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Effect of Environmental Stresses on Honeybee Population

Yashdeep [a++*], Ayush Kumar [a++], K. Dharineesh [a++], Siddharth Sa Sonar [a++], Nikhil Chaudhary [a++], Sneha Bag [a++] and S. K. Gharde [b#]

[a] *School of Agriculture, Lovely Professional University, Jalandhar, Punjab, India.*
[b] *Department of Entomology, School of Agriculture, Lovely Professional University, Jalandhar, Punjab, India.*

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Review Article

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ABSTRACT

Honeybees are essential pollinators that play a crucial role in maintaining the global ecosystem and food security. However, in recent years, honeybee populations have been declining rapidly due to a combination of factors, including environmental stresses. Environmental stresses such as habitat loss, pesticide use, climate change, and disease are some of the major stresses that affect the survival and health of honeybee colonies. These stresses can affect honeybees in several ways, including reduced foraging efficiency, impaired immune function, decreased reproductive success, and increased susceptibility to pathogens. Habitat loss and fragmentation have a direct impact on honeybees' foraging efficiency by reducing the availability of floral resources. Pesticide use, especially neonicotinoids, has been shown to affect honeybees' immune function, navigation, and

[++] *B.Sc. Agriculture;*
[#] *Assistant Professor;*
**Corresponding author: E-mail: yashdeepraao@gmail.com;*

communication. Climate change can affect the time of flowering and alter the distribution of floral resources, which can lead to reduced foraging efficiency. Varroa mites, *Nosema*, and American foulbrood are some of the diseases that can cause significant damage to honeybee colonies. The presence of these diseases can lead to reduced reproductive success, impaired immune function, and increased mortality.

Keywords: Honey bees; abiotic factors; varroa mites; american foul brood; Nosema; environment; pesticide.

1. INTRODUCTION

Honeybees are living organisms of class Insecta under phylum Arthropoda. These are one of the most successful organisms of the world [1,2]. These creatures now inhabit in most parts of the world and are considered as beneficial social insects. The rearing of honeybees and production of honey had begun 4500 years ago by humans [3-6]. “The center of origin for all the extant species excluding *Apis mellifera* is said to be in South and Southeast Asia including Philippines” [7-9].

Honey bees are important insects that play major roles in agriculture as crop pollinators (worth more than $15 billion a year in US dollars) [10,11] and plant species that enhance biodiversity in agricultural and non-agricultural landscapes. “Since 2006, honey bee populations in the United States, Canada and some parts of Europe have suffered large annual losses. Several biotic and abiotic factors are responsible for colony health and survival (example viruses, mites, microbes, climate, management standards and exposure to agrochemicals). Understanding the most influential factors and synergistic effects on honeybee health is crucial to the development of pollinator protection and management strategies that limit bee colony loss” [12,13].

Contrary to popular belief, honeybees are not threatened anywhere on earth, are not in decline, and are listed as "Least Concern" by the International Union for Conservation of Nature (IUCN). IPBES reports that the global number of managed honey bees is increasing with a current estimate of 81 million managed hives. Despite high seasonal losses in some regions of the world, few areas are experiencing true declines and global growth is exponential. This increase is being driven by a growing human population requiring increased agricultural production and increased demand for pollination services [14,15].

While there are about 20,000 bee species [16] only eight honey bee species are recognised, among the total of 43 subspecies, even though historically seven to 11 species are recognized [17-20]: *Apis andreniformis* (Black Dwarf Honey bee); *Apis cerana* (Eastern Honey bee); *Apis dorsata* (Giant Honey bee); *Apis florea* (Red Dwarf Honey bee); *Apis koschevnikovi* (Koschevnikov's honey bee); *Apis laboriosa* (Giant Himalayan Honey bee); *Apis mellifera* (Western Honey bee); and *Apis nigrocincta* (Philippine Honey bee).

“Honey is obtained from wild bee colonies or domestic beehives. On average, a beehive produces about 29 kilograms of honey per year”. (NHB, 2018) “In 2020, world honey production was 1.8 million tonnes, led by China with 26% of world production. Other important producers were Turkey, Iran, Argentina and Ukraine” [21-24].

