenoptera of class Insecta. Apis (honeybees), Trigona and Melipona (stingless bees), and Bombus (bumblebees) are the four genera that constitute the Apidae family. A combined distribution list of documented Apis species and subspecies is given in table -1.

***National level*:** In India total of five species of honey bees were recorded with their various subspecies. Documented honey bees include (1) *Apis cerana* Fabricius, 1793 with sub species (a) *Apis cerana cerana* Fabricius (b) *Apis cerana indica* Fabricius, (2) *Apis mellifera* Linnaeus, 1758, (3) *Apis dorsata* Fabricius, 1793 with sub species (a) *Apis dorsata binghami* Cockerell (b) *Apis dorsata dorsata* Fabricius, (c) *Apis dorsata laboriosa* Smith, (4) *Apis andreniformis* Smith, 1858, (5) *Aapis florea* Fabricius, 1787 (Srinivasan, 2004**;** ZSI, 2020) [45]. Various other research surveys and documentation were done in different states of India to record and update the diversity of honey bees. A list of documented *Apis* species and subspecies is given in table -2

***Regional level*:** Rajasthan has different families of Hymenoptera order viz. Apidae, Megachilidae, Halictinae, Melittidae, Colletidae, etc., here all five honey bee species are found in a diverse geographical area. *Apis mellifera* is mostly used for the pollination of commercial crops like mustard. However, research on honey bees in Rajasthan is very limited, the available information is given in table -3.

Flora pollinated and foraged by honey bees

According to Bhalchandra, (2014) [6]; Waykar *et al.,* (2014) [51]; Baburao Waykar Babasaheb Ambedkar *et al.,* (2015) [3]; Pande and Ramkrushna, (2018) [38], honey bees are the most important pollinators as their complete colony depends on the plant for various products like wax, nectar, honeydew, etc. Plants that provide nectar to honey bees are called nectariferous bee flora; plants that provide pollen to honey bees are called polleniferous bee flora. While some plant provides both nectar and pollen to honey bees. According to Ollerton, *et al.,* (2011) [34], 87.5% of plant species are pollinated by animals and bees have a major role in it, with this 5% of plant species depends only on bees for pollination service, without complete information we cannot utilize this efficient flower visitor to enhance pollination. So, documentation of different plants and crops is required that are pollinated by bees. Different surveys were done to document crops that are used by honey bees as food and in return pollinated this during. Some important Agro-Horticulture plants are described below-

***Pollination in Mango*:** Mango has both self-pollination and cross-pollination and later increases the number of fruits in the plant. Cross-pollination is mediated by stingless bees (Trigona biroi), calliphorids (Chrysomya spp.), syrphids (Eristalis spp.), and honeybees (A. cerana and A. mellifera) (Fajardo et al., 2008) [13]. Waykar *et al.,* (2015) [3] also reported pollination by honey bees in mango during their foraging activity. Similarly, Pande and Ramkrushna, (2018) [38] found honey bees as a pollinator of mango during the preparation of the bee flora calendar in the Nagpur and Wardha districts of Maharashtra.

***Pollination in Litchi*:** Litchi flowers are not capable of self-pollination they require insects for transport of their pollen from one flower to another (Badiyala and Garg 1990; DuToit 1994) [4], honey bees are the most important pollinators documented in many studies, specifically *Apis mellifera.* (Menzel and Waite; 2005. Kumar, 2014) [27, 35]

***Pollination in Citrus*:** Different citrus plant varieties have different requirements for pollination; however, several researches suggest that an increase in fruit size and production is observed if honey bee colonies are used for pollination (Sanford, 2003) [42]. According to Waykar *et al.,* (2015) [3] *Citrullus lanatus, Citrus aurantifolia* is pollinated by honey bees when they look for nectar and pollen during forage. Similarly, Pande and Ramkrushna, (2018) [38] reported honey bees as an important pollinator of Lemon (*Citrus limon)* and Kaghzi nimboo (*Citrus aurantifolia).*

***Pollination in Papaya*:** Papaya has both self and cross-pollination, later is performed by butterflies, honey bees, wasps, and other insects or wind (Crane, 2013) [10]. Pande and Ramkrushna, (2018) [38] in Nagpur and Wardha districts of Maharashtra documented Honey bee flora and prepared bee flora calendar. They also documented honey bee as a prime pollinator of Papaya (*Carica papaya*).

