The Pharma Innovation Journal 2019; 8(5): 695-702

www.ThePharmaJournal.com

The Pharma Innovation

ISSN (E): 2277- 7695
ISSN (P): 2349-8242
NAAS Rating: 5.03
TPI 2019; 8(5): 695-702

www.thepharmajournal.com
Received: 09-03-2019
Accepted: 13-04-2019

Shuvadeep Halder
Research Scholar, Department of Fruit Science, Faculty of Horticulture, Bidhan Chandra Krishi Viswavidyalaya, Mohanpur, Nadia, West Bengal, India

Subham Ghosh
Research Scholar, Department of Fruit Science, Faculty of Horticulture, Bidhan Chandra Krishi Viswavidyalaya, Mohanpur, Nadia, West Bengal, India

Rajesh Khan
Research Scholar, Department of Agronomy, Faculty of Agriculture, Bidhan Chandra Krishi Viswavidyalaya, Mohanpur, Nadia, West Bengal, India

Arju Ali Khan
Research Scholar, Department of Fruit Science, Faculty of Horticulture, Bidhan Chandra Krishi Viswavidyalaya, Mohanpur, Nadia, West Bengal, India

Tamanna Perween
Research Scholar, Department of Fruit Science, Faculty of Horticulture, Bidhan Chandra Krishi Viswavidyalaya, Mohanpur, Nadia, West Bengal, India

Md. A Hasan
Professor and Head, Dept of Fruit Science, Faculty of Horticulture, Bidhan Chandra Krishi Viswavidyalaya, Mohanpur, Nadia, West Bengal, India

Correspondence
Shuvadeep Halder
Research Scholar, Department of Fruit Science, Faculty of Horticulture, Bidhan Chandra Krishi Viswavidyalaya, Mohanpur, Nadia, West Bengal, India

Role of pollination in fruit crops: A review

Shuvadeep Halder, Subham Ghosh, Rajesh Khan, Arju Ali Khan, Tamanna Perween and Md. A Hasan

Abstract
Pollination means transfer of viable pollen from mature anther to receptive stigma. Flowers are fully dependent on vector to move pollen. These vectors may be wind, water, birds, butterflies, bats and other animals that visit flowers. An abundance of pollinators sets a greater proportion of early flowers, results in an earlier and more uniform crop with higher quantity as well as quality of fruit. Insects contribute between 15% and 30% of global food production. Honey bees are primary pollinators for the majority of the world’s angiosperms, pollinating about 66% of the world's 1500 crop species, accounting for 15-30% of food production. The flower type, shape, colour, odor, nectar and structure are very important for the types of pollinators that visit them. The characteristics are considered as pollination syndromes traits and can be used to predict the type of pollinator which helps the flower in successful pollination. But there are significant gaps in the available knowledge. The information that is available is often not consistent nor is it conclusive. Much of the information available is drawn from international experience and its direct relevance and applicability to Australia circumstances may be questionable for other country. These factors would suggest that the potential use of pollination services according to the country, region and climatic condition should be practiced.

Keywords: Role of pollination, fruit crops, stigma

Introduction

Pollination means transfer of viable pollen from mature anther to receptive stigma. Flowers are fully dependent on vector to move pollen. These vectors may be wind, water, birds, butterflies, bats and other animals that visits flowers. An abundance of pollinators sets a greater proportion of early flowers, results in an earlier and more uniform crop with higher quantity as well as quality of fruit. Insects contributes between 15% and 30% of global food production (Roubik, 1995) [54]. Honey bees are primary pollinators for the majority of the world’s angiosperms, pollinating about 66% of the world's 1500 crop species, accounting for 15-30% of food production. (Ollerton *et al*., 2012) [47]. Honeybees have proved to be effective pollinators of a variety of crops including horticultural crops, oilseeds, forage crops, fibre crops and cereal crops (Rahman, 2006) [50]. Bees are the champion pollinators in fruit crop production. Beside this Butterfly, Beetles and Flies are important pollinators during day time. After sunset, Bats and Moths take over the night shift for pollination. Nocturnal flowers with pale or white flowers heavy with fragrance attract them. The flower type, shape, colour, odor, nectar and structure are very important for the types of pollinators that visits them. The characteristics are considered as pollination syndromes and can be used to predict the type of pollinator which helps the flower in successful pollination.

Pollination of mango

The degree of self-fertility and sterility in different cultivars has not been determined properly, but there is apparently some variation. Self-sterility has not, however, been identified as a major problem for percentage fruit set. Whatever the degree of self-sterility within a cultivar, there is a definite need for pollen to be transferred to the stigma by an outside agent. The evidence showed that the importance of cross-pollination between mango cultivars is not critical, at least for most cultivars, but there must be abundance pollinating insects to transfer the pollen from anthers to stigma within the cultivar to obtain satisfactory results. Bee pollination significantly increase fruit set percentage in mango.

Sturrock (1944) [68] also considered the flowers as self-fertile. It was supported by the earlier work of Popenoe (1917) [49], who stated that though mango is self-fertile, but cross-pollination helps to increase fruit set.

Table 1: Pollination syndromes traits with example

Trait	Bees	Beetles	Birds	Butterflies	Flies	Bats	Moths	Wind
Color	Bright white, yellow, blue.	White to dull white or green.	Brightly coloured. (Red, yellow, orange etc.)	Brightly coloured. (Red, yellow, orange etc.)	Pale and dull to dark brown or purple.	Dull white, green or purple.	Pale and dull red, purple, pink or white.	Dull green, brown, or colorless; petals absent or reduced.
Nectar Guides	Present	Absent	Absent	Present	Absent	Absent	Absent	Absent
Odor	Fresh, mild, pleasant.	None to strongly fruity or fetid	Odorless (birds have a poor sense of smell)	Faint but fresh	Putrid order, like rotting meat, dung, humus, sap and blood.	Very fragrant - fermenting or fruit-like odor.	Strong sweet; emitted at night.	None
Nectar	Usually present.	Moderate nectar producers.	Ample; deeply hidden.	Ample; deeply hidden.	Usually absent	Abundant; somewhat hidden.	Ample; deeply hidden.	None
Pollen	Limited; often sticky and scented	Ample	Modest	Limited	Modest in amount	Ample	Limited	Abundant; small, smooth, and not sticky
Flower Shape	Shallow; have landing platform; tubular.	Bowl-shaped	Large funnel like; cups.	In clusters and provide landing platforms.	Shallow; funnel like or complex.	Regular; bowl shaped.	Regular; tubular without a lip.	Regular: small and stigmas exerted.
Time	Day	Day	Day	Day	Day	Night	Late afternoon Night.	Both
Example	Mango, Litchi, Apple	Strawberry	Vanilla	Papaya	Mango	Banana, Guava.	Papaya.	Anola

