SciMedCentral
Journal of Veterinary Medicine and Research

Mini Review

Bee Colony Decline: Reasons and Recommendations

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Submitted: 19 August 2024
Accepted: 30 September 2024
Published: 30 September 2024
ISSN: 2379-948X

Keywords
- Honey bee decline
- Pesticide residues
- Pyrethroids
- Chlorinated hydrocarbon
- Necotinoids

Abstract

Bees are important part of ecology. They make pollination services and nectar collections. These activities make them in the top of pollination services in the eco-system. Currently, bee colonies are declined worldwide due to exposure to biotic and abiotic factors. The effects of these parameters are not well discussed. The article discusses the effects of biotic and abiotic factors on bee colony decline and recommends a suitable method to reduce the decline. The study reveals that biotic factor such as Varroa mite attack is a strong factor stand behind bee colony decline. Abiotic parameters such as toxic pesticide have strong effects on bee population death leading to decline. The study found 92 toxic pesticide residues in honey samples from 27 countries in the world that played critical rules in bee colony decline. Land scab, land use and climate changes have also tremendous effects in bee colony decline. Furthermore, biotic and abiotic parameters may act together and produce destructive effects on bee colony. The most common pesticide residues found in honey samples are those belong to chemical classes Necotinoids (N), pyrethroids (PY), and chlorinated hydrocarbon (CH). A strong positive correlation was found between honeybee decline and honey contamination with N and PY compounds. We recommend immediate varroa control and legislative regulation to control the use of N and PY pesticides in the flowering zones to reduce honeybee decline.

INTRODUCTION

Sustainable production of honey requires good management of bee colony. Bee colony may face several threats that resulting to sever decline or population loss due to biotic and abiotic factor. Bee decline and/or bee loss is defined herein as the reduction of bee population in the colony or loss of the colony due to any reason. Honeybees are important organisms in the ecosystem. They have important rules such as pollination services and nectar collections. Honeybees may be declined due to exposure to biotic or abiotic factors. This includes parasitic diseases, toxic pesticides, climate changes and/or habitat loss. Bees decline may have a critical rule in pollination services in the ecosystem and consequently affect food production and food security. In the past few years, decline of honeybee colonies was reported in many countries' worldwide. Previous studies did not provide detailed reasons that stand behind bee colony decline. Here below we update the current state of the art on bee colony decline and discuss the effects of biotic and abiotic parameters in honeybee colony lose. Furthermore, we recommend a suitable method to reduce bee colony decline

Effects of biotic factors (parasites and disease) on bee colony decline

Biotic factors include parasites and diseases such as Varroa infection, bacteria and viral diseases and interactions between invasion species. Varroa infection has been reported as a strong biotic parameter stands behind bee decline. For instance Potts et al. [1], reported a honeybee colony decline in central Europe due to Varroa infection. van Engelsdorp et al. [2], revealed large-scale losses of managed honey bee (Apis mellifera L.) colonies in the United States due to biological factors. Effect of pathogens on substantial decline in managed honey bees has also been documented [3]. Similarly Grixti et al. [4], revealed the nature and extent of bumble bee decline in North America. Infection by protozoan parasites has been shown to spread the decline along with the imported hosts and spillover to native species, Palaearctic Bombus ruderatus and Bombus terrestris in Chile [5]. Williams et al. [6], highlighted the influence of pathogens in the decline of *Bombus* s. str. in North America. Interaction between bees and other pollinators may contribute to bee decline due to food security for them. This is in accord with Requier et al. [7], who reviewed the interaction between bee and other pollinators and recommended further studies to understand the rule of interaction in bee decline.

