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A review on: Importance of pollinators in fruit and vegetable production and their collateral jeopardy from agro-chemicals

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Abstract
A pollinator is the biotic agent, animals or vector that moves pollen from anthers to stigma of a flower. Insects and other animal pollinators are vital for the production of healthy crops for food, fibers, edible oils, medicines, and other products. It is estimated that more than 1,300 types of plants are cultivated around the world for food, beverages, medicines, condiments, spices and even fabric. Out of these, almost 75% are pollinated by animals. In fact, pollinators such as bees, birds and bats affect 35 percent of the world’s crop production which increased outputs of 87 of the leading food crops worldwide and obviously within these, fruits and vegetables are the most benefited items. With highest efficacy of honeybees, approximately 100,000 different species of animals around the world act as pollinators to 250,000 plant species on the planet. But now the population of wild, native and managed pollinators is declining at an alarming rate owing to alterations in their food and nesting habitats, shrinkage in natural ecosystems, pesticide poisoning, alien species, diseases and pests, over-collecting, human activity, climate change, smuggling and trading of certain rare and endangered species. Therefore conservation of pollinators' habitats and implementation of agro-environmental practices to enhance wild plants resources and nesting sites for bees in agricultural landscapes are vitally important.

Keywords: Pollinator, fruit, vegetable, production, agro-chemicals

1. Introduction

A pollinator is the biotic agent, animals or vector which moves pollen from the anthers of a flower to the stigma of another or same flower to accomplish fertilization or 'syngamy' of the female gametes in the ovule of a flower. Pollinators play an immense role in the production of many fruits, vegetables and field crops [1] and numerous studies have valued insect pollination as an eco-system service for agricultural food production at both global [2, 3] and national level [4]. Study of the economic benefits of an important agricultural ecosystem service, such as crop pollination by insects, is fundamental for sustainable food production and farm management. Valuation allows potential consequences of continued insect pollinator decline for food production and food security. On the other hand it can illustrate how appropriate management of insect pollination services can reduce production risks and increase rewards by addressing pollination deficits within cultivated areas [5]. Honeybees are critically important for crop pollination worldwide [1] as it is assumed to contribute 80% of insect pollination [6]. Beside Bees, other insects like beetles, wasps, butterfly and moths also pollinate at a significant rate. Among mammals, bats are the principal pollinators, responsible for pollinating a large number of economically and ecologically important plants such as agave and cacti. Key pollinating birds are hummingbirds, honeyeaters, sunbirds and perching birds. Flies, ants, midges, monkeys, lemur, possum, rodents, lizards, mosquitoes, flying fox, fruit bats, snails, slugs and even a gecko as well as human also function as effective pollinators elsewhere in the world. A well-pollinated flower will contain more seeds, with an enhanced capacity to germinate, leading to bigger and better-shaped fruit. Improved pollination can also reduce the time between flowering and fruit set, reducing the risk of exposing fruit to pests, disease, bad weather, agrochemicals and saving on water [7]. Though, developed regions such as the United States, Europe, China, and Japan rely on natural pollinators for producing crops of high economic value, whereas parts of lesser developed regions such as India, South Asia, and sub-Saharan Africa depend more on natural pollinators for the production of crops that provide essential nutrients [8]. But now the population of wild, native and managed pollinators is declining at alarming rates owing to alteration in their food and nesting habitats, shrinkage in natural ecosystems (forests and grassland ecosystems), pesticide poisoning, alien species, diseases and pests, over-collecting, smuggling and trading in certain rare and endangered species, human activity, climate change etc [9]. The inorganic insecticides affect bees in one or more ways as stomach poisons, as contact materials, and as fumigants. Arsenicals (stomach poisons), pyrethrum (contact insecticide), hydrogen cyanide, para-dichlorobenzene and carbon disulfide are examples of harmful fumigants [10]. Pollinator declines could affect different parts of the world in diverse ways. Ominously, the regions most dependent on pollination for providing nutrients were also those with a high prevalence of malnutrition and poverty.