***Pollination in Guava*:** Rajagopal, and Eswarappa, (2005) reported honey bee is the best pollinator for guava as it increases fruit size and grade. Different beneficial changes like increased size and a higher number of fruits are

observed when honey bees were used for guava pollination (Halder *et al.,* 2019) [18]. Pande and Ramkrushna, (2018) [38] also reported honey bees as a key pollinator of guava.

***Pollination in Banana*:** Different insects like honey bees, wasp, and stingless bees perform pollination in bananas. Honey bees are the most frequent flower visitors comprising 77.50% of total visitors (Kaushik et al., 2012). Pande and Ramkrushna, (2018) [38] also found banana as bee flora with several other plants.

***Pollination in Pomegranate*:** Pomegranate plant has two kinds of flowers (only male and bisexual), which make it capable of both self and cross-pollination. However, self-pollinated plants have the optimum size and quality 0of fruit but honey bee pollination increases fruit set and quality (Tao *et al.,* 2010) [48]. Bhalchandra, (2014) [6] recorded nectar and pollen providing bee flora at western ghat area of Nasik, Maharashtra. This during pomegranate is also documented as a honey bee-pollinated plant because it is a good source of nectar and pollen. Waykar *et al.,* (2015) [3] also found cross-pollination by honey bees in pomegranate in Paithan taluka of Aurangabad, Maharashtra during their study of the diversity of flora pollinated by bees.

***Pollination in Ber*:** Ber depends on cross-pollination for the development of fruit from the flowers. Honey bees forage on flowers for nectar and pollen and they pollinate these flowers. Pande and Ramkrushna, (2018) [38] documented *Ziziphus jujube, Ziziphus mauritiana* are pollinated by honey bees in Nagpur and Wardha districts of Maharashtra.

***Pollination in Custard* apple:** Custard apple is cross-pollinated by beetles and honey bees. According to Bhalchandra, (2014) [6]; Pande and Ramkrushna, (2018) [38], honey bees perform mentionable pollination in custard apple.

***Pollination in Apple*:** Most of the apple varieties have cross-pollination, farmers achieve the commercial demands by using the pollination service of honey bees (Sharma *et al.,* 2012) [43]. Several studies suggest that honey bees play a significant role in the pollination of apple plants. According to Wakjira and Kibebew, (2018) [50], honey bees are used for the pollination of apple plants in various countries. *Apis mellifera* is the most important pollinator among honey bees and other pollinators (Nayak *et al.,* 2020) [32].

***Pollination in Almonds*:** Almonds have cross-pollination and their most important pollinator is the honey bee which is used widely for increasing production. According to Degrandi-Hoffman *et al.,* (2019) [12] commercial beekeeping is used in the USA for high production of the Californian almond crops.

***Pollination in Eggplant*:** Flowers of eggplant are bisexual and can have self-pollination, pollens are released by the vibration of wind. However, insect pollinators also have an important role in fruit set, best weight, and length of eggplant. *Apis mellifera* is the best pollinator for this purpose (Nayak *et al.,* 2020) [32].

***Pollination in Cucumber*:** According to Mader *et al.,* (2010) [26]; Nayak *et al.,* (2020) [32] honey bees are used for pollinating cucumber crops because a high number of pollinators are present in each hive of honey bees.

***Pollination in Onion*:** Onion flowers are not capable of self-pollination because it has protandry conditions. These flowers require pollination by wind and animals. honey bee contributes 87% of pollination in onion crops, also increases onion bulb growth, size, and production of seeds (Saurabh Padamshali and S. K. Mandal 2018) [36]. Bhalchandra, (2014) [6]; Kewanit Alemberhe and Kidu Gebremeskel (2016); (Alemberhe and Gebremeskel 2016). Pande and Ramkrushna, (2018) [38] also documented that honey bees and solitary bees are important pollinators of onion crops.