In contrast, Singh *et al.* (1962) [62] reported that crossed flowers set fruit whereas self-pollinated ones did not, indicating a degree of self-sterility. Fraser (1927) [22] stated that fruit bud formation and pollination were the two big problems in growing mangoes and Wolfe (1962) concluded that getting fruit to set was more difficult than getting trees too Du Toit (1994) [20] found that fruit set was poor in both open-pollinated bagged inflorescences when honey bees were introduced into a South mango orchard. Singh (1989) had contrasting findings, showing that several foraging insects including the European honey bee significantly increased fruit set. Farjado *et al.* (2008) [21] studied that after the introduction of bee colonies in mango orchard, fruit set in uncaged inflorescences (41%) was significantly higher than that in caged inflorescences (0.7%). A study by Anderson *et al.* (1982) [2] in northern Australia found that large native insect species were shown to be the dominant pollinators of the mango. The pollinators, in decreasing order of efficiency, were wasps, native bees, large ants and large flies. Major pollinators included honeybees (*Apis cerana*and *Apis mellifera*) and an allodapine bee (*Brauns apishewitti)* of the Apidae and sweat bees (*Halictus* sp. and *Lassio glossum* spp.) of the Halictidae among the Hymenoptera, and *Chrysomya megacephala*, *Chrysomya pinguis*, and *Musca domestica* of the Diptera, which were considered to be the dominant species due to their frequent appearance (Sung *et al.*, 2006) [69]. Large Diptera and the native bee (*Trigona* sp.), frequently moved from one tree to another and helps in cross pollination most effectively (Anderson *et al.*, 1982) [2]. The primary pollinators were stingless bees *(Trigona biroi)*, calliphorids *(Chrysomya* spp.), syrphids *(Eristalis spp.)* and honeybees *(A. cerana* and *A. mellifera*) (Fajardo *et al.*, 2008) [21]. Singh (1988) [63] reported that major pollinating insects of mango were *Melipona* sp. and *Syrphus* sp. *Rhynchaenus mangiferae* is a pest, but it helps in pollination and to increase fruit set when its population was below the damaging level.

Pollination of litchi and longan

Self-pollination may occur in litchi; however, flowers are generally recognised as self-sterile and require insects to transport pollen from anther to stigma for fruit to set (Badiyala and Garg 1990; DuToit 1994; McGregor 1976) [6, 20, 41]. Only partial overlapping between male and female flowering occurs within a cultivar and so inter-planting of at least two different cultivars is require for satisfactory fruit set. The insect pollination increases fruit yield and quality. Several insects have been reported to visit litchi flowers including Coleoptera, Hemiptera and Lepidoptera. Honey bee has been widely recognised as the principal pollinator (McGregor 1976) [41]. Many studies have shown significant increases in yield of litchi crops as a result of honey bee pollination. Badiyala and Garg (1990) [6] introduced four honey bee colonies into a litchi orchard in India at the commencing of flowering and recorded that the fruit set is two to three times higher in inflorescences open to honey bees compared to the inflorescence bagged to restrict them. These results were supported by DuToit (1994) [20] in South Africa with a fruit set three times greater when inflorescences were open to honey bees. Pollen transfer in litchi may be by a combination of autogamous self-pollination, wind or insects, however, for commercial crops pollination by insects (in particular by the honey bee) is considered crucial to obtain a good yield (McGregor, 1976; Badiyala and Gaig, 1990; Dutoit, 1994; Menzel and Waite; 2005. Kumar, (2014) [41, 6, 20, 42, 33] reported the European honey bee *(A. mellifera*) as most effective pollinator of litchi as compared to others.

There have been few studies relating to longan flowering and subsequent pollination, although its botany is similar to the litchi (Menzel and McConchie 1998) [43]. Pollination is carried out by insects from early morning to mid-afternoon, particularly by the honey bee in litchi. Longan has been shown to be effectively pollinated by Trigona species in Queensland (Blanche *et al.* 2006) [7]. Blanche *et al.* (2006) [7] also established that pollen transfer in longan is by a combination of self-pollination and pollination by wind and bees. Both honey bees and stingless bee (Trigona spp) visited the flowers but only stingless bees were found to have a positive relationship with fruit set. In contrast around 30% increases in longan yields have been reported in Thailand as a result of honey bee pollination (DAF 2005) [15].

Litchi and longan yields are commonly unreliable, erratic and rarely approach the capacity of the tree. Fruits obtain by cross-pollination are generally heavier and yields in rows with two cultivars adjacent to each other have been shown to be 36% higher in litchi (McGregor 1976) [41]. All these studies clearly show that litchi and longan require at least one other cultivar and an abundance of insect pollinators for pollen transfer and produce a good quality yield.

Pollination in citrus

The pollination requirements for citrus are quite diverse (Sanford 2003; McGregor 1976) [56, 41], ranging from self-fertile (Valencia oranges) to almost complete self-sterile (mandarin and mandarin-hybrid complex). Pollen must be transferred to these self-sterile or partially self-sterile flowers from those of different compatible type for maximum fruit production (Sanford 2003) [56]. In others (Washington navel oranges), the plant is benefited if pollen is moved from flower to flower within the cultivar or within the species (Sanford 2003), and finally others such as lemons, have no known to be benefited from transfer of foreign pollen to the stigma (Sanford 2003; McGregor 1976) [56, 41].