Currently, about 12,699 beekeepers and 19.34 million honey bee colonies are registered with the National Bee Board and India produces about 1,33,200 tonnes of honey (2021-22 second preliminary estimate). India is one of the top honey exporting countries in the world and has exported 74,413 tons of honey worth Rs. 1221.17 million in 2021-22. More than 50% of Indian honey production is exported to other countries. India exports honey to around 83 countries. The main markets for Indian honey are USA, Saudi Arabia, UAE, Bangladesh, Canada, etc. some of the main honeys exported from India. A total of 102 projects supporting Rs.133.31 crore sanctioned to date by National Beekeeping and Honey Mission (NBHM) (Ministry of Agriculture and Farmers Welfare, 2022).

“The most commonly collected products from beekeeping are: honey, pollen, beeswax, propolis, royal jelly, poison, conditioned bees and queens. Bee products are traditional medicines with a long-established use in primary selfsupport" [25-27]. "Historically, the nutritional and medicinal values of bee products in complementary and alternative diets have been documented for thousands of years by the ancient Egyptians, Persians, Romans and Chinese" [28-31]. "Bee products are often sold as dietary supplements and/or health products in modern life" [32-35]

"*Apis mellifera* colonies declining in numbers is mainly the result of multiple simultaneous environmental pressures in which parasites, pathogens and pests play an important role" [36-40]. "Compared to *A. mellifera*, research on the health of other bee species has taken a back seat, despite their importance to economic and social systems around the world" [41-44].

Bees naturally suffer from a variety of parasites, parasitoids and pathogens, the latter including protozoa, fungi, bacteria and viruses. By far the majority of research has focused on those related to honeybees and what not to a lesser extent with bumblebees, about which very little is known pathogens of other wild bee species. Some Bee Diseases such as Deformed Wing Virus (DWV) and *Nosema ceranae*, have a wide host range and can infect both honey and honey bees and bumblebees, while others, such as *Crithidia bombi*, or *Paenibacillus larvae*, appear to be more host specific.

The most controversial cause of bee deaths is pesticides. Pesticides offer clear economic benefits when used appropriately, but put bee welfare in direct conflict with industrial agriculture. Herbicides are very effective at minimizing weed problems in most cropping systems, allowing farmers to grow almost pure monocultures, but their use inevitably reduces the availability of flowers to pollinators and can contribute significantly to weed conversion. Understandably, more attention has been paid to the direct toxic effects of pesticides on bees, particularly the effects of insecticides. 161 different pesticides have been detected in honey bee colonies and based on their toxicity, abundance in hives, and detected concentrations, Sánchez-Bayo and Goka predict that three neonicotinoids (thiamethoxam, imidacloprid, and clothianidin) and the organophosphate phosmet and chlorpyrifos pose the greatest risk to honey bees worldwide.It is clear that bees are frequently chronically exposed to pesticide cocktails during their development and adult life, but the effects of this are not well understood and are not explored through regulatory risk assessment processes.

Bees adapt their behavior to the weather conditions. They don't come out when it rains, and when it's very hot they collect water to keep the colony cool. The survival need of these bees is a water supply, which they use in large quantities to rear their larvae and regulate the incubation temperature between 34°C and 35°C.

Climate change may alter the plant flowering and pollinator flight periods. Phenological mismatches are likely to contribute to pollinator losses that subsequently disrupt crop pollination. Weather is a key factor that determines temperature and humidity. The humidity in the hives should be kept as low as possible, while the brood temperature should be kept at 34°C, and in winter the internal temperature of the hive should not drop below 13°C. Access of carbohydrate is very crucial in this temperature to survive. Prolonged periods of cold or wet weather or the depletion of food sources can also have a negative impact on the health of the honey bee colony. These can restrict flight activity and limit the supply of nectar and pollen to the hive. If the incubation temperature rises above 34.5 °C in contrast to the low temperature, the bees show behavioral differences associated with learning and memory difficulties.

The impact of climate on bee colonies as an important factor in Colony Collapsing Disorders (CCD) was reported in a study on honey bee colony losses in the United States. CCD is linked to alterations in bee habitats and malnutrition, which are indirectly caused by climate change. Additionally, climate change may allow invasive species to invade beehives, leading to disruption and further declines in bee populations.

