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Review Paper

Pollination by Hymenopterans and Economic Values of Pollination Service

Habtamu Wodaj
Addis Ababa University, College of Education and Behavioral Studies, Department of Science and Mathematics Education Addis Ababa, Ethiopia
habtamuwodaj@yahoo.com

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Abstract

This review of pollination by hymenopterans and economic values of pollination service is aimed at providing summarized information about the role of hymenopterans in pollination and the attempt made to estimate the economic values of pollination service in the world. Moreover, it also provides knowhow about the current states of the pollinating agents especially the biotic once in the world. With this aim this paper tries to review research on role of hymenopterans such as honeybee, bumblebees, stingless bees, wasps and ants in pollination and the attempts made to estimate the economic values of pollination service in the world. Furthermore, researches on the current status of the pollinators will be reviewed.

Keywords: Pollination, Hymenopterans, Economic Values, Pollination Service.

Introduction

The most important phenomenon in plant life cycle is the process of reproduction. Reproduction enables plants to survive in the world. There are two types of reproduction in plants. These are sexual and asexual reproduction. One of an important event in sexual reproduction is pollination.

Pollination is the process by which pollen grains transferred from anthers of the male flower parts to the stigma of the female flower parts[1]. After the contact of the pollen grains with the stigma, pollen tube germination occurs, in which male gamete travels to ovary for fertilization of female gamete, the ovules, in order to form the seed. Pollination allows the transfer of male gametes in the pollen to female gamete in the ovary of the flowers to effect fertilization that produces new seeds and fruits[2]. This seed helps the plant to continue its life cycle. Therefore, pollination is critical phenomena to sexual reproduction in plants life cycle[1].

The process of pollination is not as simple as the definition seems. Successful completion of pollination can be complex. The flower physiology and morphology, pollinator characteristics and weather condition are some of the factors that affect the success of pollination[1, 3].

For example, the structure of the flowers (sepal, petal, stamen and pistil), their degree of self-fertility and their arrangement on the plant affects effective pollination[4,5]. Flower characteristics such as: the overall size of a flower, the depth and width of the corolla, the color, the patterns of nectar guides, the scent, the amount of nectar, composition of nectar, etc determine the type of pollinator and affect pollination[3]. For example, while birds visit red flowers with long, narrow tubes and lots of nectar, beetles usually visit wide flowers with small nectar and abundant pollen, insects attracted by dull colors, frequently greenish etc. Moreover, the nature of the plant can also affect the success of pollination. In nature, plants can be dioecious, monoecious, dichogamous, heterostylous or even hermaphrodite requiring different types of pollinating agents to affect pollination[4].

The process of pollination needs agents (pollinators) to transfer pollen from anther to stigma. Generally, there are two types of pollination methods in flowering plants: the first one is pollination that does not need the involvement of organisms which is called abiotic pollination), and the second one is pollination carried out by living things which is called biotic pollination. Around 80% of all plant pollination is mediated by animals (biotic). The remaining 20% pollinated abiotically without the involvement of organisms of which 98% is by wind and 2% by water[6]. This review focuses on the biotic agents of pollination, particularly on the group of insects called hymenopterans.

The most commonly recognized animal pollinators (biotic) are insects. Around 85% of these pollinator species are solitary insects and the rest are social insects and vertebrates[7]. Insect pollinators for both wild and cultivated crops include bees, (honey bees, bumblebees, and stingless bee); wasps; ants; butterflies; moths; beetles and vertebrates, mainly bats and birds.

Different plants rely on these different types of pollinating agents to transfer pollen in sexual reproduction. Plants show range of adaptation to prefer some of the pollinating agents while excluding the others in effecting pollination. This is

because there is a co-evolution between flowering plants and their pollinator allies over millions of years resulting in an interesting diversity of floral strategies and pollinator adaptations[2].

Most of the visitors of the blossom of a plant are to get some benefits like food, energy, nutrients, nest etc. Plants provide nectar pollen and other fluid secretions for pollinators as a source of food. Pollinators on the other hand benefit the plant by ensuring the continuity of their life through sexual reproduction with effective pollination.

Plants provide the pollinator with the appropriate clues and positive reinforcements to make pollination effective. In some plants, nectar guides and other colour patterns may help either to guide the place where nectar deposited or to make the plant more distinguishable or orient the oncoming pollinator to make the right flight pattern landing. These adaptations of flowering plants fevered some of the pollinators and not others. This resulted in positive and negative adaptation.