The literature mentioned conflicting reports on the need for bees in some citrus varieties and therefore it is difficult to generalize regarding the responsiveness of citrus crops to honey bee pollination. Such as the variety, conditions at the site and honey bee pollination may all contribute or alternatively, have no effect in increasing yields, fruit size and seed number. Some have suggested as citrus flowers have complete or perfect flowers so they will generally pollinate themselves and produce fruit (i.e. they are self-compatible and self-fruitful). There are few special cases with tangelo and tangerines where a pollinator is required for better fruit set. Citrus trees produce an abundance of flowers. It is a natural tendency to drop its fruit, and most of the fruit set at bloom will not hold on until maturity. A good crop may be borne if only 3–7% of the flowers that are set yield mature fruit. Several studies have revealed increased fruit set and resultant production when managed honey bee colonies for pollination services (Sanford 2003) [56]. Butcher (1960) [8] discovered that honey bee foraging on Minneola tangelo increased fruit set, with optimal fruit set occurring at 60–90m from a group of honey bee colonies.

However, some growers of seedless cultivars readily discourage honey bee pollination as seedless fruits are often more sought-after, demanding higher retail prices in comparison to seeded varieties. Conflicting situations can occur when beekeepers and citrus growers (who blame the bees for causing otherwise seedless mandarins and oranges to develop pips) are operating in close proximity (McGregor 1976) [41].

It is quite next to impossible to issue pin point recommendations about citrus pollination for a wide range of reasons. There exist several citrus varieties and more are being developed all the time. Each has its own characteristic that must be addressed in order to assure adequate pollination. Recommendations for grapefruit will differ from limes which again will differ from oranges. In addition, a good many variables exist under field conditions which often do not mirror those of controlled experiments (Sanford 2003) [56].

The recordings in literature contain conflicting reports on the need for bees in some citrus varieties. It is therefore difficult to generalize. Depending on the variety and conditions at the site, honeybee pollination may increase fruit set, fruit size and seed number. Krezdom, 1970 suggested that this by no means indicates pollination is not necessary in citrus. Although cross pollination is required, use of honey bees remains the most consistent, effective and economical means of ensuring adequate yields.

Pollination in papaya

For papaya fruit to develop, pollen must be transferred from the staminate (male) flowers to the (female) flowers. The fruit may produce 1,000 or more seeds and well over 1,000 pollen grains which must be transfer to the stigma while it is receptive. Fruit with less than 300 seeds is usually not marketable, and the more seeds the larger the fruit (McGregor 1976) [41]. Papaya plants may be self-pollinating (bisexual plants) or cross pollinated by insects or wind. Pollinators include honey bees, wasps, midges, thrips, syrphid flies, and butterflies (Crane, 2013) [14]. The result of earlier research describes the pollination of papaya by insects vary as to which insects (if any) are the most important. Some have considered wind to be the primary agent for pollination while others argue a combination of wind and insect pollination is needed for optimal pollination and still others give credit to several other insects including the hummingbird moth (*Macroglos sumstellatarum*) and various species of *Trigona* and *Xylocopa* (McGregor 1976) [41]. Stingless bees also participate in papaya pollination (Heard, 1999) [26].

More recently (Garrett 1995) [24] reported that the hawk moth was the primary pollinator in Queensland orchards. Honeybees also reported to be primary pollinating agents of papaya, but conflicting evidence persists with reference to the pollinating capabilities of honey bees in papaya orchards. Westerkamp and Gottsberger (2000) [74] found that attractive nectar produced by male flowers around the rudimentary pistal is out of reach of the bees because of the long tube. Walsh *et al.* (2006) [72] highlight the importance of insects in general in the pollination of the papaya. The study was carried out with three types of netting (coarse, medium and fine mesh) for exclusion of insects to control phytoplasma diseases and the results showed that pollination was poor under netting condition, with the individual fruit weight and total harvested fruit weight reduced to around 50% compared to the control.

Pollination in guava

Honey bees were the best pollinators for increasing the fruit set and the quality of fruit was also improved (Rajagopal and Eswarappa, 2005) [51]. Twenty to forty per cent of pollination was due to honeybees. Fruit characteristics like length and girth were also significantly improved in bee pollination treatment over without bee pollination (Anonymous, 2011; Sehgal, 1961) [5, 57].

Pollination in banana

Insects which frequently visiting banana inflorescence, the honeybees (*A. cerana*, *A. mellifera* and A *dorsata*) were the dominant visitors (77.50%) followed by the wasps (*Polistes hebraeus & Vespa orientalis*) with 15.53% visitation. The remaining insect visitors comprised of other hymenoptran insects including the sting less bees (Kaushik *et al.*, 2012) [29].

Bats are also an important and effective pollinator in banana pollination.

Pollination in pomegranate

The presence of both male (unfertile) and bisexual (fertile) flowers on the pomegranate allow it to be self-pollinated as well as cross-pollinated. Several studies have shown that cross-pollination results in around about 20% increase in fruit set as well as an increase in overall fruit quality (Derin and Eti 2001) [18]. Because of its heaviness, there is very little wind dispersal of the pollen and thus insects are mostly responsible for the transport of pollen between flowers. McGregor (1976) [41] states that growers in California placed honey bee colonies in or near their fields, believing that their presence benefits pomegranate fruit production but there is little information available regarding the efficiency of honey bees in the pollination of pomegranate. Derin and Eti, 2001 [18]; Tao *et al*., in 2010 [30] stated that bee pollination could improve the fruit set and weight of pomegranate fruit significantly compared with self-pollination. The Department of Agriculture and Food in Western Australia (2005) also reported that 10% of pollination in pomegranate can be attributed to honey bees. Whilst the evidence suggests that insect pollinators including honey bees are of significant benefit in increasing the fruit set and quality of pomegranate yields, studies have shown that sizeable yields can still be obtained from self-pollination. For example, when flowers are bagged to exclude insects and cross-pollination, fruit sets of up to 45% can still be obtained (McGregor 1976) [41]. Anonymous, (2006b) [4] stated that with subsequent cross-pollination in pomegranate fruit set can increase up to 68% and additionally there is an increase in fruit quality (i.e. number of seeds per fruit, fruit size).