2. Co-evolution of pollinators and their basic working principle

Co-evolution occurs when organisms are linked with other organisms and gradually evolve together. Predators and prey, pollinators and plants, and parasites and hosts, all influence each other's evolution. Many plants rely on insects and birds to spread their pollen, this causes the plants to change themselves in ways that will entice these organisms to come to the plant. For an example, the constant threat of predators can cause prey species to evolve faster legs, strong shells, better camouflage, more effective poisons etc. Pollinators visit flowers for many reasons, including feeding, pollen collection, and warmth. When pollinators visit flowers, pollen rubs or drops onto their bodies (scoopa on hind tibia and scoopa on ventral abdomen of a bee). The pollen is then transferred to another flower or a different part of the same flower as the pollinator moves from one location to the next. This process is a vital stage in the life cycle of all flowering plants and is necessary to start seed and fruit production in flowers. Only fertilized plants can make fruit and seeds, and without them, the plants cannot reproduce [11, 12].

3. Role of pollinators in crop production

Insects and other animal pollinators are vital to the production of healthy crops for food, fibers, edible oils, medicines, and other products. It is estimated that more than 1,300 types of plants are grown around the world for food, beverages, medicines, condiments, spices and even fabric. Of these, about 75% are pollinated by animals. More than one of every three bites of food we eat or beverages we drink are directly because of pollinators. In fact, pollinators such as bees, birds and bats affect 35 percent of the world's crop production, increasing outputs of 87 of the leading food crops worldwide, as well as many plant-derived medicines [1]. The U.S. agricultural industry has depended heavily on the honey bee for its pollination needs. About 40 million acres were devoted to hay crops produced from bee-pollinated seeds (alfalfa, clovers, lespedezas). About 6 million acres were devoted to producing fruits, vegetables, and nuts- most of which are dependent upon insect pollination. These plants provide about 15 percent of our diet [13]. The commodities produced with the help of pollinators generate significant income for producers and those who benefit from a productive agricultural community. Pollination by bees therefore increases fruit production by 50% over that achieved by wind [14]. High yield and high quality crops are produced by the pollinators. Pollinating insects improve the yields of around three-quarters of crops. In Arabica coffee, though can set berries through self-pollination, when bee visits are allowed the berry set will almost the double [15]. Insects (butterflies, moths, bees, wasps, ants, beetles, etc.) numbering about 500 species are an important supplementary source of calories and proteins and fats in many regions of the world. Pollination is critical for food production and human livelihoods, and directly links wild ecosystems that many wild animals rely on for food and shelter with agricultural production systems. Without this service, many interconnected species inhabiting, and processes functioning within, an ecosystem would collapse. There is a relationship between hybrid vigour and pollinators. Pollinated plants produce fruit and seeds which are a major part of the diet of approximately 25 percent of bird species, as well as many mammals in US [16]. Pollinators support biodiversity, and there is a positive correlation between plant diversity and pollinator diversity. The pollinator population of an area is a great indicator of the overall health of an ecosystem. Pollinator dependent plant communities help to bind the soil, reducing erosion. With ample pollination, the grower may also be able to set his blooms before frost can damage them, set his crop before insects attack, and harvest ahead of inclement weather [13].

4. Value of pollination service

Worldwide economic value of the pollination service provided by insect pollinators, bees mainly was €153 billion in 2005 for the main crops that feed the world. This figure amounted to 9.5% of the total value of the world agricultural food production [2]. Insect-pollinated crops directly contributed $20 billion and the value of agricultural crop production due to honey bee pollination was $14.6 billion in 2000 in U.S [17]. The total economic value of insect pollination of Chinese fruits and vegetables amounted to 52.2 billion US dollars in 2008, which represented 25.5% of the total production value of the 44 crops produced in China [18]. In Ontario 3,000 registered beekeepers operate 100,000 honey bee colonies. Ontario's managed honey bees and bumble bees generate about $897 million of the roughly $6.7 billion in sales for agricultural crops grown in the province each year. This is equivalent to about 13% of the province's total annual crop value. Commercially raised bumble bees are the primary pollinator in greenhouses and the crops they help to pollinate contribute approximately $502 million to Ontario's economy each year [19]. The vulnerability ratio as described to the ratio of the economic value of insect pollination divided by the total crop production value was varied considerably among crop categories with a maximum of 39% for stimulants (coffee and cocoa are insect-pollinated), 31% for nuts and 23% for fruits [20]. Most flowers use size and color to attract pollinators and humans have placed a high value on their uniqueness, beauty, and aroma. As a result, the production of cut flowers and potted plants and use of plants for perfumes, shampoo and other cosmetics and pharmaceuticals have developed into multinational industries that rely to some degree on the services of pollinators.