The declining rate of honey bee population is a critical issue faced globally today. As a result, it is seen that the pollination rate has also decreased and the overall honey production declines. So, in this paper there is a small review on the biotic and abiotic stresses which are responsible for the depleting rate of honey bee population.

2. EFFECT OF ABIOTIC STRESS ON HONEYBEE POPULATION

2.1 Effect of Temperature

Bee development, survival, range, and abundance are all directly affected by temperature [45], which is also serves as the key predictor of pollinator activity [46]. Different species' activity patterns are anticipated to be changed differently by climate warming (Radar *et al*., 2013). The average temperature within a honeybee colony is 34.5 ± 1.5°C [47-50]. Honey bee brood is likely to be exposed to overheating when the temperature exceeds 36 °C on an individual basis. Even under typical colony conditions in adults, the induction of a heat shock protein is stimulated to better withstand any passive effects (Severson *et al*., 1990). Although never consistent, air temperatures measured close to the brood combs are always within a range of 33-36°C. Collective management of brood temperature is a crucial component of honeybee behaviour. By introducing water inside the hive and evaporating it through wing fanning, high temperatures outside the hive are offset. Individual bees' thoracic muscles produce heat, which is then passed to the brood, to make up for the low temperature inside the hive. Compared to eggs or larvae, pupae in sealed cells are especially susceptible to low temperatures [51] (Groh *et al*., 2006). According to Li *et al*., 2016 and Petz *et al*., 2004 worker brood had more precisely controlled temperatures than drone brood. Because of the considerable temperature dependence of the brood development, the bees must maintain the brood nest worm to ensure appropriate development. However, weak colonies or colonies that are constantly under the stress of high or low temperatures may struggle with this task and frequently die. Compared to bees grown at 34.5 or 36°C, those raised at 32°C were unable to perform a dance (Tautz *et al*., 2003). The adult brain can also be affected by brood temperature. Honey bee pupae were raised by Jones et al. [52] at temperatures between 31 and 37 °C. He discovered that adult workers' short-term learning and memory abilities were negatively impacted by rearing temperatures (other than the ideal) due to modest brain abnormalities.

2.2 Effect of Pesticides

“Pesticides are poisonous substances having a particular mode of action, which means they are created to particularly control a target population of organisms by obstructing specific metabolic processes. Bee pollinators are clearly at risk due to the high volume and frequency of chemical residues reported in crop plant pollen and nectar. The hazards associated with thiamethoxam and lindane residues in honey, which primarily impact nectar foragers and subsequently the larvae, are extremely significant” (Francisco *et al.,* 2016). “Daily consumption of nectar or honey contaminated with these compounds at the average residue levels found worldwide would cause nectar forager mortalities of 50% or above within 3 days for lindane or one week for thiamethoxam. When applied to agricultural crops, the insecticides fipronil, thiamethoxam, bifenthrin, lambda-cyahalothrin, and chlorpyrifos pose the greatest risk to bees. The concentrated toxin is contained in tiny microcapsules that bees can transport to the hive, making the microencapsulated formulation of lambda-cyhalothrin highly dangerous. Residues of the pyrethroid cypermethrin in honey pose a moderate risk to nectar foragers (4-6.8%) but a low risk to larvae (0.1%). Moderate risks (1-5%) are also found for the organophosphorous coumaphos and quinalphos, the neonicotinoid dinetofuran and the carbamate methiocarb, but only coumaphos and dinetofuran present some risk to larvae. Nectar foragers are at low risk (0.1-1%) when feeding on honeybee contaminated with 9 more insecticides: the organophosphorous chlorpyrifos, dimethoate, pirimiphos ethyl, diazinon and malathion, the carbamates carbaryl and Pirimicarb, beta-cyfluthrin, a pyrethroid, and total DDT residues” (Richard *et al.,* 2012). “Residues of the synergistic fungicides, myclobutanil, penconazole and propioconazole have so far not been detected i honey, and therefore nectar foragers are exempt of higher risks in this regard. Bees were exposed to pesticide treatments in the food chamber using a gravity feeder placed on a petri dish (90mm diameter) lined with filter paper” (Francisco *et al.,* 2014). Pesticide label guidance concentrations and application rates are approved on the basis of ecotoxicological tests using single pesticides and set at a level for field use deemed ‘sublethal’.