Pollination in sapota

Thrips are the main pollinator in sapota pollination. Mostly two spices of thrips (*Thrips hawaiiensis* and *Haplothripstenuipennis*) live on nectar, pollen grains and stigmatic exudations of sapota and do the service of pollination. Most of the geitonogamous pollinationis done by thrips (Reddy, 1989) [53].

Pollination in ber

The ber flowers are protandrous in nature so the fruit set depends on cross-pollination. The pollinators attracted by the fragrance and nectar of flower. The thick and heavy pollen of the Indian jujube is transferred from flower to flower by honeybees. Kumar (1990) [34] reported that among different insect visitors, *Apis* spp. were observed foraging on both nectar and pollen while dipteran and lepidopteran insects foraged for nectar only. Singh (1984) [61] recorded that honeybees and other hymenopteran insects on jujube *(Zizyphus mauritiana* L.) were more active on upper branches while housefly and other dipteran insects were abundant on middle and lower branches.

Pollination in anola

Anola is mostly cross-pollinated plant and wind, honeybees and gravity play important role in effective pollination. The studies showed considerable variation with respect to fruit set and retention. The use of pollinators (honey bees) and pollinizers in aonla orchards is necessary for increasing the yield and quality of fruits (Allemullah and Ram, 1990) [1].

Pollination in custard apple

In custard apple the most important pollinators are the beetles. Honeybees are also mentionable pollinators. About 10% of yield can be attributed to pollination of honeybees (Anonymous, 2006a) [3].

Pollination in fig

Every of fig plant has its own fig wasp for pollination. The species female fig wasp plays important role in pollinating certain edible figs, especially Smyrna fig (*Ficus carica*). It is critical to the fig grower, as most economically valuable figs require fertilization to ripen (Kjellberg *et al.,* 1987; Noort, 2004; Moe *et al.,* 2011) [31, 46, 44].

Pollination in dragon fruit

This fruit have lack of genetic diversity and sometimes there is absence of pollinating agents in certain production areas is reported. To overcome the problem manual cross-pollination is needed to ensure fruit set and development (Weiss, et. al., 1994; Le Bellec, 2004 and Castillo et. al., 2003) [73, 39, 9]. Manual pollination may be carried out from before anthesis of the flower (from 4:30 P.M.) to 11:00 A.M. These manual pollination helps to obtain excellent quality fruit (Le Bellec, 2004) [39]. A butterfly belonging to the Sphingideae family, of the genus Maduca (Daubresse Balayer, 1999) [16] and early morning by bees (Anon, 2017). The pollen of two flowers will be enough for around 100 pollinations with a brush. The pollen can be stored for (3 to 9) months at very low temperature (–18 °C to – 196 °C) without any risk. The quality of the fruits resulting from free pollination is significantly lower than the fruits obtained by manual cross-pollination (Le Bellec, 2004) [39].

Pollination in strawberries

The strawberry has the peculiarity of producing flowers with different potentials which allows the prediction of the chronological sequence of flowering, the number of pistils per flower and thus the relative size of the strawberries. The primary flower bears about 350 stigmas, the secondary ones about 260, and the tertiary ones about 180. Nitsch (1950, as cited in McGregor 1976) [41] stated that the weight of a strawberry is directly proportional to the number of fertilized achenes. These achenes, resulting from fertilized ovules, are large and surrounded by well-developed fleshy tissue, whereas the achenes resulting from unfertilized ovules are less voluminous and closer together (Chagnon *et al*. 1989) [11]. Strawberry flowers are hermaphroditic (having both sexes) and self-fertile and 80% of fruit production is due to abiotic factors such as gravity and wind; however, pollinating insects play an essential role in obtaining maximum fruit set as well as reducing deformities (Chagnon *et al*. 1989) [11].

Effect of insect pollination increases fruit yield and quality (Williams, 1994) [75]. Strawberry pollination was done using by *Bombus lucorum* and *A. mellifera* in greenhouses (Li Ji-Lian *et at*, 2006) [40]. Many different types of insects visit strawberry flowers, flies, beetles, thrips, butterflies and various bees; however, only the bees, especially the honey bee (*Apis mellifera* L) have been shown to be the most efficient in effectively without injuring flower parts. Bee pollination increases strawberry weight and shape and plays important role (Connor, 1975; Chagnon *et al.,* 1993; Zebrowska, 1998) [12, 10, 77]. Pollen transported by bees is important for optimal development of these first berries harvested for market. There are so many studies over a long period of time showing the benefits of incorporating honey bees to increase the fruit set and improving the quality of strawberries. Several authors in different times have shown the benefits of honey bee foraging behaviour to strawberry production even in greenhouses Petkov (1963, as cited in McGregor 1976) [41] who found that when flowers were grown without bees only 31 to 39% developed fruit, as compared with fruit developing on 55 to 60% of flowers open to bees. Flowers visited by bees and the average weight of fruit developed from flowers visited by bees was approximately two-thirds greater than isolated flowers (McGregor 1976) [41].

The results of a study conducted by Kakutani *et al.* (1993) [28] given a comparison between *Trigona minangkabau*, a Japanese native stingless bee, and *Apis mellifera*, the European honey bee, as pollinators of strawberry and the result shows that one visit of the honey bee pollinated 11% of achenes and one visit of the stingless bee pollinated 4.7% on average and that 11 visits of the honey bee or 30 visits of the stingless bee are required per flower to attain normal berries (fertilization rate, 87%). In this study, the rate of deformed berries in the stingless bee area (73%) was also higher than that of the honey bee area (51%).

Pollination in kiwifruit

The relative importance of honey bees and wind in kiwifruit. The relative importance of honey bees and wind in kiwifruit pollination is unclear, although several researchers have demonstrated the value of honey bee foraging of kiwifruit production. Vaissiere *et al.* (1996) [71] found that fruits from bee-visited flowers showed a significantly higher number of seeds compared to those from control flowers and demonstrated that honey bees are effective pollinators of kiwifruit.

