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Pollination in the Tropics: Role of Pollinator in Guava Production

Nurul Alia Omar[1], Nur Athirah Zariman[1], A. Nurul Huda[1*]

ABSTRACT

Pollinators are the key point for successful pollination in most flowering plants where around 90% of plants depend entirely on them. Majority of the pollinating species are wild, comprising bees, certain species of flies, wasps, moths, butterflies, thrips, beetles, bats, birds and other vertebrates, and among them insect pollinators are the most crucial. Fruit crops benefit in an impressive way from insect pollination, where there is a remarkable improvement both in the productivity and the quality of self-fertilized, self- incompatible and cross-cropping crops worldwide. The pollinators are responsible for assisting these flowering plants with their reproduction. However, the crisis of the pollinator's decline (wild and managed pollinators) which could seriously disrupt pollination activities in the ecosystems has attracted the attention of the world. Despite the growing concern about the decline in pollinators worldwide, some issues remain uncertain as data are often limited and undermined. Guava, *Psidium guajava* is a marketable fruit in numerous tropical and subtropical regions around the world. There has been a growing interest in pollination studies on guava because of its great economic importance. In guava, self-pollination is evident, however, it benefits greatly from insect pollination. This article aims to provide an overview of tropical pollination and pollination problems that have occurred around the world with a focus on pollination activities in guava.

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Introduction

Pollination process is the act of pollen transfer to ensure reproduction. The meaning of pollination also includes the allocation of sustainable pollen from the mature anther to the receptive stigma, where the flowers are vector dependent to move pollen [1]. The Convention of Biological Diversity (CBD) has recognized pollination as an important component in the maintenance of biodiversity and plays a role in the ecosystems [2]. Pollinators are essential for the environment in which around the world 90% of the species of angiosperm are reliant on biotic pollination, for the reproduction and maintenance of genetic variability [3]. Pollinators show vital role in our daily lives by pollinating an estimated 35% of overall food volume [4]. Insects like bees are the most familiar

[1] Department of Plant Science, Kulliyyah of Science, International Islamic University Malaysia (IIUM), 25200 Kuantan, Pahang, Malaysia.
*Corresponding Author: A. Nurul Huda, anhuda@iium.edu.my

pollinators in the production of fruit. Apart from bees, butterflies, beetles, and flies are important pollinators during the day while bats and moths pollinate during the night [1]. Pollination success can be measured based on the percentage of fruit- and seed-set. Therefore, better quality fruit production can be assessed by studying the pollinator species and their roles in pollination activities [5].

However, the world is facing the decline in both wild and domestic pollinating insects for many reasons that could greatly disrupt pollination activities. The progress of pollination studies and their application in crop production, especially in the tropic are slow and complete study is yet to be carried out to utilize these pollinators to increase crops or horticultural productions. Nevertheless, the factors that lead to pollinator decline need to be clarified first in order to manage the issues. As for guava or goyave (*Psidium guajava* L.) from family Myrtaceae, it is native to tropical America and Mexico and well known as the "apple of tropics" [6]. Guava is now widely dispersed throughout the tropical and subtropical areas of the world where the chief producer of guava fruit is India followed by Pakistan, Mexico, Brazil and other countries such as Thailand, Egypt, Indonesia, Colombia, Sudan, Venezuela, Cuba, Bangladesh, the US, Vietnam and Malaysia [7]. Guava is a cross-pollinated crop but self-pollination also occurred [8,9]. In guava, studies showed that the distribution of cross-pollination by insects is about 35% and it is said that cross-pollination was the most common form of pollination in guava [10].

The present review aims to provide a general overview of the pollination in the tropics and the pollination issues that happened worldwide with emphasized on the pollination activities in guava. This review specifically highlights the guava pollination requirements and the diversity of possible guava pollinators which will be able to help produce better crop and increase productivity. Besides, the potential issues of pollination that occurred all over the world are discussed in order to measure the global crisis of declining pollinators. Finally, the future prospects for research on pollination in guava are analysed.