Effects of abiotic factors on bee colony decline

Abiotic factors include land-use, niche overlaps, habitat loss, floral abundance, climate change and chemical factors. Land-use changes and its associated negative effects through reductions in food plants in many parts of the world resulted in bumblebee species declines in Europe, North America, and Asia [6]. Land use and landscape have been shown to affect the scale on bumblebee nest density and survival in UK. For instance Goulson et al. [8], found bumblebee species appeared to differ markedly in survival over time. Intensive land use may lead to the loss and fragmentation of natural habitat resulting to a reduction of bee and other pollinator population, Bee declines may occur due niche overlaps between introduced and native bumblebees. So far Inoue et al. [9], highlighted the importance of niche overlaps between introduced and native bumblebees in terms of morphological characteristics, seasonal flight activity, foraging and nesting habitat use, and plant species visited in Japan. The same authors found considerable niche overlaps in flower resource use between B. terrestris and B. hypocrita sapporoensis/ B. pseudobaicalensis. Bombus terrestris also potentially competes for nest sites with B. hypocrite sapporoensis. Pant biodiversity has been shown to create bee decline. For instance Carvalheiro et al. [10], found that biodiversity change of plants and flowers in Great Britain, Netherlands and Belgium, significantly affected flower visiting insects. Similarly Burkle et al. [11], indicated that global change over 120 years disrupted plant-pollinator interactions in a temperate forest understory community in Illinois, USA. The same authors found degradation of interaction network structure and function and extirpation of 50% of bee species. Additionally, they indicated network changes can be attributed to shifts in forb and bee phenologies. Habitat loss, floral abundance may significantly affect bee decline. For instance Goulson et al. [12], reported the declines in bumble bee species in the past 60 years in Europe and America, due to habitat loss and declines in floral abundance. Furthermore Xie et al. [13], revealed the decline of bumblebee in summer time in China due to significant reductions in bumblebee-food-plant abundance and bumblebee diversity and the changes in absolute flower availability. Similarly Potts et al. [14], emphasized the influence of habitat loss, fragmentation, alien species, and climate change in bee colony decline. Similar observation was found in the decline of the Palaearctic Bombus ruderatus [5]. Notably Van Engelsdorp et al. [15], indicated that honeybees decline reached 59% in North America due to contagious conditions and/or colony collapse disorder.

Bee colony decline due to chemical factors

Chemical factors includes exposure to pesticides, hormones, pharmaceuticals, air pollutants and water contaminants, Brittain et al. [16], emphasized the effects of a pesticide on pollinator species richness at different spatial scales in Italy. The same authors highlighted the interaction between the application regime of the insecticide and the point in the season was important for species richness. Moreover, they also indicated that wild bee species richness appeared to be unaffected by one insecticide application, but declined after two and three applications. Honey bee death rate in different locations in Spain during citrus and stone fruit trees blooming season was emphasized due to application of pesticides [17]. The same author found an average of four pesticides per honeybee sample was detected. Among detected pesticides were Coumaphos, chlorpyrifos and dimethoate imidacloprid, organophosphate neonicotinoid insecticides. Budge et al. [18], highlighted the influence of neonicotinoid seed coatings in honey bee colony declines over an 11 year period across England and Wales. Similarly, Godfray et al., have also highlighted the impact of neonicotinoid insecticides on honeybee losses in UK and Netherlands whereas Samson-Robert et al. [19], found similar observation in a different location. In a further study Woodcock et al. [20], indicated that Clothianidin, a Neonicotinoid insecticide was the most frequently detected neonicotinoid in honey samples in UK. A similar observation of Neonicotinoid and honey sample contamination was previously reported [21]. Additionally Bryden et al. [22], revealed the influence of sublethal levels of neonicotinoid pesticide on bumblebee colony decline. Furthermore Pisa et al. [23], indicated that neonicotinoids and fipronil showed high acute toxicity to honeybees. A reason for bee decline.

DISCUSSION

Biotic Factors

Bees colony decline may be associated with disease and/ or parasite attack. For instance, honey bees may be attacked by protozoans, fungi, bacteria, viruses and/or mites. Parasites, specially varroa contributed to the loss of honey bee colony in Asian in the 1960s, European, New Zealand and North America [24,25]. This was due exchange honey samples and honey bees due to commercial reasons without agricultural quarantine. So far, bee parasites have also been detected in wild bumblebees in Europe, China, and South America [26-28], and in solitary bees in Europe [29]. Furthermore, bee parasites caused considerable damage to B. impatiens colonies in African North America, Egypt, Australia, and Europe [30,31] Notably commercial trade in bumblebee colonies, which are mainly used for pollination of greenhouse crops may stand behind bee disease distribution around the globe. Previous studies reported intensive honey bee colony decline in worldwide [15,32], due to Varroa infection. Furthermore, Varroa infection was reported as a major pest of Western honey bees, *Apis mellifera* [33].