A kiwifruit vine produces either male or female flowers so the planting of both male and female vines in the field for pollination is very important. Pollination of kiwi strictly depends on vectors like honey bees and wind. Kiwifruit produces no nectar and requires a high level of pollen transfer to produce a properly sized and shaped fruit. A well-pollinated kiwifruit contains 1,000–1,400 seeds. By contrast, a well-pollinated apple contains 6–7 seeds (Howpage *et al.* 2001) [27].

The vectors for pollination are not clear. So many studies showed that the value of honey bee foraging of kiwifruit production. Vaissiere *et al.* (1996) [71] found that fruits from bee-visited flowers showed a significantly higher number of seeds compared to those from control flowers and demonstrated that honey bees are effective pollinators of kiwifruit. Furthermore, Howpage *et al.* (2001) [27] found that vines that had no access to honey bees had significantly lower fruit set compared to those vines open to honey bee foraging Honey bee pollination was also found to significantly increase the mean number of fruit in higher weight classes, resulting in more marketable highly sought-after product for growers (Howpage *et al.* 2001) [27]. These results show that honey bees were responsible for higher fruit set, increased yields, and larger fruit with higher seed numbers in kiwifruit.

Evidence demonstrates that adequate pollination will help ensure adequate seed formation and reduce the incidence of deformed fruits, which in turn results in better outcomes for the grower, it has been suggested that management to ensure good pollination often may not be given sufficient attention, especially during the busy spring season (Howpage *et al.* 2001) [27].

Pollination in passion fruit

The most frequent insects visiting passion fruits are *A. mellifera* (honey bee) and *Xylo copavanpuncta* (carpenter bees). Carpenter bee is the most effective pollinator as it has large body and its body brushes along the anther and stigma while obtaining nectar (Kishore *et al.,* 2010) [30]. The richness of bee species influenced the fruit set of yellow passion fruit and such diversity of pollinators added to their frequency on flowers and seemed to maintain a much higher reproductive efficacy (Yamamoto *et al.,* 2012) [76].

Pollination in apple

Most of the apple varieties are self-incompatible. The best way to ensure a good crop in apple is to provide enough cross-pollination of two or more varieties. Flowering crabapples are becoming a popular pollination method with commercial growers. The bloom dates for crabapples must be selected to coincide with the bloom of the main cultivars. At least one pollinator is required for 2-3 mature tree or 1 row pollinator should be planted for 2 rows of main crop. In case of HDP every 6$^{th\ tree}$ should be pollinator.

Several studies suggested that for enhancing the productivity of apple fruits, pollination services through bees has a significant value (Sharma *et al.,* 2012) [60]. The impact of increased bee visits and placement of bee colonies in terms of increased fruit set and low fruit drop in apple. These observations support the earlier observations of Gupta *et al.* (1993) [25], Sharma and Gupta (2001) [58] and Sharma *et al.* (2004) [59] who have also reported low fruit drop and increased fruit set in orchards with managed pollination system.

Pollination in cherries

Except the new self-fertile types (Stella, Compact Stella) Sweet cherries require cross-pollination between two different cultivars for fruit set. Some cultivars are not compatible with each other or the blooming period may not overlap sufficiently. On the other hand, Tart or sour cherries are mostly self-fertile and do not need a pollinator for pollination. Sam, Van, Montmorency, Rainer, Stella, Compact Stella, Garden Bing etc are mainly used as pollinizer cultivar.

Pollination by honey bees shown to increase yields. Unsatisfactory crop yield from sweet cherries has been traced to insufficient or ineffective pollination (Somerville 1999) [64]. Several studies reported that increased fruit set and production when using managed honey bee colonies for pollination Services (Langridge and Goodman 1973; Somerville 1999) [38, 64]. A studying Victoria demonstrated the importance of bees as the primary agent for pollinating cherries (Somerville 1999; Langridge and Goodman 1973) [64, 38]. Trees caged from bees had a 2% fruit set, as compared to uncaged trees exposed to bees had 35.9% fruit set. The yields were1.9kg/tree for the caged trees and 35.2kg/tree for the uncaged trees which was significantly higher.

Sugar concentration is very higher (55%) in sweet cherry necter which makes the blossom very attractive to bees. For plums and cherries2-3 hives/ha is adequate to pollinate most crops properly (Somerville, 2000) [66].

Pollination in pear

The pear cultivars are either self-fruitful or partially self-fruitful or self-unfruitful. Cross pollination is considered essential for the production of good crop in pear which is achieved by planting suitable pollinizers at planting time. Beurre Hardy, Doyennu Du Commice and Flemish Beauty are selffruitful, whereas Le Conte, Magness and Winter Nellis are self-unfruitful and majority of other cultivars partially self-fruitful. In a study of self-incompatibility obtained 20-26% fruit set by self-pollination and 90-100% by cross pollination. Planting of pollinizer cultivar in every fourth position in every fourth row is adequate.

Most pear varieties are considered self-infertile and require cross-pollination (DPI.VIC 2008; Sakamoto *et al*. 2009) [19, 55]. Therefore, a transportation agent (i.e. wind, insects) is required to transfer pollen from a pollinising variety to the stigma of a fruit-bearing variety. The literature does give credit to several pollinators from the orders of hymenoptera, diptera and coleoptera; but honey bees (*Apis mellifera*) are the primary and most effective pollinators of pears (McGregor 1976) [41].

Numerous scientists support the value of honey bees in pollinating pears, some dating back as far as 1900 have been cited by McGregor (1976) [41] and they also shown that honeybees increase in yield and fruit quality(shape) of pears. Langridge and Jenkins (1975) [36] shown the role of honey bees in the pollination of 'Winter Nelis' pears in Victoria. Trees were open pollinated and caged to restrict honey bees. Results revealed that enclosing the trees in bee-proof cages caused a marked decline in fruit yields and number of seeds per fruit of pears.