For example, the narrow tube or spur of *Impatiens sodenii* is adapted for butter fly pollination with long proboscis. The butterflies feed the nectar from narrow tube flower of *impatiens sodenii* resulting pollination. The long, narrow tubes or spurs found in *Impatiens sodenii* are mainly a positive adaptation to the long proboscis of their adapted visitors (butterflies). Butterflies with the long proboscis form co-adaptation for penetrating into narrow opening of the spur of to get nectar. Whereas, the spur of *Impatiens sodenii* is a negative adaptation to other insects with short proboscis. Bees cannot efficiently exploit the nectar resources of *Impatiens sodenii*, as a result, the morphological adaption of other insect with short proboscis discourage them to visit. Thus, the development of spur in *Impatiens sodenii* is a negative adaptation to insects that cannot get nectar from the deep spur. The development of various flower traits in relation to different pollinators is known as pollination syndromes.

Pollination is important in agriculture to increase productivity of crops. According to Sharma H. D. et al.[8], nearly 70% of the cultivated agricultural crops all over the world depends on insects like honeybees for pollination because of their cross-fertile characteristics. It is reported that the most common pollinators of many agricultural and horticultural crops are insects. Pollination also plays a great role in maintaining healthy and biodiversity of the environment. This is because of its importance in the reproduction of many wild plants[9].

Among insect pollinators, bees, wasps, flies, butterflies, moths and beetles are considered as an important once involved in pollinating most of crops in agricultural activity. Moreover, birds, bats, lizards and other animals are responsible for pollination in agricultural crops. Of all the pollinating insects, researchers indicated that honeybees are regarded as as the most efficient, reliable and well known 'managed' crop pollinators than any other pollinators in the world[8, 9].

Although some species of insects are generalists, most efficient, reliable and pollinate a variety of plant species (e.g. honeybee), there are also other species which have evolved a very particular obligate relationship with a specific plant (eg. fig wasps) and useful for pollination process as far as the environmental condition is good[10]. In the following parts of this paper, pollination by one group of insects, hymenopterans, will be reviewed briefly.

Pollination by Hymenopterans

Hymenopterans: Before we go to how this group of animals involved in pollination, it is better to have information about general characteristic of hymenopterans. The hymenopteras are one of the largest orders of insects and richest in species globally. According to Gaston K. J. et. al.[11] it is the third-largest order of insects and it is reported that around 300,000 species occur in the world. He added that, of these estimated number of species, more than 100 000 species have been described. It includes insects commonly known as bees, ants, wasps and sawflies.

In relation to their habitat, hymenopterans are inhabited most terrestrial environments and they play important roles in the ecosystems, notably as pollinators of flowering plants[12]. This key role of hymenopterans in pollination is related to the process of co-evolution between the flowers and the hymenopterans, resulting in better pollination and fertilization[12]. They have evolved different structures for pollination of different plant species and mechanism of mutual adaptation in different aspects. Both the plants and the hymenopterans benefit from the relationship developed through evolution. As explained by[13,] the bees obtain food from plants while providing the plants with an effective means of reproduction through the process of pollination. The plants are evolutionary adapted to insects in flowers shape, color, and scent to attract bees so as to effect pollination. The pollen and nectar serves as a reward of calories to feed the bees well. Just like that of bees, other insects have also concurrently evolved to effectively transfer pollen with the help of their hairs from flower to flower of each plant species to effect pollination.

Bees are one group of Hymenoptera with estimated number of more than twenty-five thousand species which are involved in pollination all over the world[8,10,14]. This group of insects includes bumble bees, honeybees, stingless bees and solitary bees. It is reported that bees are the most effective pollinators of natural flora and more than 70% of the world's cultivated crops[8]. Research has also indicated that domestic bees pollinate about 15 percent of the principal crops, while wild bees pollinate about 80 percent of the principal crops[15].