Pollination and Role of Pollinator in Crops Production

Pollination include transferring pollen to ensure fertilization and reproduction that give rise to fruits and seeds [10]. The pollen grain will germinate and pollen tube grows, developing through the supporting style to the ovary after landing on a receptive stigma [11]. Usually, angiosperms exhibit two types of pollination which are self-pollination or selfing and cross-pollination or outcrossing [12]. Self-pollination takes place within a

flower while cross-pollination occurs when pollen from one flower is passed to the stigma of another flower. The pollen cannot move by itself as it is a non-mobile spore, so it must be transported from the anther to the stigma by some vectors. The vectors include the action of abiotic forces such as water and wind, however, 80% of the flowers count on biotic forces including butterflies, bats, flies, birds, beetle and other insects [11].

Pollinators need to forage on plants or flowers to ensure fruits productions for crop productivity. Report suggested that a sufficient number of pollinators are able to increase the fruit crop productions [13]. Moreover, pollination has economic importance where more than one third of human diet resources are contributed by insect pollinators [14]. Pollinators also play a significant role in most terrestrial ecosystems and represent a fundamental ecosystem service that is mandatory for maintaining both wild plant populations and agricultural yield [15]. The effectiveness and efficiency of pollinators can be measured by the amount of pollen deposited by insects, so it is important to have access to the role of pollinators and species. Besides, pollination success can also be measured based on the percentage of fruit-set and seed-set [5]. Apart from this, plants and pollinator have mutualistic relationships where insects need food such as nectar while plants need these pollinators services for reproduction [14]. Moreover, the productivity and quality could be improved by pollinators, where good pollination activities could improve the stability of agricultural production, reducing yield variability annually, protecting the effects of climate change and changing land use. If there are not enough suitable insects to pollinate the crops that need them, then they will not yield to their full force.

It was mentioned that around 73% of global crops are based on pollination by different types of bees, 19% from flies, 6.5% from bats, 5% from beetles, 5% from wasps, 4% from moths and butterflies and 4% by birds [16]. Research found that the main groups of insects pollinating plants belong to the four largest orders namely Hymenoptera (bees, ants and wasps), Diptera (flies), Coleoptera (beetles), and Lepidoptera (butterflies and moths) [17]. Hymenoptera is a large order of insects which consists of sawflies, wasps, bees and ants. They can be found in most habitats, particularly in tropical and subtropical regions where bees are the most abundant and prosperous pollinators because they depend entirely on flowering plants as they only feed on pollen and nectar

during their lifetime [1,18]. Diptera such as male mosquitoes, pollen-feeding Sryphidae and midges also able to pollinate flowering plants [17]. Meanwhile, some beetles families such as Scarabaeidae, Elateridae and Cerambidae are known to visits flowers and could also pollinated them [19]. As for Lepidoptera, some butterflies are known to visit flowers with a variety of morphologies and colours [20]. The minority of pollinators includes the Orthoptera that feed on pollen and some Heteroptera that visit flowers for nectar as well as the insects that use the flowers as spots to attract their prey. Thrips (Thysanoptera) are found on flowers and frequently fodder on flower tissues and pollen which give more damage than good. Among pollinators, insects are vital in the production of most of the fruits and vegetables consumed and for the regeneration of many fodder crops used by livestock [21].

Bees are the native pollinators that are found abundant in tropical countries including Malaysia that pollinates local crops such as starfruits, guava, citrus, mango, watermelon, durian and coconut [22]. Recent studies reported that pollinators that visited guava flowers consisted of insects that belongs to the family Hymenoptera, Diptera and Lepidoptera [10]. Meanwhile, other researchers stated that guava visitors includes Hymenoptera, Diptera and Coleoptera [23]. Hymenopteran are said to be the most dominant pollinators in guava [10,23]. Study conducted on tropical mango orchard found that insect pollinator services contributed about 53% of total mango fruit production [24]. In addition, Hymenoptera and Diptera order are most dominant pollinators in mango orchards, although other order such as Lepidoptera and Coleoptera were recorded but they are remarkably not so much important pollinators [25]. Other than that, there are about 94% of bees that visited watermelon where out of these, 85% are honeybees and 15% wild bees [26]. In apple fruit crop, solitary bees contributed to more than 50% of pollination service in three out of four varieties (Cox, Gala and Bramley) meanwhile bumblebees contributes about 38% of services in Braeburn and less than 21% in other varieties [27]. In addition to that, honeybees contributed to around 23% to 28% of total crop while hoverflies contributes to less than 3% of pollination to all apple varieties [27]. For avocado and citrus, there are three major pollinator orders found visiting their flowers which are Hymenoptera, Lepidoptera and Diptera with visits that accounted for 42%, 33% and 25%, respectively [28].