***Pollination in Mustard*:** Mustard is cultivated all-over India to obtain comestible oil. This plant belongs to the Cruciferae family and has open pollination. The mustard flower has a high amount of nectar which attracts pollinators like honey bees (Mohapatra *et al.,* 2010). A different study reported that honey bees increase the yield of mustard. Field experiments of Sanas *et al.,* (2014) [41], documented more yield by open pollination and pollination by *A. cerana indica*. Bhalchandra, (2014) [6] also reported honey bee as a major pollinator of mustard in the western ghat area of Nasik, Maharashtra. According to Sima *et al.,* (2014) [44], honey bees play important role in the pollination of mustard in agricultural areas of Jhunjhunu Rajasthan. Patidar *et al.,* (2017) [39] compared an experiment on mustard variety 'BIO—902' in three different chambers to evaluate the importance of pollinator insects. One chamber was open for all pollinators, the second chamber had mustard with a beehive and the third one was without any pollinator They recorded that the chamber open for all pollinators had maximum seed production followed by the chamber with beehive where honey bees alone performed pollination during foraging and least seed production was in the chamber without any pollinator.

***Pollination in Groundnut*:** Honey bees are good pollinators of different oilseed plants grown in various states of India. Groundnut, one of the major oilseeds consumed in India is pollinated by honey bees and its production is

also increased by this renowned pollinator (Bhalchandra, 2014**;** Pande and Ramkrushna**,** 2018; TNAU 2020) [6, 38, 47].

Conclusion

Since the Indian economy dominantly depends on agriculture, we have to look forward to an intense increase in agriculture production to meet the world's economic growth. Commercial beekeeping is used in different countries for a qualitative and quantitative increases in crop production. In India beekeeping is an old tradition that is used to produce honey and bee wax, in modern times after understanding the relationship between honey bees and crop pollination, beekeeping is united with agriculture by various farmers. This relation could be used at the national level as the Indian government has approved an Rs. 500 crores for the National Beekeeping & Honey Mission (NBHM) for three years (2020-21 to 2022-23) as a part of the Atma Nirbhar Bharat scheme.

We must have documentation of honey bees found in different states of India with a list of flora that is pollinated by them, this can serve as a guidebook for combining the approach of agriculture and apiculture. This guidebook must be used by the ministry of agriculture and farmer welfare, also by the national bee board to promote this combined approach properly. Beekeeping will also help in other ways as pollinators are regularly declining due to several factors like pesticides pathogens, parasites, environmental changes, habitat fragmentation, habitat degradation, etc. We can use bees to compensate for this loss, damage control, restoration of the ecosystem. We need more work and data on 1. What flowers are preferred for visits by bees? 2. Environmental factors affecting both beekeeping and agriculture.3. Competitions between native pollinators and bees and their collective effect on crop production. 4. Performance of bees as pollinators in relation to other pollinators. 5. Clear relation between flower visit and role in pollination must be found out because most of the studies focus on visitation frequency considering it equal to pollination but pollinator importance is described as multiplication of visitation frequency with per visit effectiveness. Repeated visits damage flowers and the reproductive success of flowers decreases. so it will affect crop/ fruit production.

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Declaration of Interest

The authors declare that there is no conflict of interest.