Pollination in plums

Most European plums will set fruit with their own pollen but will produce better crops with pollinizers but most of the Japanese plums require pollinizer cultivars for pollination and fruit set. Beside pollinizer honeybees and wild bees are important pollinating agent which help in pollination.

However, a few cultivars may also be completely self-compatible where a full crop is set from the tree's own pollen (i.e. Italian prune) and some are also cross-incompatible (i.e. not receptive to pollen of certain other cultivars) (McGregor 1976) [41]. The most appreciated and highly demanded fruit according consumers choice are those from self-incompatible varieties that need cross-pollination, and this is usually achieved by employing honey bees for pollination (DAF 2005) [15]. Bumble bees and other insects may have mentionable influence in the pollination of plums and prunes, but the honey bee has been recognised as the primary and most effective pollinating agent since the early 1900s (McGregor 1976) [41].

A review on the pollination benefits that honey bees provide to prune and plum orchards was conducted by the Department of Agriculture and Food in Western Australia (DAF 2005) [15]. Several studies showed differences in yield of 150% in Japanese plums between open and bee-restricted plots and with French prunes, trees that were caged to restrict bees only set 1.3% fruit compared with a 3.6–21.8% fruit set with open pollination and 15–19% when trees were caged with honey bees (DAF 2005) [15].

Langridge and Goodman (1985) [37] also conclude by an experiment that the trees which were accessible to honey bees had a higher percentage of pollination rate, greater fruit weight and more fruit than the trees which were enclosed to restrict bees and other large insects.

Pollination in almonds

The need for insects to pollinate almond blossom is not a question, neither is the use of honey bees for this purpose (McGregor 1976; Somerville 2007) [41, 65]. Generally, the almond flower is self- incompatible. Therefore, there is a need for the pollen of one cultivar to be transferred to the stigma of another cultivar (Somerville 2007) [65]. Only bees that carry pollen from one cultivar to another receptive flower contribute to fruit set. Not all flowers set, thus, to obtain a maximum crop of almonds, essentially 100% of the flowers must be cross-pollinated (McGregor 1976) [41].

Repeated visits to every flower, by the populations with enough density, occur and the bees must 'shop around'; for they should not only visit many flowers on the one tree but also must visit between cultivars to obtain their loads of nectar and pollen (McGregor 1976) [41]. During flowering, fair weather with daytime temperatures above 12°C is essential to permit flight of pollinating insects with flight of honey bees maximized above 19° (Somerville 2007; McGregor 1976) [65, 41].

Honey bees are recognized as the most efficient pollinators of almond blossom by several scientists (Somerville 2007) [65] and it is shown that the fruit set and the production of almond is increased remarkably by managed honeybee pollination. With very few exceptions, cross-pollination is essential for fruit set in almonds and honey bees have been recognizes the most efficient pollinators time and time again.

Conclusions

A number of matters of significance to the pollination and apiary industries arise from work reported here. There are significant gaps in the available knowledge. The information that is available is often not consistent nor is it conclusive. Much of the information available is drawn from international experience and its direct relevance and applicability to Australia circumstances may be questionable for other country. These factors would suggest that the potential use of pollination services according to the country, region and climatic condition should be practiced.

References

1. Allemullah M, Ram S. Causes of low fruit set and heavy fruit drop in Indian gooseberry (*Emblica officinalis* Gaertn). Indian J. Hort. 2009; 47(3):270-277.
2. Anderson DL, Sedgley M, Short JRT, Allwood AJ. Insect pollination of mango in northern Australia. Australian J. Agric. Res. 1982; 33(3):541-548.
3. Anonymous. Bee pollination benefits for nut crops- West Au stralia Dept of Agriculture, 2006a. http:// archive.agric.wa.gov.au/PC_94129.html?s=1001. (Visited 30 Dec, 2018)
4. Anonymous. Grower and beekeeper guide: Avocado pollination - best practice guidelines, Avocado Industry Council Ltd., Tauranga, New Zealand, 2006b.
5. Anonymous. Annual report of AICRP on honeybees and pollinators. PC Unit, CCS HAUHisar, 2011.
6. Badiyala SD, Garg R. Studies on the pollination and fruit production by *Apis mellifera* L. in seven cultivars of litchi (*Litchi chinensis* Sonn). Indian Bee J. 1990; 52(1-4):28-30.
7. Blanche KR, Cunningham SA. Rainforest provides pollinating beetles for atemoya crops. Journal of Economic Entomology. 2006; 98:1193-1201.