Pollinator Issues, Status and Impact

Pollination services are expected to add billion dollars to global crop productivity and contribute greatly to dietary security. Developed countries, such as the United States, Europe, Japan and China count on natural pollinators for crop production, while less advanced regions, such as South Asia, India and Sub-Saharan Africa rely highly on natural pollinators to produce crops that provide essential nutrients [29]. Some studies have shown that number of pollinators is decreasing and eventually lead to a decrease in plant production owing to poor pollination, despite the fact that the global demand for pollination services is high at all times and is likely to grow continuously [30]. However, so far, no complete research has been done on the pollinator's overall performance. Although there are increasing concerns in this regard, data on the current status and population trends of most pollinating species worldwide remain unknown and generally is taxonomic and geographically biased [31]. Furthermore, information on pollinators in other countries outside Europe and the United States is almost inaccessible. Most of the data on the declines of pollinators globally are said to be biased because it is highly restricted to Western countries only. Besides the published evidence of pollinator declines likely to come from Western countries, there is also increasing data on the decline of pollinators in other regions such as Asia, although it is not well established. For example, some researchers have reported a decline in local bee populations such as the loss of *Apis andreniformis* in Thailand and Vietnam, *Apis koschevnikovi* in Malaysia, *Apis dorsata* in Cambodia and *Apis laboriosa* in Vietnam [32]. The pollinating species will disappear with time and the world will lose the key and irreplaceable species for ecosystems. When the pollinators disappear, there will be huge environmental influences and the number and variety of wild plants will decrease and disturb the balance of the ecosystems.

Wild and managed insects provide the pollination services that depended heavily on the number of insects and could be improved by various pollinating communities. However, with the long-term decline in species distributions, pollination services for wild crops and plants are expected to be reduced in the long term. As a society that increasingly dependent on pollinators, the decline in both wild and domestic pollinators could significantly disrupt pollination activities, as pollinators bring significant economic importance to plant production by enhancing the quality and quantity of crops [33].

Research suggested that the decline in pollinators would have an impact on three main crop categories, including edible fruit, vegetables and oilseeds [29]. In the region that is heavily dependent on pollinators for the production of crops, lack of pollinators could result in loss of nutrients such as vitamin A, folate and iron deficiencies [4]. The decline in pollinating populations could lead to a significant increase in preventable diseases associated with nutrient diets, particularly in areas that are vulnerable to nutrient deficiencies. Moroever, simultaneous decline in native and managed pollinators could also affect various ornamental plants, crops for fibers, biofuels, fodder, wood and protection plants that depend on pollinators [34]. Their pollination services are responsible for global biodiversity and the maintenance of human food supply. This pollination crisis can threaten worldwide and native food security, which can exacerbate the existence of species and the flexibility of ecosystems.

The loss of diversity and abundance of pollinators has been debated in many studies and reviewed worldwide [15,35] where there is a significant reduction in the abundance and diversity of wild bees recorded in continental Europe and Britain [36]; Asia [37]; South America [38]; North America [39]; and South Africa [40]. Other pollinators such as honeybees, hoverflies, butterflies, moths, flower-visiting wasps, birds and mammals also have been observed to decline in their diversity and abundance. Study found that the request and intake of insect-pollinated crops is increasing at a higher rate than managed bee colonies [41]. The reduction of the pollination service can lead to inadequate seed formation and reduce the quality of fruits that disrupt food supply in natural communities. This would entail a huge loss for farmers and create an economic gap.