Table 1: Vegetable crops dependent upon pollinators

Crops	Pollinators / Visitors
Tomato	Honey bees,Wild bees, halictid bee (*Augochloropsis ignita* Smith), bumble bees (*Examalopsis glubosa)*, wild solitary bees (*Anthophora urbana).*
Watermelon	Honey Bees, bumble Bee, and different species of bees (*Apis mellifera L., Halictus* spp. *Augochlorella gratiosa* Smith, *Agapostemon splendens* Lepeletier, *and Augochloropsis caerulea, Apis Cerana, A. Florea, Melipona* spp. and *Tigona iridipennis*)
Pumpkin and squash	Honey bee, wildbees (*Peponapsis* spp. and *Zenoglossa* spp), cucumber beetles (*Diabrotica* spp.), scarab beetles, meloid beetles, flies and moths.
Muskmelon	Honey bees, ants and thrips.
Cole crops	Honey bees, wild bees, and flies. Bees of the family Andrenidae, Megachilidae, and Nomadidae more important than honey bees in the pollination of cabbage (Bombus, psithyrus and wild bees).
Carrot	Flies and Bees. Most of the species of visitors were in the superfamily Apoidea, or the Ichneumonidae, Psammocharidae (Pompilidae), Sphecidae, and Vespidae families of the Hymenoptera, and the Bombyliidae, Sarcophagidae, Stratiomyidae, Syrphidae, and Tachinidae families of the Diptera.
Bitter gourd	Small bees
Beet	Thrips, syrphid fly, honey bees, solitary bees and hemipteran insects.
Coriander, Cucumber, Radish, Turnip/Rutabaga, Globe artichoke and Asparagas	Honey bees.
Brinjal	Bumble bees, carpenter bees and honey bees.
Lettuce	Honey bee, flies, wild bees and butterflies.
Okra	Honey bees and bumble bees.
Onion	Flies, honey bees, small syrphid flies, halictid bees and drone flies.
Peppers	Honey bees and other bees.
Parsnip	Honey bee, other bees, beetles and dung flies.
Beans	*Apisdorsata spp., A. florea, Trigona* spp. and bumble bees.
Field beans	Honey bee and short toungue bumble bee and carpenter bee.
Cowpea	Bumble bees.
Lima bean	Honey bee, bumble bee and thrips.
Scarlet runner bean	Honey bee and bumble bee.

(Thamburaj and Singh, 2001) [21]

Table 2: Fruit crops dependent upon pollinators

Crops	Pollinators / visitors	References
Mango	Honeybees (*Apis cerana* and *Apis mellifera*), allodapine bee (*Braunsapis hewitti*), sweat bees (*Halictus* sp. and *Lassioglossum* spp.), *Chrysomya megacephala, Chrysomya pinguis*, and *Musca domestica*	[22, 23]
Cashew	*A. mellifera* and *Trigona spinipes*	[24]
Guava	Honey bees	[25]
Strawberry	*Bombus lucorum* and *A. mellifera* in greenhouses	[26]
Pomegranate	Bees	[27, 28]
Avocado	The honey bees, hover flies, native bees and european honey bee (*A. mellifera*)	[29, 30]
Litchi	European honey bee (*A. mellifera*)	[31]
Banana	Honeybees (*A. cerana, A. mellifera and A. dorsata*); wasps (*Polistes haebraceous* & *Vespa orientalis*) and sting less bees	[32]
Passionfruit	*A. mellifera* (honey bee) and *Xylocopa vanpuncta* (carpenter bees)	[33]
Custard apple	Honeybees	[7]
Sapota	Thrips (*Thrips hawaiiensis* and *Haplothrips tenuipennis)*	[34]
Ber	*Apis* spp.	[35]
Apple	Bees	[36]
Cherries and plums	Honeybees	[37]
Fig	Female fig wasps	[38]