8. Butcher FG. Pollinating insects of lychee blossoms. Proc. Flo SI. Hart. Soc. 1960; 70:326-328.
9. Castillo RM, Livera MM, Alicia E, Brechú F, Márquez-Guzmán J. Compatibilidad sexual entre dos tipos de Hylocereus (Cactaceae), Rev. Bio. Trop. 2003; 51:699-706.
10. Chagnon M, Gingras J, Oliveira D. Complementary Aspects of Strawberry Pollination by Honey and Indigenous Bees (Hymenoptera). J. Econ. Entomol. 1993; 86(2):416-420.
11. Chagnon M, Gingras J, Oliveira D. Effect of Honey Bee (Hymenoptera: Apidae) Visits on the Pollination Rate of Strawberries. J. Econ. Entomol. 1989; 82(5):1350-1353.
12. Connor LJ. The role of cultivar in insect pollination of strawberries. Proc. 3rd Int. Symp. Pollination, 1975, 149-154.
13. CR. Insect pollinators and floral visitors of mango (*Mangifera indica* L. cv. Carabao). The Philippine Agricultural Scientist. 2008; 91(4):372-382.
14. Crane JH. Papaya growing in the floridahome landscape-factsheetHS11. Aseries of the Horticultural Sciences Department, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida. 2013, 1-6.
15. DAF. ‘Honey bee pollination benefits for crops and orchards in Western Australia’. [Online]. Department of Agriculture and Food in Western Australia. Available, 2005. [Accessed 2009].
16. Daubresse Balayer M, Le pitahaya. Fruits Oubliés. 1999; 1:15-17.
17. DeGrandi-Hoffman G, Spivak M, Martin JH. Role of thermoregulation by nestmates on the development time of honey bee (Hymenoptera: Apidae) queens. Ann Entomol Soc Am. 1995; 86:165-172.
18. Derin K, Eti S. Determination of pollen quality, quantity and effect of cross pollination on the fruit set and quality in the pomegranate. Turkish Journal of Agriculture. 2001; 25:169-173.
19. DPI VIC. Department of Primary Industries Victoria Available, 2008. [Accessed 2009].
20. Dutoit AP. Pollination of avocados, mangoes and litchi. In: ligtings bulletin–In stitu utvir Tropieseen Subtropiese Gewasse, 1994, pp262.
21. Fajardo AC, Medina JR, Oscar Opina S, Cervancia CR. Insect pollinators and floral visitors of mango (*Mangifera indica* L. cv. Carabao). The Philippine Agricultural Scientist. 2008; 91(4):372-382.
22. Fraser S. American fruits, their propagation, cultivation, harvesting and distribution. Orange- Judd Publishing Co., Inc., New York, 1927, 829.
23. Free JB, Raw A, Williams IH. Pollination of coconut (*Cocos nucifera* L.) in Jamaica by honeybees and wasps. Applied Animal Ethology. 1975; 1(3):213-223.
24. Garrett A. The pollination biology of papaw (*Carica papaya* L.) in central Queensland. PhD Thesis, Central Queensland University, Rockhampton, 1995.
25. Gupta JK, Goyal NP, Sharma JP, Gautam DR. The effect of placement of varying number of Apis mellifera colonies on the fruit setin apple orchards having different proportions ofpollinizers. Veeresh GK, Uma Shanker R, Ganeshaiah KN. (eds.). Proceedings of the International Symposiumon Pollination in the tropics, 8-13 August 1993, Bangalore, India, 1993, 197-201.
26. Heard TA. The role of stingless bees in crop pollination. Ann. Rev. Entomol. 1999; 44:183-206.
27. Howpage D, Spooner-Hart RN, Vithanage V. Influence of honey bee (*Apis mellifera*) on kiwi fruit pollination and fruit quality under Australian conditions. New Zealand Journal of Crop and Horticultural Science. 2001; 29(1):51-59.
28. Kakutani T, Inoue T, Tezuka T, Maeta Y. Pollination of strawberry by the stingless bee, Trigona minangkabau, and the honey bee, Apis mellifera: An experimental study of fertilization efficiency. Research on population Ecology. 1993; 35(1):95-111.
29. Kaushik HD, Yadav S, Nadaf HA. Role of insect pollinators in tropical/ sub-tropical/arid fruit crops. In: Advances in bio-ecology and management of insect pollinators of crops. Centre of advanced faculty training, Department of Entomology, CCS, Haryana Agricultural University, Hisar, 2012, pp113.
30. Kishore K, Pathak KA, Shukla R, Bharali A. Studies on floral biology of passion fruit (*Passiflora* spp.). Pak. J. Bot. 2010; 42(1):21-29.
31. Kjellberg F, Gouyon PH, Ibrahim M, Raymond M, Valdeyron G. The Stability of the Symbiosis between Dioecious Figs and Their Pollinators: A Study of *Ficus carica* L. and *Blastophaga psenes* L. Evolution. 1987; 41(4):693-704.
32. Krezdorn AH. Pollination requirements of citrus. In: The Indispensable Pollinators, Ark. gr. Ext. Serv. Misc. Pub. 1970; 127:211-218.
33. Kumar R. Planned Honey Bee Pollination in Litchi (*Litchi chinensis* Sonn.)-a New Production Strategy for Enhancing Fruit Yield and Quality in India. Acta Hort. 2014; 1029:281-286.
34. Kumar S. Studies on insect pollination in ‘ber’, *Zizyphus mauritiana* Lamk. M.Sc. Thesis. Haryana Agricultural University, Hisar, 1990.
35. Langridge DF, Goodman RD. A study on pollination of sunflowers (*Helianthus annuus*). Austr. 1. Exp. Agric. Anim. Hush. 1975; 14:201-204.
36. Langridge DF, Jenkins PT. ‘A study on pollination of ‘Winter Nelis’ pears’. Australian Journal of Experimental Agriculture and Animal Husbandry. 1975; 15:105-107.
37. Langridge DF, Goodman RD. A study on pollination of oilseed rape (*Brassica campestris*). Australian Journal of Exjerimental Agriculture and Animal Husbandry. 1985, 15, 285.
38. Langridge DF, Goodman RD. A study on pollination of sunflowers (*Helianthus annuus*). Australian Journal of Experimental Agriculture and Animal Husbandty. 1973; 14:201.
39. Le Bellec F, Pollinisation et fécondationd’ Hylocereusundatuset d’H. costaricensisà l’île de la Réunion, Fruits. 2004; 59:411-422.
40. LiJi-Lian, Peng Wen-Jun, Wu Jie, An Jian-Dong, Guo Zhan- Bao, Tong Yue-Min, *et al*. Strawberry pollination by Bombus lucorum and Apis mellifera in green houses. Acta Entomologica Sinica. 2006; 49(2):342-348.
41. Mcgregor SE. Insect pollination of cultivated crop plants. USDA, Tucson, Arizona, 1976.
42. Menzel CM, Waite GK. Litchi and longan: botany, production and uses. CABI Publishing, 2005.
43. Menzel CM, McConchie CA, Lychee and longan. The New Rural Industries (K.W. Hyde, Ed.). Rural Industries Research and Development Corporation, Canberra, 1998, 288-295.