Potential Cause of Pollinator Decline

In year 1998, the first major global conference was held in Sao Paulo, Brazil to discuss any major problems related to the decline of pollinators. This conference was attended by more than 60 pollinators experts representing different countries in the New and Old World [17]. The issues discussed were the documentation on the decline of pollinators; the reasons of the drop and restoration of pollinators; increase study on non-honeybee pollinators; conservation of pollinators and increasing awareness of pollinator services. However, to manage these issues, the factors leading to the reduction of pollinators should first be identified. The causes of the decline of pollinators continue to be widely

discussed. Globally habitat loss due to land use transformation and land management changes following agricultural intensification are the main reasons [30]. However, the reasons for pollinator declines may differ according to each region. Degradation and fragmentation of near and semi-natural habitats could alter pollinating populations and harm insect pollinators communities [42]. In addition, the rate of genetic erosion due to habitat fragmentation and degradation by reducing the genetic flux between demes would increase the probability of extinction in populations and species. Besides, the other possible reason for the decline in pollinators was the loss of significant resources, such as food, foraging ground, nesting area and reproduction because of habitat transformation, fragmentation and degradation for human demand and needs [43]. Since some wild pollinators may need habitat without disturbance to nest and search for food, they are very vulnerable to habitat fragmentation and degradation.

In most parts of the world, the intensification of agriculture appears to be an important factor in the decline of the insect populations. Increase on the use of agrochemicals, leading to possible habitat deprivation within agricultural regions [44] that results in major declines in insect biomass and diversity. The intensification of agriculture leads to misuse of pesticides particularly herbicides and insecticides that may pose as imminent threat to pollinators [15]. Pesticides and herbicides used to control pests and weeds could also cause loss of direction in bees and could have unintended direct and indirect effects on the beneficial pollinators [45]. The use of insecticides may also have killed useful pollinators by direct poisoning [46] and may lead to local changes in the diversity and abundance [47]. Moreover, fertilizers and herbicides may indirectly influence pollinators by reducing the inflorescence availability [48]. All handled or wild pollinators must be protected against excessive use of pesticides and other chemicals that may interrupt reproduction when these chemicals reduce the sources of nectar for pollinators, reduce nesting materials for bees, and destroy host plants of butterflies and moths larvae [45].

The other factor that calls for the decline of pollinators is the inception of invasive alien species including plants, pollinators, parasites and pathogens. The introduced exotic plants can thrive by evading the biological regulation of population size, by possessing or evolving phenotypic characteristics or by occupying a vacant ecological niche in the receiving ecosystem evolving phenotypic traits that confer a competitive advantage to

indigenous plant species [49]. As a result, pollinators may physiologically or behaviorally compensate for spatial and temporal variations in nutrient accessibility due to invasive alien plants, which effects are indirect, chronic and possibly not detected before or when in combination with other stress factors. For example, alien plant *Impatiens glandulifera* in Northwestern Europe increase the persistence of native bumblebees when native nectar were depleted where the alien plants with attractive flowers reduced the reliance of native bees on native plants [50]. Meanwhile, the introduction of managed pollinators for crop pollination and honey production may influence native pollinators through competition for resources. For example, the rivalry of extraterrestrial bees has transformed the behaviour and reproductive success of indigenous pollinators. The possibility is that with little competitive displacement of native pollinators, the super-generalist bee introduced becomes readily incorporated into native pollinator systems by inhabiting a distinct ecological niche [49]. The result of transcontinental transport of pollinating bees beyond their native areas leads to a higher probability of transfer of pathogens and parasites to new hosts that may cause the population of indigenous pollinators to decline. Evidence shows that transferred alien bees can also surge the risk of pathogens spreading, including the spread of *Varroa mites* which is a virus transmitter in hives that affect honeybees [45]. Climate change could also be one of the most damaging threats to pollinating biodiversity that affects the spatial-temporal dynamics of plant-pollinator relationships [51,52]. Most effects of weather on pollinators are on butterflies, although research on other pollinators is still scarce [15]. Bumblebees mainly show adaptations to colder climates due to their thick hair, which is also one of the reasons why they are so good pollinators [53]. Yet, a relationship between the climate niche and the decline in British bees where their population is declining due to closer climate change was observed [54]. The effects of climate change occur at all organizational levels, from the individual level, through the genetics of the population, movement at the species level and at community level. Estimates of the reaction of pollinators to climate change depend to a large extent on the ability of species to adapt to the warmest climate and/or to disperse and colonize new appropriate areas [53]. In addition, climate change causes incompatibility in temporal and spatial coincidence and in morphological and

physiological interdependencies of plants and pollinators that react differently, which could disrupt their interaction [15].