Table 1: Global distribution of various honey bee species

***Apis* species**	**Distribution**
Apis melifera (Linnaeus 1758) European or Italian bee	
Apis melifera litorea	Tanzania, Kenya, and Mozambique
Apis melifera scutellate	East Africa
Apis melifera moniticola	Tropical Africa
Apis melifera adansonil	Senegal, Guinea, ivory coast, upper Volta, Cameroon, Nigeria, the people's republic of Congo, and Gabon
Apis melifera yementica	Yemen, omen, Saudi Arabia
Apis melifera Lamar Kim	Nile valley
Apis melifera capensis	Cape peninsula of South Africa
Apis melifera unicolor	Madagascar, Mauritius, Reunion
Apis melifera sahariensis	Algeria, Sahara South of Atlas Mountain
Apis melifera intermissa	African coast, West Mediterranean
Apis melifera ibesica	Central and South part of Africa
Apis melifera mellifera	Southwestern France to Norway
Apis melifera syriaca	Syria and Palestine
Apis melifera caucasica *Apis melifera ramies*	Caucasian mountain range Of Mediterranean
Apis melifera carnica	Balkan peninsula
Apis melifera cypria	Europe, U.S., Cyprus of Mediterranean
Apis melifera ligustica	North of the Mediterranean, various other parts
Apis melifera adami	Mediterranean area
Apis melifera sicillana	North Germany
Apis cerana (Fabricius1793) Indian hive bee	
Apis cerana creana	Afghanistan, North India, North Vietnam, China, Pakistan
Apis cerana indica	South India, Bangladesh, Indonesia, Sri Lanka, Burma,

	Malaysia, Philippines
Apis cerana japonica	Japan
Apis cerana Himalaya	Central and east Himalayan
Apis dorsata (Fabricius1793) Rock bee	
Apis dorsata berviligula	Philippines
Apis dorsata dorsata	India
Apis dorsata binghami	Celebes beyond Wallace line
Apis florea (Fabricius1787) Little bee	India, Persian Gulf, Pakistan, Sri Lanka, Thailand, Malaysia, Indonesia, Philippines
Apis andreniformis (Smith1858)	Sri Lanka, Malayan Peninsula,Thailand, Sumatra, Java, Borneo
Apis koschevnikovi (Enderlein 1906)	Malaysia, Indonesia, Borneo

Table 2: Diversity of honey bees in different states of India

Apis spp.	**Area**	**Reference**
Apis dorsata dorsata	Uttrakhand	Gupta, (2013)
Apis dorsata laboriosa		
Apis cerana indica		
Apis cerana cerana		
Apis florea,		
Apis mellifera		
Apis mellifera	Hariyana	Kumar *et al.,* (2013)
Apis dorsata	Assam	Rajkumari *et al.,* (2014)
Apis cerana		
Apis florea		
Tetragonula irridipennis		
Certain sp.		
Thyerus sp.		
Amegilla sp.		
Anthophora sp.		
Apis dorsata	Anjaneri and Dugarwadi hills of Western ghats of Nasik, Maharashtra	Bhalchandra, (2014)**,**
Apis cerana indica		
Apis florea		
Apis mellifera		
Apis dorsata	Aurangabad, Maharashtra	Bhalchandra and RK, (2016)
Apis cerana indica		
Apis florea		
Apis mellifera		
Apis mellifera	Tamil Nadu	Anbalagan, Paulraj and Ignacimuthu, (2015)
Bombus sp. (Bumble bee)	Meghalaya	Pande and Verma, (2016)
Apis cerena Himalaya (Himalayan honey bee)		
Apis florea (little honey bee) *Anthophora sp.*		
(digger bee)		
Apis dorsata	Nagpur and Wardha districts of Maharashtra	Pande and Ramkrushna, (2018)
Apis cerana indica		
Apis florea		
Apis mellifera		

Table 3: Bee diversity in Rajasthan

Apis dorsata Apis florea	**Western arid region of Rajasthan**	**Gorain *et al.*, (2012)**
Apis mellifera	Bikaner	Bhardwaj *et al.,* (2012)
Apis dorsata	Jhunjhunu	Sima *et al.,* (2014)
Apis cerana		
Apis florea,		
Apis mellifera		
Apis floraea	Government Post Graduate College, Jhalawar	Kulshrestha and Jain, (2016)
Apis dorsata		
Apis dorsata	Kota	Bishnoi and Dang, (2019)
Apis florae		

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