44. Moe AM, Rossi DR, Weiblen GD. Pollinator sharing in dioecious figs (Ficus: Moraceae). Biological J. Linnean Soc. 2011; 103(3):546-558.
45. Nitsch JP. Growth and morphogenesis of the strawberry as related to auxin. Am. J. Bot. 1950; 37:211-215.
46. Noort SV. How fig trees are pollinated. Veld and Flora, 2004, 13-15.
47. Ollerton J, *et al.* How many flowering plants are pollinated by animals. Oikos. 2011; 120:321-326.
48. Perween T. Thesis entitled Studies on the effect of nutrient application in vegetative and reproductive phenology of dragon fruit submitted to the Bidhan Chandra Krishi Viswavidyalaya, Mohanpur west Bengal, India, 2017, 29-44.
49. Popenoe W. The pollination of the mango. U. S. Dept. Agr., Bur. Plant Ind., Bull, 1917, 542.
50. Rahman A. Apiculture. *In:* Kumar AT. and Pradhan S. (eds.) Hanbook of Agriculture. Indian council of agricultural Research, New Delhi, 2006, 509-529.
51. Rajagopal DE, Swarappa G. Pollination potentiality of honeybees in increasing productivity of guava in Karnataka. Adv. Pollen Spore Res. 2005; 22:131-141.
52. Rana BS, Gautam DR, Goyal NP, Sharma HK. Effect of honey bee pollination on yield parameters of apple in relation to pollinizers propoprtion. Indian Bee J. 1988; 60:9-11.
53. Reddy EB. Thrips- pollination in Sapodilla (*Manilkara zapota*). Proc. Indian natn Sci Acad. 1989; 55(5):407-410.
54. Roubik DW. Pollination of cultivated plants in the tropics. FAO Agricultural Services Bulletin 118, Rome, 1995.
55. Sakamoto D, Hayama H, Ito A, Kashimura Y, Moriguchi T, Nakamura Y. ‘Spray pollination as a labor-saving pollination system in Japanese pear (*Pyrus pyrifolia* (Burm. f.) Nakai): Development of the suspension medium’. Scientia Horticulturae. 2009; 119:280-285.
56. Sanford RL, Paaby P, Luvall JC, Phillips E. Climate, geomorphology, and aquatic systems. *In* L. A. McDade, K. S. Bawa, H. A. Hespenheide, and G. S. Hartshorn [eds.], La Selva: ecology and natural history of a neotropical rain forest. University of Chicago Press, Chicago, Illinois, USA, 2003, 161-182.
57. Sehgal OP. Studies on morphology and blossom biology in guava (*Psidium guajava* L.) M.Sc. Thesis. IARI, New Delhi, 1961.
58. Sharma HK, Gupta JK. Impact of bee pollination on sustainable production in apple orchards. Pest Manag. Econ. Zool. 2001; 9:45-48.
59. Sharma HK, Gupta JK, Thakur JR. Effect of bee pollination and polliniser proportion on apple productivity. Acta Hort. 2004; 662:451-454.
60. Sharma HK, Uma Partap, Bisht K, Tewari P, Phartiyal P. Impact of honeybee pollination in enhancing the apple production in Nainttal district of Uttarakhand. Adv. Pollen Spore Res. 2012; 30:99-102.
61. Singh MP. Studies on the activity of some insect pollinators on jujube (*Zizyphus mauritiana* Lamk). Entomon. 1984; 9(3):177-180.
62. Singh RN, Majumdar PK, Sharma DK. Self-incompatibility in mango (*Mangifera indica* L.). Cur. Sci. 1962; 31(5):209.
63. Singh G. Insect pollination of mango and their role in fruit setting. Acta Hort. 1988; 231:629-632.
64. Somerville D. Honeybees (*Apis mellifera* L.) increase yields of faba beans (*Vicia faba* L.) in New South Wales while maintaining adequate protein requirements from faba bean pollen. Aust. J. Exp. Agric. 1999; 39:1001-1006.
65. Somerville D. Review of supply of honeybees for the pollination of almonds. Timber Corp, 2007.
66. Somerville D. Honey bees in cherry and plum pollination. Agnote DAI/126, State of New South Wales NSW Agriculture, 2000.
67. Stern RA, Sapir G, Shafir S, Dag A, Goldway M. The appropriate management of honey bee colonies for pollination of Rosaceae fruit trees in warm climates. Middle Eastern and Russian Journal of Plant Science and Biotechnology. 2007; 1(1):13-19.
68. Sturrock TT. Notes on the mango. Sturart Daily News, Inc., Sturart, Fla, 1944, pp122.
69. Sung HI, Ming-Ying Lin, Chin-Hsing Chang, Ann-Shiou Cheng, Wen-Shyong Chen. Pollinators and their behaviors on mango flowers in Southern Taiwan. Formosan Entomol. 2006; 26:161-170.
70. Tao De-shuang, Dong Xia, Dong Kun, Zhang Xue-wenand, Yu Yu-sheng. Study on the effects of pollination by honey-bees on pomegranate (*Punica granatum* L.). J Bee. 2010; 3:10-11.
71. Vaissiere BE, Freitas BM, Gemmill-Herren B. Protocol to Detect and Assess Pollination Deficits in Crops: A Handbook for its Use. FAO, Rome, 1996.
72. Walsh KB, Guthrie JN, White DT. Control of phytoplasma diseases of papaya in Australia using netting. Australasian Plant Pathology. 2006; 35:49-54.
73. Weiss J, Nerd A, Mizrahi Y. Flowering behaviour and pollination requirements in climbing cacti with fruit crop potential. Hort Sci. 1994; 29:1487-1492.
74. Westerkamp C, Gottsberger G. Diversity pays in crop pollination. Crop Science. 2000; 40:1209-22.
75. Williams IH. The dependence of crop production within the European Union on pollination by honey bees. Agric. Zool. Rev. 1994; 6:229-257.
76. Yamamoto M, Silva CI, Augusto SC, Barbosa AA, Oliveira PE. The role of bee diversity in pollination and fruit set of yellow passion fruit (Passiflora edulis forma flavicarpa, Passifloraceae) crop in Central Brazil. Apidologie. 2012; 43:515-526.
77. Zebrowska J. Influence of pollination modes on yield components in strawberry (*Fragaria* x *ananassa* Duch.). Plant Breed. 1998; 117:255-260.