Pollination of Flowering Plant with Emphasize on Tropical Guava

Psidium guajava; apple of tropic

The genus *Psidium* has about 150 species [55,7] that are all trees or fruit shrubs originating in tropical and subtropical America and *Psidium guajava* is one of the most important fruits of this genus. Guava (*Psidium guajava* L.) belonging to the Myrtaceae family, originated from southern Mexico and Central America, was already widespread in the American tropics, Asia, Africa and the Pacific Islands a long time ago [56]. Guava is known as *guayabo* or *guayavo* in Spanish, *goyave* or *goyavier* in French, guyaba or goejaaba in Dutch, *guave* or *goejaba* in Surinamese, *goiaba* or *goaibeira*. in Portugese, k*uawa* in Hawai, *abas* in Guam and guava or *jambu batu* in Malaya [57]. There are a number of marketable varieties of guava worldwide and in Malaysia, the common cultivars include 'Kampuchea', 'Jambu Kapri', 'Jambu Biji', 'Putih', 'Hong Kong Pink', 'Bentong Seedless', 'Maha 65', 'Taiwan Pear' and 'Vietnamese' [7,58].

Guava fruit can weigh about 100-250 g and 5-10 cm in diameter with four or five sepals protruding at the apex. The fruit comes in various forms including spherical and ovoid and surfaces from rough to smooth. Depending on the cultivars, the unripe fruit is usually dark green colour that changes to yellow-green, light yellow and yellow with red flushing at the ripening stage. The seed cavity in the center of the fruit may be small or large with many hard or semi-hard seeds. Due to the presence of stone cells (78%), which have highly lignified cell walls, the outer mesocarp of the fruit of the guava is sandy or thick in texture while the endocarp tissue is high in parenchymatic cells and weak in the stone cells [7]. Guava is widely known as food cultivation and medicinal plant that benefits humans. Apart from being consumed due to its sweet-sour taste and pleasant aroma, guava fruit consists of high vitamins, phenolic compounds, tanins, essential oils, sesquiterpene alcohols, flavonoids and triterpenoid acids which are considered healthy. The guava plant is traditionally used in many countries as a medicinal plant for treatment of variety of diseases as all parts of the tree are considered useful to treat illnesses [59].

Pollination requirement of guava

Pollination requirements needed by guava tree is not commonly known to the public due to insufficient studies published [54]. The authors [54] focused on the pollination of guava cultivar '*paluma*' that widely cultivated in Northeastern Brazil as an important crop. The concept of pollination of the guava flowers such as the time of stigma receptivity, duration of anthesis and the type of pollination that usually occurred in guava flowers was discussed in the paper. The claimed included that the stigma becomes receptive 2 days before anthesis and during pre-anthesis that lasts for 30 hours. They also stated that when anthesis occurs, the stigma becomes receptive, and this occurred 2 to 3 hours after flower opening. Adding to that, the research stated that the maximum set of fruits occurs when the stigmas are pollinated within 2 hours after anthesis and the greatest period of susceptibility to stigma is within 1 hour of flower opening in the wild species of *Psidium* [54]. Nevertheless, for a pollinating agent to be considered effective, their foraging behaviour should favours the pollination requirements, visiting the flowers during the stigma receptivity hours and performing in a way that provides the transport of pollen from the anthers to the stigma of that flower or another flower [60].