Generally, as indicated by Bernauer O. M., et. al.[16], bees provide fundamental pollination services to most of flowering plants in both agricultural systems and natural world. Pollination of fruits, vegetables, and forage crops in the world largely depend on bees[17]. Research has reported that approximately 90% of flowering plants require insect mediated pollination[18]. Pollination in economically important crops such as watermelon, apples, squash, pumpkins, grapefruit, tomatoes, coffee, sunflowers, and many others carried out by bees. In addition to helping human being to get food and money from economically important crops, plants pollinated by bee also help to feed the animals we eat, for instance alfalfa pollinated by bees and help to fed cattle and others[19].

In this review pollination by hymenopterans particularly bees (honey bee, bumble bee and stingless bee), wasps and ants will be presented as follow.

Pollination by Honeybee: The honey bee (Apis mellifera) is probably the most familiar and well studied social insect. It is indicated that some colonies of honey bee will contain as many as 20,000-60,000 bees, though most commercial hives are usually smaller than this number[14].

Everybody can easily understand as honeybees are well known for the production of honey. But, it is not only just for the honey they produce that honey bees are best known but also for their role in pollination. Honey bees are well studied pollinating agents of most plants. Research findings on honey bees indicated that they pollinate many various plants and are considered the best insect pollinator in the world [20].

Naturally, honeybees pollinate varieties of flowering plants and increase seed production in quantity and quality as well in both wild and cultivated plants[8]. He pointed out that both flowering plants and honeybees dependent on one other in their biology and life cycle. They have mutual adaptation for their survival. That is, honeybees obtain nectar and pollen from flowering plants and flowering plants benefit from pollination service of honeybees to maintain genetic diversity and ensure existence of the plant species in the future. Honeybees are the most important agricultural pollinator worldwide[21]. The pollination service they offer helped farmers to increase agricultural crop production both in quantity and quality globally[8]. Hence, they are the most widely used bees for crop pollination.

Honey bees are the most efficient pollinators of wild flora and cultivated crops in agricultural systems. One of the reasons is because they can be managed and relatively easy for humans to keep and move them around their agricultural area for pollination. Honey bee body parts also played a role to become efficient pollinator. The body parts of honey bee are adapted to collect pollen grains. They have body hairs, capable of working for long hours, show flower constancy, and adaptability to diverse climatic condition[22]. In honey bees, the corbicula or modified basitarsus of the hind legs which is referred as the "pollen basket" [12], holds the pollen during transport.

Another reason for honey bees to be more effective pollinators is because of the number of bees in their colony which consists of 20 to 60,000 honey bee workers[8,14]. The necessity of feeding such number of bees per hive required each bee to travel long distance daily visiting the same species of flowers in search of food allowing pollination. During all this trips, bees collect nectar and pollen from varieties of plant species and serves as food for them[21]. Nectar serves as the primary energy source for bees whereas pollen provides essential amino acids, minerals, and dietary sterols. Research indicated that honey bees routinely search for these foods in traveling a wide area of 8,000–10,000 acres in a 2-mile radius around their hive[21]. A single honey bee visits the same species of flowers during a foraging trip, and this is important for ensuring pollination of a particular plant. Because they are large in number, teams of foragers sent out for each type of blooming plant in the vicinity of their hive, so that they efficiently pollinate a wide variety of important crops and vegetables simultaneously[21,23].

Moreover, their effectiveness is also due to while individual worker bees from a single hive may visit many species of plants a day, individual foragers display flower fidelity or constancy[10,23,24]. This means that a forager honey bee begins collecting nectar or pollen from the flowers of one species of plant and continue to visit flowers of only that species for at least one foraging trip and more often for several days or until the resource is no longer producing nectar or pollen. This is the important aspects of pollination in which pollination occurs between flowers of the same species that resulted in effective fertilization.

Even though honeybee are most widely managed pollinator and pollinate varieties of both wild and cultivated plants, there are situations where honey bees are not capable of pollinating plants[25]. For instance, when the environment is cold and raining, honeybees will not travel to forage and do not pollinate. Moreover, it is reported that some crops, such as those with deep flowers (e.g. red clover) cannot be adequately pollinate by honeybees because of their short proboscis. Similarly plants like or tomatoes and potatoes that require buzz pollination cannot be pollinated by honeybees because of the reason that honey bees are unable to vibrate their wing muscles while holding a flower that cause the release of large amount of pollen[25]. Furthermore, researches on honey bees have suggested that they are less effective in greenhouse pollination[20] because of the reason that the glass ceiling is invisible to them and they cannot find their way home[24]. Honey bees are much more aggressive and also having a longer flight radius, so they prefer flowers outdoors than in green house.

