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Editorial

Monitoring of Honey Bee Colony Losses: A Special Issue

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Abstract: In recent decades, independent national and international research programs have revealed possible reasons for the death of managed honey bee colonies worldwide. Such losses are not due to a single factor, but instead are due to highly complex interactions between various internal and external influences, including pests, pathogens, honey bee stock diversity, and environmental change. Reduced honey bee vitality and nutrition, exposure to agrochemicals, and quality of colony management contribute to reduced colony survival in beekeeping operations. Our Special Issue (SI) on "Monitoring of Honey Bee Colony Losses" aims to address specific challenges facing honey bee researchers and beekeepers. This SI includes four reviews, with one being a meta-analysis that identifies gaps in the current and future directions for research into honey bee colonies mortalities. Other review articles include studies regarding the impact of numerous factors on honey bee mortality, including external abiotic factors (e.g., winter conditions and colony management) as well as biotic factors such as attacks by *Vespa velutina* and *Varroa destructor*.

Keywords: honey bee diseases; stressors; pathology; honey bee mortalities; colonies management

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High mortality in honey bee colonies has been reported worldwide in recent decades without definitive identification of the causes [1]. Several hypotheses have been postulated to explain these losses, but the causes have not been clearly identified [2]. Many factors, including internal and external pressures, exposure to various pathogens, lack of diversity of food sources, management problems, exposure to agrochemicals and a variety of stressors [1,3,4], act in isolation or, more often, in combination, to drive increased mortality among individual bees or managed honey bee colonies [4–6].

This SI includes 6 research articles, 4 reviews, and 13 other pertinent papers addressing honey bees as individual or social organisms responding to a variety of pathogens and nonpathogenic factors such as environmental stressors, honey bee colony management, and beekeeping practices. Many previous studies relied on meta-analyses to interpret the underlying causes of global bee decline, identify gaps in current research, and propose new priorities for research [7]. Authors in this review [7] analyzed 293 international scientific papers. They examined the methodologies used to link various biotic and abiotic stressors to global losses in managed populations of *Apis mellifera*. They concluded an urgent need for standardized testing of the lethality of stressors. The stressors and associated mortality rates in managed honey bee colonies vary globally. Neov et al. [8] describes five stressors responsible for most global declines in managed honey bee colonies. The first stressor is the human-driven spread of pathogenic and pest organisms (e.g., *Varroa destructor* and *Aethina tumida*). More recently, a highly invasive insect predator, *Vespa velutina*, or the Asian yellow-legged hornet have represented a serious new threat to managed honey bees and native pollinators, thus necessitating monitoring and appropriate management actions to prevent further beekeeping losses in affected areas [9]. Varroa (*Varroa destructor*) is the single most significant cause of lower winter survival in honey bees, and improved control of this parasitic mite is still urgently needed [10]. Gregorc and

Sampson [11] showed greater effectiveness of Varroa control and greater colony survival with improved diagnostic methods, organic acid treatments and other integrated methods. Moreover, treatment timing is critical for varroa control and improved colony health. For example, control was improved by following-up short-term evaporation of formic acid in summer with oxalic acid trickling in winter. Similarly, in Croatian bees hives, Tlak Gajger et al. [12] used repeated hive monitoring followed up with applications of commercial products to continuously induce mite mortality and prevent reinfestations.

The second stressor involves landscape changes, both positive and negative. Negative changes more typically involve habitat loss or degredation. However, Buchori et. al. [13] identified positive habitat effects while studying the impact of land use patterns, agricultural intensification and insecticides residues on honey bees (*Apis cerana* and *A. mellifera*) and stingless bees (*Tetragonula laeviceps*) in Indonesia (Bogor and Malang regions). They discovered certain habitat types alleviate bee stress and promote colony growth and queen reproductive output, especially forests with abundant sources of honeydew.

The third stressor, intensification of agricultural production, includes the use of fertilizers and pesticides as well as other chemical compounds originating within highly managed colonies or stored honey products. Pesticides even at sub-lethal doses can harm honey bee health and colony productivity. Currently, few studies are addressing the sub-lethal effects of biotic [14] and abiotic stressors [15] on bee health and the vulnerabilities among subspecies of honey bees. Sublethal pesticide effects are not as well studied as lethal effects. There are several potential ways that honeybees can be exposed to sublethal levels of pesticides and other environmental pollutants, for example, through water collection, by contact with foliage, or through contaminated pollen and nectar [16]. The application and proper dosage of pesticides (acaricides) inside the hive to control parasitic mites could also affect the health of brood, worker bees [17], and queens [18]. Therefore, it is of great interest to study the effects of acaricides and other pesticides on honey bee health and productivity. Martinello et al. [19] extensively surveyed, in Italy from 2015 and 2019, the occurrence of pesticide residues in the bodies of dead honey bees, in samples of comb, in bee bread, and on plant tissues (leaves, corn seedlings, and maize). From 696 samples, honey bees were exposed to 150 pesticides, with 50% of the honeybee samples testing positive for one or more active ingredients with an average of 2 and a maximum of 7 pesticides per sample. By analyzing dead bees and plant materials from the field, these studies contributed to a better understanding of the influence of individual or combined pesticide mixtures on honeybee health, even when chemicals occurred at sublethal concentrations. Later, an integrative protocol was developed for monitoring the effects of field-realistic exposure of honey bees to neonicotinoids by monitoring honeybee colony activity along with electronic measurements of internal and external hive temperture and humidity as well as colony weight. It was found that quality samples preparation and follow up of honeybee colonies and honey/pollen flows can be successfully performed by using classic methods to monitor weather conditions; activities and population of colonies; weight gain; or contemporary technologies, including electronic sensors combined with the Internet of Things and big data storage [20].

Pesticides are not the only harmful environmental compounds encountered by honey bees. Managed colonies are vulnerable to a honey-breakdown product, hydroxymethylfurfural (HMF). Gregorc et al. [21] showed that HMF at higher concentrations reduces longevity and midgut integrity of caged worker *Apis mellifera carnica*. Negative effects of HMF on bees after 15 feeding days included extended midgut cell death and increased worker mortality.

The remaining two stressors are attracting increased attention, despite the logistical challenges they pose to researchers. These stressors are related to ecological change brought about by climate change and resulting weather intensification and recent invasions of new, non-native plant species [22]. Moreover, additional studies are also needed that can account for genetic variation (e.g., subspecific differences), which can be profound, in bee responses to these and other stress factors [23]. A citizen science survey identified additional causes of high overwintering losses (15.2%) in Austrian honey bee colonies (2018/19) [10]. These causes were related to certain beekeeping practices that create queen problems (reduced fecundity, reduced lifespan) during the season. Colonies can be affected by introduction pesticides via contaminated food sources, wax from outside a given operation, collecting melezitose, and foraging for a late catch crop.

In conclusion, this SI highlights the most important research or extension topics associated with honey bee colonies mortalities worldwide. I hope readers have gained new knowledge and directions for further scientific work.

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