2.3 Effect of Relative humidity

Within the Honey bee colony, relative humidity is very significant since the development of the brood primarily depends on high humidity (Human *et al*., 2006). Relative humidity (RH) is important factor for brood development within the colonies. Li *et al*. (2016) found that RH is regulated largely by workers. For egg hatching, relative humidity is extremely crucial. RH below 50% hindered egg hatching; the optimum relative humidity range for normal hatching was from 90-95%. Relative humidity about 75% within colonies could be considered as suitable for immature stages (Ellis *et al*., 2008). No definite direct effect of relative humidity on exterior behaviours, such as foraging behaviour, has been noted in the case of honey bees (Joshi, 2010). Under low levels of relative humidity, within colonies, honey bee workers try to increase humidity by various means including nectar water evaporation and water collection (Human *et al*., 2006). “Relative humidity has a significant effect on larvae during incubation. Higher or lower relative humidity significantly reduced the number of normally hatched eggs” (Doull, 1976). “No eggs were able to hatch at 30% relative humidity. In case of low relative humidity conditions, bees show specific behavior such as nectar water evaporation and foraging for water collection to increase relative humidity” (Human *et al*., 2006). During elevated relative humidity, fanning behavior can work well to reduce relative humidity to be within the optimum range. It is worth mentioning that for in vitro rearing of honey bee larvae, a temperature of 34°C and relative humidity of 96% [53] (Silva *et al*., 2009) or relative humidiy of 90% [54] were suggested. “At a temperature of 35°C honey bee workers have been found to survive better at 75% relative humidity, whereas at low relative humidity of 50% to 15% worker survival was adversely impacted, especially at 15%” [55].

3. EFFECT OF BIOTIC STRESS ON HONEYBEE POPULATION

3.1 Effect of Diseases

Like the other living organisms, honey bees can be infested with diseases. It is important for the bee keeper to be able to recognize conditions which might be disease related and respond accordingly.

3.2 American Foulbrood Disease

In 1769, Schirach named a disease condition in honey bee brood ‘foul brood’. This disease was called American foul brood because the investigations were carried out in New York State, USA. American Foul brood disease is a serious disease of honey bee brood and has been considered the most destructive of the brood diseases. This is because the causing organism produces heat- and drought-resistant spores that can germinate whenever conditions are right. *Bacillus larvae*, a spore-forming bacterium, causes the disease. (Hansen, 1999) It attacks older larvae and young pupae, which are literally digested by the bacterium's enzymes. The symptoms of American foulbrood include: 1. Cappings with perforations or sunken areas that are darker in colour than healthy brood cappings. 2. The resulting black scales, which are difficult to remove from the cell due to their stickiness. Gorging colonies of honeybees with sugar sirup or dusting them with dry powdered sugar containing tylosin lactate or sodium sulfathiazole controlled most cases of American foulbrood disease when the treatments were repeated once a week for at least three weeks [3].

3.3 Chalk Brood Disease

Ascosphaera apis causes the fungal disease chalk brood in honey bee brood. Chalk brood is now found in honey bee colonies around the world and there are some indications that the incidence of chalk brood has increased in recent years (Health, 1985; Kluser and Peduzzi, 2007). Although the disease is fatal to individual larvae, it does not usually wipe out an entire bee colony. However, it can result in significant losses in both bee numbers and colony productivity (Bailey, 1963; Wood, 1998), with reported reductions in honeybee production ranging from 5 to 37% (Heath, 1982; Yacobsan *et al*., 1991; Zaghloul *et al*., 2005). The disease is characterized by infected brood, called “mummies”, which when removed from the comb, appears to be solid clumps, reminiscent of chalk pieces. The “mummies” colours can range from white to dark grey or black. There is no recommended chemical treatment for chalk brood; requeening a colony is often an effective treatment. (Katherine *et al.,* 2010).