Generally, honey bees are generalist and effective pollinators for both wild and cultivated plants than any other type of pollinators. They are important in increasing agricultural

productivity and maintaining biodiversity of the ecosystem in the world providing healthy environment suitable for the society to live in.

Pollination by Bumblebees: Bumblebees are social insects, with estimated number of over 200 species in the world[26]. Bumble bees obtain their food almost exclusively from flowers and are very useful as pollinators of many different plant species[14]. They are important pollinators that contribute to agricultural food production. Even though they are regarded as economically and ecologically valuable insects but they are not as honey bees for commercial crops[14,26] because of the reason that only a few crops that are found in cooler temperate areas depend on bumble bees for effective pollination[14].

During pollination, the worker bumblebees gather pollen and nectar to fulfill both their own nutritional requirements and those of the bees in the nest[27]. Just like that of honey bee, bumble bees gather nectar for carbohydrates which serves as a source of energy and gather pollen which serve as a protein source for larvae. Most species of bumblebees probably travel no more than 600-1,700 m from their colonies to collect nectar and pollen except some that can travel a few more distance from this[28,29].

The physical characteristics, behavior and the abundance of bumble bees make them exceptional contributors to plant pollination[2]. Just like that of honey bees, bumble bees are important generalist pollinators of plants. However, unlike honey bee, bumble bees display a behavior known as buzz pollination, a process known as sonication. In this type of pollination the bee vibrates her wing muscles while holding the flower with her jaws, causing the release of large amounts of pollen[10,24,25,27].

This buzz pollination behavior help bumble bees to extract numerous amounts of pollen in plants like tomato, blueberries and eggplants, in which they become around 400 times more successful pollinators than honeybees for these plant species[30,31]. Hence, growers of such plants benefit from this behavior because it leads to better fruit set than pollination by honey bees. As a result of this, a commercial bumble bee industry has emerged to benefit from buzz pollination for greenhouse tomato farmers[30,31].

In addition to buzz pollination behavior**,** bumblebees are active in a wide range of climatic conditions and for a longer season than honey bee because of their large size and dense pile[2,24]. Moreover, bumblebees will collect food in very cold environmental conditions and during raining[32]. Studies showed that bumblebees are more active in mornings and afternoons at temperatures between 10-30^{o}C and have the best performance at temperatures between 5 and 25^{o}C[20]. Generally, in a temperature between 10 and 32 °C, they are most active and can fly in light rain and can collect nectar and pollen in cold condition[2].

Moreover, bumble bees are better than honeybees in locating home when inside enclosures like for instance greenhouse[24]. As a result of buzz pollination and homing ability, bumble bees are considered as ideal pollinators for greenhouse plants like cucumbers and tomatoes. Furthermore, their high capacity of foraging in low light intensity and temperatures made bumblebees as important pollinators in the greenhouse[20].

As a result, today in the most countries, bumblebees are presented in the most greenhouse tomato[20].

When we compare bumble bee with honey bee in terms of how they are fast in pollinating plants, bumble bees are much faster than honeybees. For instance, a study on pollination of blueberry showed that a bumble bee pollinated 80 percent of their blueberry floral visits while honeybees only about 25 percent and they also deposited 34 tetrads of pollen per visit while honeybees only 13 [24]. This makes a bumble bee more efficient than a honey bee in blueberry pollination.

Generally, even though honey bees are well known pollinators and commercially important, bumblebees are also known to be important pollinators in buzz pollination and in situation like cold temperature, rain and greenhouse.

Pollination by Stingless bees: Stingless bees are a group of small- to medium-sized bees, with vestigial stings, found in tropical and many subtropical parts of the world[33]. As a result of this stingless bees are important pollinators of crops in tropical and subtropical parts of the world[34]. Stingless bees are considered as a generalist flower visitors because they visit a wide range of plant species. Just like that of bumble bees, *s*tingless bees are capable of buzz pollination[33].

Among plants grown in the tropics for food and other purposes, more than 250 species have been pollinated by stingless bees[33]. Bispo dos Santos and his colleague pointed out that, stingless bee pollinated tomatoes had better fruit set and higher fruit quality than those without pollination[35]. Moreover, they reported that, the largest number of fruits (1414 tomatoes), the heaviest and largest tomatoes, and the ones with the most seed were collected from the greenhouse with stingless bees' pollination[35]. Research indicated that some of the characteristics of stingless be that influence their ability as pollinators includes polylecty, adaptability, floral constancy, domestication, perennial colonies, large food reserves are stored in nests etc[33].