Table 3: Effectiveness of honey bee pollination in temperate fruit crops

Fruit crops	When to place honey bee colonies in crop	Number of colonies needed per acre*	Placement of Colonies	Attractiveness to honey bees	Symptoms of low pollination
Apple	After 5% bloom	1.5	Large orchards: groups of 8-16 at 200-300 yard intervals & Small orchards: groups of 4- 6 at 150 yard intervals	Medium; honey bees occasionally get nectar without pollination	Misshapen, small, early fruit drop, lower concentrations on calcium leading to a shorter storage life, lower yield
Blackberries	About 5% bloom; majority of pollination occurs in first 2 days	2.7	-	Very attractive pollen and nectar	Misshapen, lower yield
Blueberries	About 5% bloom; majority of pollination occurs in first 3 days	3		Attractive pollen and nectar, but difficult for honey bees to pollinate	Smaller berry size, slower ripening, lower yield

				due to flower shape	
Sour Cherries	One day after bloom; pollination is best immediately after the flower opens		Groups of 4-12 at ≤100 yards apart	Nectar poor attractant; pollen high attractant	Lower yield
Cranberries	Colonies do best when given time to acclimate to the bog prior to bloom.	3		Both pollen and nectar poor attractants	Low yield
Pear	0-10% bloom	1.5		Poor attractant	Misshapen, lower yield
Plum		1.3		Attractive	Misshapen, lower yield
Raspberries	10% bloom	0.8	Best if placed throughout the field	Attractive	Misshapen, lower fruit weight, lower yield
Strawberries	10% bloom	3.5		Medium	Misshapen, lower fruit weight, lower yield

*These numbers were found by averaging the recommended colony densities found in the literature [39].

5. Effect of agro-chemicals on pollinators

From pesticides 500,000 colonies were killed or damaged in the United States in 1967, of which 70,000 were in Arizona and 76,000 in California. Losses in California in 1968 were even greater- 83,000 colonies [40]. The number of commercial U.S. bee colonies had fallen from 5.9 million in the late 1940s to 2.7 million in 1995. The loss of one quarter of all managed honeybee colonies since 1990 signals one of the most severe declines in the U.S. An estimated 20 percent of all losses of honeybee colonies involve some degree of pesticide exposure [41]. Major problem confronting the beekeeping industry was bee losses due to pesticides. All indications point to an annual loss by the industry in the neighborhood of 10 percent caused by pesticides alone [20].

6. Status of different agro-chemicals used worldwide

In the U.S., neonicotinoids are currently used on about 95 percent of corn and canola crops; the majority of cotton, sorghum, and sugar beets; and about half of all soybeans, cereal grains, rice, nuts, and wine grapes, majority of fruit and vegetable crops, including apples, cherries, peaches, oranges, berries, leafy greens, tomatoes, and potatoes. Neonicotinoids are one of the leading suspected causes of colony collapse disorder, and the European Commission announced its controversial decision three months after the European Food Safety Agency concluded that the pesticides represented a “high acute risk” to honeybees and other pollinators. However, with the development of other chlorinated hydrocarbons, phosphates, and carbamates, the problem increased to an even higher intensity, severity further increased to the point of disaster for many beekeepers. In the late 1960's when usage of DDT and some other chlorinated hydrocarbons was decreased sharply by legislation as a reaction to public concern, and they were replaced in the majority of instances by the more toxic phosphates and carbamates. After the use of DDT on sweet corn was discontinued, the other materials applied on this crop caused serious damage to bees [42]. Some pesticides highly toxic to bees and birds like, aldrin, carbaryl, carbofuran, diazinon, dieldrin, endosulfan, EPN, fenthion, heptachlor, malathion, monocrotophos, parathion, phosmet, etc. In a recent field study at Cornell University in the U.S.A., it was found that monarch butterfly caterpillars eating Bt corn toxic pollen blown on to milkweed plants near Bt corn fields had suffered significant adverse effects leading to death of nearly 20 percent of the caterpillars. These chemicals and toxins can eliminate nectar sources for pollination, destroy or adversely affect larval host plants for moths and butterflies, and deplete nesting materials for bees. Pesticide exposure can impair both detoxification mechanisms and immune responses, rendering bees more susceptible to parasites. The less hazardous for pollinators were pyrethroid insecticides, the most hazardous were organophosphorus ones [43].

Table 4: Notorious impact on pollinators (mainly bees) to the applied agro-chemicals