Additionally, Varroa mites may be a vector for many honey bee viruses [24,34]. Several studies showed that varroa mites and associated viruses caused considerable honey bee colony decline in many country [15,33]. Biotic factors can be the strongest destructor of bee colony elsewhere due to the fact that the bees can be treated with pharmaceuticals to control varroa disease. Although this treatments are successful in many country. This treatment did not produce immunity in the new generation against disease. Additionally, the hives are not treated and may remain as a source for disease for the next generation. Moreover, the medical treatment may not be very effective to eliminate varroa and associated virus or bacteria resulting in more damage of bee colony leading to a decline. This is in agreement with Melathopoulos et al. [35], who found ineffective medical treatment of bees by the traditional pharmaceuticals.

Abiotic Factors

Land-use, niche overlaps, habitat loss, floral abundance,

climate change and chemical factors: Few reports described honeybee's decline in the past few years. For instance Potts et al. [36], reported the potential effects bee colony due several reasons such as habitat loss and fragmentation, agrochemicals, pathogens, alien species, climate change and the interactions between them. Furthermore Goulson et al. [37], found bee declines due combined effects from parasites, pesticides, and lack of flowers. Additionally Vanbergen [38], highlighted the influence of land-use intensification, climate change, and the spread of alien species and diseases on honey bees declines. So far, there are four seasons in the year. Theses seasons reflect the effects of the climate changes in a country or worldwide. Theses seasons have different temperature range, different humidity range and different sun shine. These affect, the flowering activity of the plant, growth and nesting behavior of bees, and their adaptation ability in the zone. Dry season may lead to the migration of bees to another zone where food abundance is high. Additionally, some country may have early summer season or late winter season. This flocculation may result in changing bee activity and flower abundance leading to bee decline. Furthermore, winter season may become very intense or summer season become very dry leading to a destructive effects on bee colonies. This suggestion agree with Punko [39], who found decline of bees due to winter and summer season interaction.

Habitat loss may be an important factor for bee decline due to the fact that bees require food that cannot be obtained from any part of plants except flowers. Accordingly, losing habitat may significantly contribute to bee decline. This explanation agrees with previous authors who provided a clear consensus indicating that habitat loss contributed to bee declines [12]. Additionally, suitable habitat or floral resources provide nest sites, attracting environment for pollinators due to the biodiversity of plants. This may enable some solitary species. Furthermore, it can be suggested that changing bee habitat to farm land may destroy the nests, plant biodiversity resulting in bee colony decline. This suggestion agrees with previous authors who found that converting natural habitat to farmland in UK [40], and North America [41], contributed to significant bee decline.

Additionally, changing gardens to buildings and roads may significantly contribute to bee decline. This is in agreement with a previous report that revealed that building of roads and other infrastructure can also cause direct mortality of bees through collisions [42].

Effects of insecticide in bee decline can be an important factor: Pesticide application is necessary for sustainable agriculture. Its correct application may result in a severe damage in the ecosystem. Previous studies El-Nahhal and El-Nahhal 2021a [43], reported wide contamination of drinking water resource worldwide which may cause damage to wild animals and pollinators. Further study El-Nahhal and El-Nahhal (2021b) [44], demonstrated the heart damage of human beings and animals. Additionally, a previous study [45], detected 50 insecticide residues in 2620 honey samples from 23 countries around the world. The number of detected insecticide residue ranged from 1-33. The highest number of insecticide residues was detected in Italy whereas the lowest number was detected Lebanon. Furthermore, the detected insecticide residues included 19 organophosphorus (OP) compounds, five carbamate compounds (CT), 13 organochlorine compounds (OC) six synthetic pyrethroids (PY) and seven insecticide residues from neonicotinoid family (N). and two residues have different chemical structure. Classification of these insecticides according to their LD50 shows 18, 20, 8 and 4 extremely toxic, highly toxic, moderately toxic and less toxic insecticides respectively. These insecticides are from different chemical classes.