Pollination by Wasps: According to the information obtained from Wikipedia, the free encyclopedia, any types of insect in the order hymenoptera that is neither a bee nor an ant is a wasp. There are more than 20 recognized genera of wasps considered as pollinators[36]. Within these genera there are over four thousand wasp species which are involved in pollination all over the world[10]. Those many wasp species are closely associated with the inflorescence of Ficus species[37].

Pollination by wasps mainly related to Ficus species. It is reported as there are more than 750 species of Ficus species worldwide[38]. Fig trees have a distinctive inflorescence, the syconium, which is an important site for fig wasps to continue their life. This means that the flowers of fig trees are totally hidden within the fig and consists of several tiny florets covering the inside of a inner cavity. There is a mutual relationship between ficus wasps and ficus trees. This relationship between Figs and wasps represent the most extremely co-specific pollination mutualism known[41]. This obligate mutualism in terms of morphological adaptations, extreme host specificity, and life cycles have been believed that the result of co-evolution for over ninety million years[39-41].

Wasps are the only pollinators of ficus trees and in turn, ficus trees are the only place for wasps to breed in, which is a typical example of an 'obligate mutualism' relationship where one cannot survive without the other[39,40]. This means that pollination in ficus species completely dependent upon the wasp to make fertilization effective that result in production of seeds and fruits. Completion of the life cycle of wasps is also completely dependent upon the ficus tree[42,43]. All fig wasps complete growth and development within the fig inflorescence.

Fig pollinators show morphological and behavioral specializations that are associated with the host life cycle[37]. For colonizing new hosts, the female wasps have wings and eyes. They have also modified head and antennae that fit with the shape of the inflorescence opening[44] as an adaptation for pollen transport mechanisms[45]. The female head is flat and contain appendages with rows of teeth to push the inflorescence bracts covering the fig opening (or ostiole) in to the center. Pollen transport by wasps is efficient due to the presence of unique features like corbiculae on the forecoxae, pockets on the mesothorax or grooves between the abdominal segments[45].

After the female fig wasps completed their reproduction and fully grown, they emerge out of the fig and fly to search another fig tree to continue their life cycle assisting pollination. Locating a receptive fig is a difficult task and only some of them become successful[39]. After the female fig wasp locate the receptive fig, it enters in to fig cavity through a tiny bract-lined opening at the apex of the fig, called the ostiole, to get in to the florets of inflorescence. Entering through ostiole is difficult task which may result in breaking of wings and antennae of female wasp in the ostiole, but this breaking of wings and antennae luckily does not influence her pollinating or egg-laying ability of wasps[39]. However, the wasps are remarkably adapted to enter in because of they have extremely flattened and elongate head and thorax and row of teeth on her mandibular appendage. The presence of few strong teeth on her legs helped to minimize the difficulty. These teeth of the female fig wasps aid her movement through the ostiole and also prevent her falling backwards. After the female wasps enter in to the floret, they lay eggs in the ovules of some of the florets, and actively pollinate the pistillate flowers along the way[39,40,46]. After the eggs hatched in to wasp larvae, it uses the endosperm tissue in the galled ovary of the flower as a food. Development may take from three to twenty weeks depending on the season.

Some weeks later, once the wasps have reached maturity they chew their way out of the galls and the wasp offspring emerge from their galls into the syconium, just as the male flowers have matured their pollen sacs[40]. The wingless males mate with the females before chewing a hole through the fig wall to the exterior to allow the females to escape. Then, the new generation of female wasps leaves the scyonium through holes made by the males and carry pollen to receptive syconia elsewhere searching a young receptive fig to complete the cycle[40]. Before leaving the scyonium, the female wasps take pollen in two ways. The first one is by actively loading up pollen from ripe anthers of the fig into special pollen pockets. The second way of taking pollen is when they passively become covered with pollen to pollinate the other new fig[39].

There are literatures on the great synchronization between ficus species and wasps life cycles[47]. For instance, egg-laying time of wasps is closely synchronized with the receptivity of ficus flowers, and the discharge of adult wasps from the old ficus to new ficus match exactly with pollen presentation[48].