Agro-chemicals	Effects
Insecticides	Affect bees in one or more ways as stomach poisons, as contact materials, and as fumigants. Arsenicals are typical stomach poisons, pyrethrum is a typical contact insecticide, and hydrogen cyanide, paradichlorobenzene, and carbon disulfide are examples of fumigants.
Botanicals	Sabadilla dust is sometimes used on citrus where it can create a bee poisoning problem.
Inorganics	These pesticides include arsenicals, fluorides, mercury compounds, and sulfur. The method and limited use of the mercury compounds precludes their presenting a hazard to bees. Elemental sulfur alone or when used with other insecticides in the field, presents only a slight repelling action, although fumes from burning sulfur are highly toxic to insects. In certain sections of Europe, fluoride compounds from smelters frequently cause bee damage. Whenever arsenicals are used they pose a serious threat to bees.
Organics	The chlorinated hydrocarbons, organophosphates, and carbamates vary in their toxicity to bees from relatively nonhazardous to highly hazardous, depending upon the individual material or combination of materials.
Defoliants, desiccants and herbicides	Most tests have shown this class of materials to be nonhazardous to bees, except for their removal of the food source from the plant; however, reported that paraquat, MAA, MSMA, DSMA, hexaflurate, and cacodylic acid were extremely toxic when fed to newly emerged worker honey bees at 100 and 1,000 ppm concentrations.
Fungicides	As used, the copper compounds, mercury compounds, pentachlorophenol, sulfur, and zineb have caused no trouble to bees.
Sex lures, attractants and other hormones	These usually cause no problems to bees, and their use near bees is generally welcomed.

(Morton *et al*., 1972 [44] & Hamilton *et al*., 1970 [45])

7. Future impact of declining pollinators for use of poisonous pesticide

According to FAO estimation, the decline of pollinators would have effects on main three crops categories; fruits and vegetables are especially affected with a loss of €50 billion each, followed by edible oilseed crops with €39 billion. A 100% decline in pollinator services could reduce global fruit supplies by 22.9% (19.5-26.1), vegetables by 16.3% (15.1-17.7), and nuts and seeds by 22.1% (17.7-26.4) and 71 million people in low-income countries could become newly deficient in vitamin A [4]. Pollinators' decline has a direct impact on the stability of food production and consumer prices. A decrease of fruit and vegetable availability could impact the health of consumers worldwide. The World Health Organization (WHO) has set a lower limit of 400 grams per capita per day for fruit and vegetable consumption. Some studies demonstrated that even now more than 50% of the European households fall below this recommendation. In the case of pollinator declines and increasing food prices, this situation is very likely to be worsen. Pollinator decline could affect various regions of the world in very different ways. Ominously, the regions most dependent on pollination for providing nutrients, were also those with a high prevalence of malnutrition and poverty. Vitamin A and iron deficiencies were three times more likely to occur in areas where nutrient production was most dependent upon pollinators. Vitamin A deficiency is associated with vision loss and increased mortality, whereas iron deficiencies have been linked to pregnancy complications and impaired development and risk of death in children [46]. Pollinators have a major role for the potential effects on crop production - both economically and nutritionally. Reduction in pollination service can result in improper seed set formation and also decreases the quality of the fruit which disrupt food supplies in natural communities. This would impose immense loss to the farmers and create economic discrepancy. Without bees, our produce sections in supermarkets would look bare with up to 50% less fruit and vegetables and our favorite foods, such as apples, carrots, lemons, onions, broccoli, and not to mention honey, would become a luxury of the past. The situation would be considerably altered following the complete loss of insect pollinators because world production would no longer be enough to fulfill the needs at their current levels. Net importers, like the European countries, would especially be affected. Inadequate pollination can result not only in reduced yields but also in delayed yield and a high percentage of culls or inferior fruits. Pollinator disappearance would translate into a consumer surplus loss estimated between €190 and €310 billion [2]. As an example, after 3000 years of sustainable agriculture, farmers in the Chinese province Sichuan have to use pollination sticks to pollinate apple flowers. This is one small example of a problem occurring world-wide, including Europe [47]. Biodiversity is declining, with direct and indirect effects on ecosystem functions and services that are poorly quantified. In early 2004, California almond growers realized there were looming honey bee shortages and scrambled to get sufficient hives for their crop. Over the past decade, farmers in the Himalayan region have been complaining about the decline in apple production and quality due to pollination-related problems. The general observation of farmers is that, in the past, there used to be a lot of insects such as wild bees, butterflies and moths during the apple flowering season but now they have all disappeared [48].

8. Conclusion

Declining bee population poses a threat to global agriculture. Improving the health of bees and other pollinators is a necessity. Without pollinators, much of the food we eat and the natural habitats we enjoy would not exist. Taking action now to protect pollinators and reduce the usage of toxic pesticides is a positive step for our environment and economy. In the long run, if we don't find some answers, we could lose a lot of bees. A realistic way to ensure pollinator conservation is to promote and enhance its value to society.

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