Although Pesticides are toxic agents to bees and caused severe damage and death to them, they are not considered the major driver for bee decline. This probably due to the fact that bee species and genotypes have different sensitivity to pesticide beside the fact that bees have different age groups, and functions. Furthermore, exposure to dilute concentration of some pesticides or their mixtures for several times may generate cross resistance to other pesticide. This is in agreement with Yao et al. [46], who found similar observation for other cases. The generated resistance may enable bees to survive for longer period in the hive. The toxic effects of pesticide may be modulated by physiological and/or environmental parameter and become less effective on bee decline. This explanation is in agreement with previous reports that provide clear evidence of variable response of bee-pesticide exposure relationship [47]. On the other hand, bee exposure to pesticide may be associated with varroa disease and/or climate changes resulting with a sever bee decline or loss. This combined effect may affect the toxicokinetics and toxicodynamics in bees resulting in variable response to pesticide. The changes in the ecology conditions of bees may provide longer life for insects. This in accord with [48], who observed that bees live longer time under optimal conditions in the laboratory than bees live under field conditions.

Converting pesticide residues found in honey samples worldwide [45], to relative acute toxicity dose (RATD) by subdividing the concentration found in honey sample by the corresponding acute oral LD50 obtained from PPDB, 2019, El-Nahhal and El-Nahhal 2022 [49,50].

$$\text{RATD} = \frac{conc\, ng\, /\, g}{LD50\, ng\, /\, bee}$$

So far, RATD values equal or higher than one is considered high concentration in honey sample whereas, values lower than one are considered low concentrations. Thereafter, the obtained values are subdivided into six groups as follows: Group1, very diluted concentration, RATD <0.0001; Group 2, diluted concentration, RATD ranged from 0.001-0.099; Group3, marginally diluted concentration, RATD ranged from 0.01-0.099; Group 4, marginally high concentration, RATD ranges 0.1-0.499; Group 5, high concentration, RATD ranges 0.5-0.999 and Group 6, very high concentration, RATD >1.

Additionally, the following insecticides Azinphos-methyl, Carbaryl, Carbofuran, Chlorpyrifos, Clothianidin, Cyfluthrin Cypermethrin, Dichlorvos Dieldrin, Diazinon, Fenitrothion, HCB, Imidacloprid, Lindane, Malathion, methidathion, Paraoxon-methyl, Parathion ethyl, Permethrin, Thiamethoxam, γ-HCH contributed to marginally high RATD (0.1-0.49) in Ghana, China, Colombia, Egypt, France, India, Kenya, Pakistan, Portugal, Spain, Turkey, UK, USA. The occurrence of these very high, high and marginally high RATD is due to the fact that the concentrations of some of these insecticides are exceeding and or equal the value of LD50.

Some of above mentioned insecticides are highly toxic according to PPDB, 2019 [49], such as Imidacloprid, Thiamethoxam and Clothianidin that have LD50 values 3.7, 5, and 7.9 ng/bee, respectively. On the other hand Morandin et al. [51], indicated the effects of lethal and sub-lethal doses of spinosad, a biopesticide, on bumble bees (*Bombus impatiens* Cresson) toxicity and showed brood and adult mortality resulting in colony death two to four weeks after initial pesticide exposure.

Recommendation to control bee colony decline: Varroa mite control could a critical point to reduce bee colony decline. In this point using natural products such as organic acids, essential oils and other safe materials could be recommended. Additionally, we strongly recommend using new pharmaceuticals each one or two years to avoid resistance of varroa mites against pharmaceuticals. Application of legislative measures for using pesticide will significantly reduce bee colony decline. Urbanization reduction and road building will keep bee habitat health and reducing its lost and decline.

CONCLUSION

The rational of this study emerges from the fact that bees are critical pollinators and a strong part of the economy. Biotic factor can be considered the major destructor of bees elsewhere due to varroa mites. Although pesticides are toxic compounds but they are not the major destructor of bee decline. The article founds that bee decline occurred due to varroa mite attack and viral disease. Habitat loss, garden destruction, read building and urbanization have critical effects on bee decline. Furthermore, application of pesticide can significantly contribute to bee decline worldwide. In conclusion, to reduce bee colony decline it is strongly recommended to use safe and new medical drug to control varroa mites and associated viruses, reduce application of pesticides specially in the flowering plants that can be attracting places for bees. Reduction of urbanization, road building, protect gardens and finally application of legislative measures for using pesticide.

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