Commonly, it is thought that each fig species pollinated by a fig-specific wasp species[41]. Meaning, each wasp species usually pollinates one fig tree species associated with it. This is a relationship that a ficus tree (host) has one specific wasp pollinator in which hybridization between different species of fig trees is prevented[39]. This is considered as a ‘one-to-one rule’ in pollination[41]. Even though there are evidences that support the commonly used view that explains as figs and wasps have highly correlated, the one-to-one rule between wasp and fig tree does not always hold true[39]. One fig species may have two or more wasp pollinators and vice versa.

Whatever the relation between ficus and wasps, there are two major modes of fig pollination based on the differences in wasp behavior and morphology. These are active pollination and passive pollination[49,37]. When a wasp species remove pollen from the thoracic pockets with their forelegs, depositing it on the stigmatic surface, it is active pollination[50,51]. On the other hand, when pollen is transported on the abdomen due to lack of functional pockets or active pollination behavior it is passive pollination. However, some of them contain both passive and active pollinators and beneficial to the host plant[49].

In addition to pollinating wasps there are also fig wasps that breed in figs without pollinating the plant and have negative impacts on their hosts (fig) as well as other fig pollinators[46]. More commonly three to fifteen species of non-pollinating fig wasps are associated with each fig species in Africa[39]. Moreover, research indicated that a single ficus species can host up to 30 diverse non pollinating fig wasp species.

Some groups of the wasps that do not pollinate the plant either evolved morphological adaptations like those pollinators to enter the fig through ostiole to lay eggs, or lay eggs by inserting their ovipositor through the fig wall from the outside of the fig[39,40]. These wasps that lay eggs by inserting their ovipositor often evolved extremely long external ovipositor 'tails', based on the thickness of the fruit wall of their host fig species[39]. Within the syconium, niche space might be partitioned via different subsets of flowers or timing of oviposition as well as by larval diets[52,53].

Pollination by Ants: Ants are one group of hymenopterans that form a great group of social insects. Two castes (workers and reproductive ants-females and males) can be found in most colonies[54]. Ants are small in size and they are not specialized insects and unable to move beyond short distance between plants which in turn restricts their ability to visit different plants minimizing their role in pollination[12].

Ants are often observed visiting flowers but little attention has been given toward the purpose of their presence. Ants have different characteristics that limit their role as pollinators. As described above**,** ants are small, unspecialized, and wingless and hence move slowly into each flower to reach the place where energy rich nectar is located in short distance. Moreover, some ant species secrete chemical substance to protect themselves from bacterial and fungal infections[56]. This secretion from glands on ant bodies generally reduces pollen viability or kills a pollen grain[56]. It is also reported that this antibiotic substances inhibit pollen tube germination[55].

Due to this, research findings indicated that ants are not considered as an important pollinators, although they usually patrol flowers and pollen grains are found attach to their bodies. Different literatures discussed that ants are seldom seen playing a role of pollinators[57,58]. Hence, ants are generally considered as not possible pollinators[56].

However, even though ants are rarely considered as pollinators due to all these drawbacks, such as unable to fly and secretion of chemical substances, there are instances in which ants are pollinators[59]. Small number of plant species such as alpine nailwort (*Paronychia pulvinata*), Small's stonecrop (*Diamorpha smallii*), and Cascade knotweed (*Polygonum cascadense*) in North America have been reported as they are pollinated by ants[56]. In recent times, studies in some area of the Mediterranean mountains and arid lands of Spain and France have indicated that ants in this region act as important pollinators for plant species visited at high frequencies[59,58].

Moreover, study by Gómez[60] on the reproductive structure of Lobularia maritima (L.) Desv. (Cruciferae) showed that ants regularly visit these flowers, and he reported that ants acted as pollinators of this species. He indicated that, ants' pollination significantly increased the number of seed produced by this plant species. Furthermore, he pointed out that, even though such few studies have shown that ants played the role of pollinators of some plant species, the overall effectiveness as pollinator has been underestimated.