In majority of guava cultivars studied in India, the peak opening (anthesis) is between 5.00-7.00 a.m. though anthesis starts at 4.00-10.00 a.m. while the dehiscence of anthers occurs about 15-20 minutes after anthesis [61]. Adding to that, the authors mentioned that in guava even though in the early times of the day, visits made right after the flowers opened, theoretically can lead to better pollination rates [54]. They added that the stigma is more receptive at this period and lasts for about 2 hours before starting to become unreceptive. At this moment, the flower has a pleasant aroma and releases most of the pollen, attracting many floral visitors. This account is strengthened by the fact that the morphology of guava flowers indicates a tendency towards melitofilia as they have white flowers that discharge sweet odour during the day, anthers with a lot of pollen and flowers without depth that ease the access of the pollinators [6]. Guava bears a hermaphrodite flower and can self-pollinate. However, self-pollination are unusual without the help of pollinators [62]. Besides, cross-pollination are considered as the most frequent form of pollination in guava [6].

Moreover, study showed that the distribution of cross-pollination by insects is about 35% where it is said that cross-pollination was the most common form of pollination in guava because of the two appearances/criteria [10,63]. As mentioned earlier, the first criteria include the morphology of the guava inflorescence that points to a tendency towards melitofilia. Moreover, the style is longer than filaments thus self-pollination is uncommon in guava. The second criteria include the fact that guava flowers are likely to be visited by solitary and social bees. Several studies on guava pollination mentioned that bees, especially honey bees are their major pollinators [64–66] that contribute about 25.70 to 41.30 % cross pollination [10]. The authors added that cross pollination in guava could lead to a better fruit yield, higher production of fruit mass and number of seeds.

Generally, if flowers are not fertilized early, they may fall early or insufficient pollination may lead to distorted fruits. Even auto-pollinated varieties produce more and better fruits when they are cross pollinated than when auto-pollinated [13]. The studies of pollination in guava is not widely done yet. Nevertheless, the effect of different pollination treatments on guava fruit yield was observed [67]. The authors stated that in the cross-pollination between plants of the same cultivar and between plants of different cultivars followed by free pollination gave the best results in fruit retention. At harvest, cross-pollination treatments of the same cultivar or a different cultivar also produced the highest number of fruits avenged. In guava, different types of pollination were compared and observed which showed that cross-pollination produces significantly more fruits compared to self-fertilization and restricted pollination [67]. Besides, the existence of floral visitors to promote cross-pollination favours increase in fruit production in guava[6].

The viability of pollen is crucial in plant breeding as it marked the fecundation and fertilization efficiency of the male gamete [68]. It is important to control the profitability of pollen in order to ensure possible germination and pollination. The viability of pollen can also be considered as an additional parameter when selecting genotypes in the selection of parents [69]. The most common method to tests for pollen viability is staining method as it ensures rapid results based on colour changes. Pollen viability test can also be done through *in vivo* and *in vitro* germination. Staining methods expressed the germination potential, meanwhile *in vivo* and *in vitro* show the

occurrence of germination. *In vivo* germination will stimulates natural germination and more valid than *in vitro* germination, but, it is requiring considerable time and effort [70]. Other than that, a good nectar content also important for guava production. Flower nectar can influence the type, schedule, and behaviour of pollinator visits and affect both pollen transfer and fitness [71].