3.4 Nosema Disease

Nosema disease is a microsporidian *Nosema* sp. Parasitic disease of adult bees caused by *Nosema apis* zander, retards colony development, thus affecting pollination, honey production and package bee production. In package of bee colonies, it is a major cause of queen supersedure. The disease has spread throughout the world, causing significant losses in apiculture and the economy as a whole. (Gajger *et al.,* 2009) High incidence of nosema is directly related to stress such as periods of long confinement, rapid brood buildup, nutritional imbalance and inclement weather. The disease's symptoms are not always clearly evident and can be difficult to detect even at high levels of infestation. They can include: unhooked wings, distended abdomens. Controlling nosema disease can be accomplished by feeding the antibiotic fumagillin, marketed under the trade names of Fumidil B and/or Nosem-X [4].

4. EFFECT OF PESTS ON HONEYBEE POPULATION

Honeybees, like all living things, are attacked at all stages of development by various insect enemies acting directly as predators or indirectly by disrupting the colony.

4.1 Greater Wax Moth

"The greater wax moth, *Galleria mellonella* is an important pest of honeybee. The larvae of the greater wax moth burrow into the edge of unsealed cells, carrying pollen, bee brood, and honey all the way to the midrib of honeybee comb. *Galleria mellonella* larvae cause severe damage in tropical and subtropical regions, and it is thought to be one of the factors contributing to the decline in both feral and wild honeybee populations. The greater wax moth was first reported in honeybee colonies of Asian honey bee *Apis cerana*, but later spread to northern Africa, Great Britain, some parts of Europe, Northern America and New Zealand. Because of its destructive feeding habits, the greater wax moth is regarded as one of the most serious pests of honeybee products. The larvae cause damage by creating silk-lined tunnels through the hexagonal cell walls and the comb surface. The most effective management of the greater wax moth is by maintaining good sanitation. This includes: keeping the colony strong and with adequate food resources, sealing cracks and crevices" (Charles *et al.,* 2017).

4.2 Varroa Mite

The Asian hive bee, *Apis cerana*, is the varroa mite's natural host. "Damage to Asian honey bee colonies is rarely experienced since a stable host parasite relationship has been established over a long evolutionary scale" (Rath, 1999). It is a well-known pest that has emerged as the most serious economic threat to apiculture on a global scale. The ectoparasitic mite, *Varroa destructor* is a major contributor to the ongoing honey bee health crisis. Varroa interacts with honey bee viruses, making them more pathogenic. The reproduction of the varroa mite takes place inside the capped worker and drone brood cells although, in the drone cells, the reproductive success of the mite is higher than in the worker cells. The loss of hemolymph during the ontogenetic development within the brood cell significantly reduces the weight of the hatching bee. The amount of weight loss is determined by the number of mother mites and the rate of mite reproduction. Organic acids derived primarily from active components of plant and essential oils are widely used in conventional and organic honey bee colonies to control varroa mites. Thymol, a natural constituent of thyme (*Thymus vulgaris*) and a volatile monoterpenoid with acaricidal activity against varroa, is one such component (Elzen *et al.,* 2004).

5. EFFECT OF VIRUSES ON HONEYBEE POPULATION

Viruses pose serious threats to the health and well-being of honey bees. A better understanding of bee viral infections will be critical in developing effective and environmentally friendly disease control strategies to mitigate the threats posed by these invasive organisms.

5.1 Deformed Wing Virus

Deformed wing virus has transformed from a largely unknown, minor pathogen of honeybees to the most well-known, widespread and intensively studied insect pathogen in the world. This dramatic rise in Deformed wing virus prevalence and infamy is solely down to its association with the Varroa mite (*Varroa destructor*), an ectoparasite and also, devastatingly, an efficient virus vector between honeybees. This introduction of a new Deformed wing virus transmission route-i.e., inoculation directly into the hemolymph during mite feeding-has been closely associated with the death of millions of honeybee colonies and has changed the entire viral landscape of honeybees and other associated insects. Deformed wing virus is now the most common virus in honeybees, infecting at least 55% of colonies/apiaries in 32 countries.

6. CONCLUSION

Honeybees are very important insects that plays a major role in agriculture as crop pollinators. Pollination is very important process in agriculture. As human population is increasing day by day, because of this food requirement is also increasing and as pollination is important process in agriculture and honeybees are very important pollinating agent. But, nowadays their population is decreasing because of different environmental factors like temperature, relative humidity, pests, disease. Honeybees require certain amount of temperature but because of increasing global warming temperature is rising and same is the case for other factors. Because of these environmental factors honeybee population is decreasing. This is a big concern in today’s world.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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