In addition to the drawback of ants to be important pollinators mentioned above, different reasons have been mentioned to explain the rare role of ants as pollinators in pollination. One of the reasons is the low rate of pollen transfer by ants from one plant to another[56]. This is because of ants go to plants by walking forming a line and consistently return to the same food source through that line and this may prevent movement of pollen from one plant to another encouraging self pollination[56,60]. This type of self-pollination generally increases the rates of seed abortion[58]. This could affect overall effectiveness of pollination by lowering seed production and increasing seeds with low germination ability and seedlings with high mortality.

The other reason is that their body surface is not suitable to hold pollen grain hence pollen does not adhere to the surfaces of ant bodies reducing the chance of carrying more pollen for pollination[56]. However, in addition to pollination, there are some studies as there is a mutualitic relationship between ants and plants[55]. It is reported that ant-plant mutualism can be described as ants provide defense for their host plants against herbivores and the host plants provide protection and food for ants[57].

Economic Value of Pollination Services

Pollination provides an ecosystem service that economically has both ecological and agricultural values[1]. In feeding relationship (food chain and food web), plants are producers which is the base for all organisms. Within this relationship, the ecological values of pollination are described in terms of the regulatory functions provided by an ecosystem in supporting the reproduction success of different plants which intern regulates the feeding relationship. Agricultural productivity depends on the process of pollination. However, very few attempts has been made to value such ecological and agricultural role of pollination both regionally and globally[1]. The following researches are among the attempts made to estimate the ecological and agricultural value the pollination service globally and regionally.

Costanza and his colleagues are among many researchers who attempted to provide a global value for ecological value of pollination. According to these researchers the annual value of pollination service was estimated to be US$ 120 billion for all ecosystem[61]; whereas another researcher estimated the value of pollination in global agriculture alone to be US$ 200 billion[62].

If we look at pollination value to agriculture at a global basis, research findings indicated that pollination is an important input of crop production, just like that of fertilizer, labor or pesticides[1]. The economic value of insect pollination was

estimated to be $153 billion annually during 2005 overall the global which is 9.5% of the total economic value of world agricultural output taking only crops that are used directly for human food in to consideration[63]. It is indicated that, among insects, bees are responsible for pollinating more than 75% of all crops that are used as a source of food for human being worldwide[18]. This shows that a substantial proportion of the worlds crops rely on insect pollination[25]. Of all pollinators, native pollinators in the world are considered as an important agent in pollination services which provides an estimated value of $200 billion of services worldwide[18]. The estimate to the value of the native pollinators provide in pollination service may vary from country to country. For instance, native insects' wild pollination service values, for overall United States economy alone, were estimated approximately $3 billion[13].

At regional level, for instance in USA, the value of pollination in all aspects has been reported to range from US$ 4.5 billion in the 1960s to US$18.9 billion in the late 1980s[64]. Findings also indicated that the input the US agriculture provided from pollination service was estimated to be between US$ 6 and 14 billion per year[65]. A research conducted in 2003 reported an estimated value of between $18 and $27 billion for insect-pollinated crops in the US with additional value for secondary products used to feed animals[31]. Bees are one group of insects. Even among the group of bees the cultivated honeybees and bumblebees, are a highly valued once for their pollination services. For instance, a study conducted in 2004 for estimation of the value of bumble bee pollination service in 99,000 acres of greenhouse tomato production reported that, the value of this pollination service to be approximately $15 billion[66].

Researchers estimated the agricultural value of US honey bees to be approximately 19 billion dollars. Out of this estimated value of honey bee pollination service, nearly US$ 10 billion related to the production of crops such as fruits, vegetables, nuts and the remaining US$ 9 billion mostly for the production of hay[67]. The current estimate of the value honey bee pollination service of crops put around $14 billion per year in the US[24]. Research reported that in Michigan, many fruits and vegetables such as apples, cherries, blueberries, peaches, pears, strawberries, cucumbers and squash which rank in the top 10 nationally produced crops, depend on honey bee pollination, for either fruit setting or better yield and quality[24]. The total value of these crops is estimated to be $290 million per year[24].

In the UK, researchers valued honeybee pollination at US$ 321 million annually[68]. According to these authors, the value of honey bees and bumble bees pollination service for major selected UK crops has been estimated to be £172 million for outdoor crops such as rape, beans, tree and soft fruit and £30 million for glasshouse crops like tomatoes and sweet peppers.