In addition, guava harvest is greater in the open pollination treatment, where this could be explained by the pollinators' act, in particular insect pollinators, where several species of bees have been reported visiting guava flowers favouring cross pollination [67]. They found out that the bees *Apis mellifera, Trigona spinipes, Xylocopa frontalis, Melipona subnitida* and *Partamona cupira* are important floral visitors. Aligned with the findings, guava flowers are moderately dependent on bee pollination such as honeybees, bumble bees and wild bees [72]. Research claimed that the first insect that visited guava is the bee where, during the anthesis, it would search for pollen by attacking the petals in order to remove the obstacle and as the daytime where temperature increases, other insect pollinators may appear too. In this context, the role of insect pollinators especially bees in guava production has to be realized and enhanced to attain better yield of fruits [61]. In addition, the abundance and diversity of insect associated with guava plant were observed and they were classified as pests, predators and pollinators [64]. The authors found that the pollinators species range from 1.5% to 30.1% and consisted of 10 species in 8 families and 3 orders (Lepidoptera, Diptera and Hymenoptera) and it was suggested that among the pollinators, house fly showed the highest abundance. Studies also found 3 different insects species that visited organic and conventional guava ecosystems which includes Hymenoptera, Diptera and Lepidoptera species where Hymenoptera species was the most dominant pollinator group that accounted for maximum relative abundance of 95.85% for organic guava ecosystem and 94.42% for conventional guava ecosystem [10]. After fertilization, the flowers will develop into ripe fruits that are berries or capsules, varying in size from 2.5 to 10 cm in diameter and have 4 or 5 outstanding floral remnants at the apex. The form of the fruit may be ovoid, elongated, globose, or pear-in diameter. The surface of the fruits can be smooth or rough. The colour of the skin of some varieties can be pink, salmon, white or yellow [73]. The interior walls of the carpels are lush and variable in thickness and the seeds are incorporated into the pulp.

The fruits may have thick pulp with only a few seeds in a small central cavity, or thin flesh with numerous seeds incorporated in a large mass of pulp [7]. Moreover, most commercial varieties are diploid, while the seedless variety is triploid and crosses have been made between these two varieties to produce a variety with fewer seeds and better yield potential. The seeds are small, bony, kidney-shaped, flattened, light yellow or yellowish brown. Depending on the temperature during the development of the fruit, the days from the anthesis to the harvest may differ from approximately 120 to more than 220 days, where the variation between the different cultivars can be up to 60 days [74].

Future Prospect and Conclusion

Pollination leads to seed production and is important for breeding in many crops around the world. There is less value in improving resistance to crops and diseases if it is not accompanied by high quality, so it is necessary to give priority to the development of good fruit quality. As for guava, its demand is increasing worldwide for fresh and processing purposes, as guava fruits offer the consumers diverse of shape, skin and fresh colour and flavour. Research on the pollination of guava has been conducted over the past decades. Although pollination studies have been conducted all over the world, the available information on the pollination of guava remains limited and focuses mainly on the countries that produce higher guava crops such as India and Brazil. In addition, the use of pollinating insects is not well known in countries producing smaller guava crops. Many of the newly grown species and cultivars require or benefit from insect pollination mostly by bees such as honeybees in guava. The pollination of insects preserves the genetic diversity of plant populations and offers benefits such as increasing the quality and quantity of fruits, seed production and fertility, leading to a better vigour of the next generation. Both community and species-level studies are important for understanding current trends in plant-pollination interactions. Studies on bee pollination are widely studied, however, for non-bee pollinators are clearly underwritten. Pollinators such as butterflies, moths, wasps, flies, mammals and birds may be important for certain plant crops. More studies are required to highlight the importance of these poorly studied pollinators. There are many ways for action to help these issues include collaboration among interested biologists through the management

of habitat protection plans for several threatened species if the land stewards also able to participate along with the stakeholders. In addition, the biologists strive to conserve known areas to naturally host healthy pollinator populations.

Among temperate environments, there is a large number of studies which provides significant evidence that cross pollination between trees is essential for effective pollination and fruit plethora. With regard to guava cultivars, further study should be made of the pollination of wild guavas and native wild-type cultivars. For insect pollinators their places of origin should be investigated to better understand the pollinators that could be used for commercial orchards. Moreover, since tropical insect pollination studies are less compared to temperate countries, the pollination of insects in the tropics should focus more on the search for new effective native pollinators of crops such as guava and the use of their already known pollinators such as honeybees.

In conclusion, this review suggests that understanding pollination requirements and the impact of pollination problems on crops such as guava are fundamental to the success of pollination leading to better crop productivity. Interactions of environmental factors such as temperature, relative humidity, wind speed and their effects on crops and insect behaviour, especially in tropical climate, should also be taken into account. Many types of pollinators, habitats and regions have received little attention, which is why this review is designed to encourage researchers, farmers, horticulturalists and researchers to look more closely at the role of pollination and to identify new innovative ways to produce better crops production in the future.

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