In Australia, a value of pollination service has been reported to be between US$ 0.5 billion to US$ 1.4 billion[1]. Gill[69] estimated the value of the service to be $156 million for Australia, while Winston and Scott[70] put the estimated value the service for Canada to be $1.2 billion. An estimate of insect pollination service in 1989 indicated at it worth $5 billion ECUs, of which 4.2 billion ECUs was ascribed to honeybees[25].

Similar attempts were made to estimate pollination service in Africa. For instance, in South Africa and in Uganda in which the annual economic value of pollination services delivered to crop production sector alone in Uganda was estimated to be worth of US$0.49 billion for a total economic value of crop production of US$1.16 billion[83,84].

Globally, the honey bee is the primarily well managed pollinator to enhance agricultural production. When compared to other bee species, the honey bee, which has been well studied and documented and is, reported that they are capable of increasing yield in 96% of animal-pollinated crops[18]. The honey bee also provides pollination services to many wild plants, but the amount they contribute is not always well supported by empirical data, and the contribution of wild pollinators might be higher than previously acknowledged[18]. Similarly, Bumble bees provide the vital ecosystem service of pollination in both natural and managed systems[71,72].

If the value of pollination, even though there is a variation, is estimated to be such huge amount of money why developing country did not use this alternative to increase their agricultural productivity? Is the issue to be addressed. In Ethiopia, I don't think that farmers and agricultural expertise are looking this alternative of pollination service in a modern, managed manner except what we get from naturally occurring pollination because I am unable to get documents on this issue. So I recommend to use this pollination service opportunities in a well scientifically managed system so as to increase our crop productivity and reduce poverty.

Current Status of Pollinators

Despite the fact that pollinators are key component of global biodiversity and important in maintenance of the global ecosystem and agriculture productivity, researchers provided evidences that shows the gradual declines in both wild and domesticated pollinators, and parallel declines in the plants that depend on them to sustain their life[74]. These evidences suggest that there is a dramatic decline of many wild pollinators in recent decade worldwide[25].

Among pollinators, bees are the most important and well studied in the world but both managed honey bees and wild, native bees have been declining around the world[74,75]. Numerous studies documented the worldwide declines in honeybees, bumble bees and other pollinators forwarding suggestions as there is a need to take necessary measures[76-78.]

Beside these worldwide documents in relation to decline in pollinators, there are also evidences that indicate the decline of

pollinators in different parts of the world. For instance, pollinating insects as a whole have faced serious declines in the last ten years in North America, matching similar global trends[79]. Particularly, there is clear evidence for severe regional declines in domestic honey bee stocks in the USA (59% loss of colonies between 1947 and 2005)[80] and Europe (25% loss of colonies in central Europe between 1985 and 2005[63]. Moreover, numerous studies from Europe have documented recent declines in many species of bumble bees[72,81]. For instance, in Belgium and the UK there are evidence of an ongoing decline in diversity [26,82].

Pollinator declines can result in loss of pollination services which have important negative ecological and economic impacts that could significantly affect the maintenance of wild plant diversity, wider ecosystem stability, crop production, food security and human welfare[73]. Pollinator loss will affect two major groups of flowering plants: wild flowering plants and cultivated crops which in turn affect human being and animals. The decline in pollinator diversity and abundance can bring with it a decline in pollination services for wild and cultivated plant populations, potentially affecting populations of animals and human beings.

Researchers have been proposed many causes for pollinator declines, and frequently suggest that a combination of several factors has reduced the pollinators' numbers. The declines were often observed in areas where anthropogenic changes in habitats have occurred, such as agricultural intensification and urbanization[71,84]. Hence, several factors have been implicated including habitat loss and fragmentation as a result of intensification of farming practices, disease, and exposure to agricultural chemicals, alien species, climate change and the interactions between them[16,25,63,73,84]. So measures should be taken to alleviate these causes of pollinator decline so as to get the benefit of pollination.

Conclusion

Pollination is a process by which pollen from male reproductive organ of a flower (anther) transferred to the female reproductive organ of a flower. Pollination occurs by different pollinating agents, biotic and abiotic. Pollination is important for the existence of biodiversity. It has both economical, agricultural and ecosystem values for human being. However, recently there is a decline in pollinators affecting the process of pollination due to different reasons. This in turn affects the global biodiversity, agricultural productivity, the ecosystem and the survival of human being. So there is a need of understanding the role of pollination and take necessary measures to increase the value of the service and reduce the decline of pollinators.

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