Review Paper

An overview of biological safety and health promotion of honeybees (*Apis mellifera*)

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Abstract:
Food production and nutrition of human society are highly dependent on natural ecosystems and production systems in agriculture. More than three thousand plant species are responsible for providing food for the world's population, of which only 300 species are cultivated for food supply, and 12 species provide about 90% of the world's food consumption. The most important role of the bee is pollinating flowering plants, which unfortunately is not paid attention to because of little information and lack of culture. In addition to honey bees, other bees also play an essential role in plant pollination, which directly preserves the diversity of flowering plants and indirectly preserves the survival of a large part of animals. These insects play an essential role in preventing soil erosion and providing oxygen. In addition to honey bees, other bees also play an essential role in plant pollination, which directly preserves the diversity of flowering plants and indirectly preserves the survival of a large part of animals. Applying correct management to prevent losses and extinction of insects, guarantees food for living beings and preserves the ecosystem.

Keywords: Honeybee, Insect, Biodiversity, Pest, Disease.

1. Introduction

The agricultural industry is highly dependent on insects for the production of food needed by humans. The beneficial aspects of insects include thousands of benefits, including the production of edible products, decorative products, medicinal products, honey production, silk production, lacquer production, *etc*. The importance of insects in agriculture is more about pollination and control of some plant pests. Pollinating insects are worth 200 billion dollars a year due to their essential role in pollination. In fact, at least one-third of all agricultural crops rely on pollination by insects [1]. Honey bees do about 80% of all pollination worldwide. Seventy of the top 100 human food crops, which provide about 90 percent of the world's food are pollinated by bees. As agriculture developed and the need increased for pollinators, modern agricultural practices also reduced bee populations through pesticide use and land use [1-3]. In recent years, honey bees have become increasingly endangered, especially in areas with high-scale agriculture. The situation has deteriorated with new bee diseases and pests. Their destructive effects are intensified by reducing the resistance of bee colonies. The increasing demand in modern agriculture and the concomitant decline in honey bee health have led to a "pollination crisis" [4, 5].

In recent years, beekeepers have reported losses of their colonies, especially in Western European Union countries such as France, Belgium, Germany, England, Italy, Spain, and the Netherlands. Similar problems exist in many other parts of the world, including the United States, Russia, and Brazil, indicating a global problem. There is ample evidence of pollinator decline worldwide, and the consequences are visible in many agricultural regions. The researchers evaluated these consequences by measuring 1) the contribution of insect pollination to the economic value of global agricultural products and 2) the vulnerability of world agriculture to the decline of pollination. They used a bioeconomic approach that integrated the ratio of production dependence on pollinators for 100 crops worldwide and listed by FAO. The total economic value of pollination worldwide was estimated at 153 billion euros, which represented 9.5% of the value of world agricultural production for human food production [6].

Vegetables and fruits in terms of dependence on pollinating insects and global production are shown in Figure 1 [6].

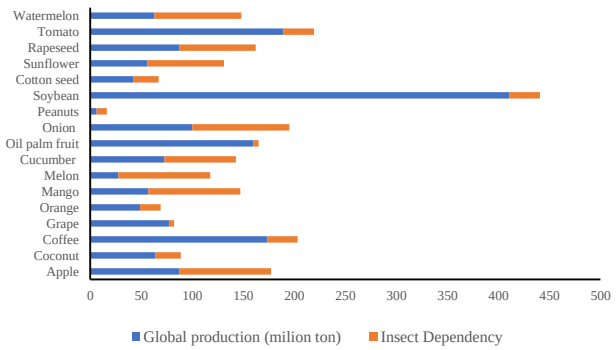

Figure 1. Major crops related to insects and their global production

The most important factors in reducing the population of honey bee colonies are Colony collapse disorder, some

important pests and diseases of honey bees, especially Varroa destructor, some agricultural pesticides, continuous droughts, and reduction of vegetation. Air pollution, especially the phenomenon of fine dust in some areas, and finally the unprincipled management of colonies by beekeepers are also other factors. Honey bee diseases and pests have become an important limiting factor for providing the number of strong bee colonies needed by farmers and impose a lot of costs on beekeepers [7].

There are more than 20,000 species of bees. Non-Apis bees are often surprisingly diverse in form and function and alone are worth conservation. For example, we can refer to Wallace's Giant bee, also known as Megachile Pluto or Dodo [8]. Wallace's big bee is the name of a species of leaf-picking bees. This bee, with a wingspan of 5.63 mm, is the largest species of bee in the world and is found in Indonesia. Another one is the bumble bee, which is one of the most important pollinating insects. It existed millions of years before humans and pollinated various plants. The bumble bee or humble bee comprises more than 250 species in the genus Bombus, of the Apidae family. Bumble bees are one of the most numerous bee species in Europe and one of the main species used in greenhouse pollination [7]. These bees are the main factor of biodiversity. In general, bees are the most important pollinators for plants, which play an important role in the production of high-quality agricultural products. For a long time, honey bees have been used by farmers to pollinate gardens and fields. The bumble bee is considered the best option for use in greenhouses due to its greater adaptability to environmental conditions. The beginning of bumble bee domestication dates back to 1912, and after many efforts, it became a reality in the 1970s [9].

The species of bees are different in terms of choosing food for themselves and each of them picks flowers based on their special shape, color and smell. This indicates the symbiosis between plants and pollinators, and means that each flowering plant with its own characteristics is compatible with certain species of bees and depends on them for pollination. For example, plants whose nectar is located deep depend on bees with long tongues to access the nectar for pollination. Therefore, with the loss of the diversity of wild bee species, many cultivated and wild plants lose their effective and useful pollinators. Although wild bees have received less attention, they contribute a lot to pollination, and the interaction of other species of bees and honey bees can have many benefits for the pollination of crops, pastures, *etc*., which leads to an increase in the production of agricultural products [10].

Increasing awareness about the importance and role of bees as well as bee products plays an important role in efforts to protect bees and the beekeeping industry. Climatic changes, air pollution and other things have caused the death and destruction of honey bee colonies, and urgent action should be taken to protect this insect for the survival of plant species. Improving the conservation performance and increasing the health of honey bees and thousands of other bee species is a major global challenge that this article has addressed to some extent.

2. Stress and mortality factors

Currently, there is no scientific data on the complete picture of the problem; but there is evidence of a significant reduction of pollinators due to human activities. Bees and butterflies are the species for which the best data is available, showing that one in ten species of bees and butterflies in Europe is at risk of extinction. Honey bee colony losses vary greatly from year to year, but are generally getting worse. Annual surveys of honey bee colony loss demonstrate meaningful changes in time and place, as well as factors contributing to this decline. Varroa mites and viruses that spread in colonies are now the biggest cause of these losses. Although the problems of queen production, lack of natural resources and new pests also play an important role in this relationship [11, 12].

Insect extinctions since the industrial era are probably around 5–10%, involving 250,000–500,000 species. At least one million species will face extinction in the coming decades, half of which are insects. Modern agriculture and human factors have vastly affected honey bees and many species of solitary and social bees around the world. A network of stressors can indirectly or synergistically affect honey bee health [13].

Stress factors are different in various parts of the world and change over time. Studies have revealed, these factors have harmed both bee longevity and average honey production per colony [14]. Understanding these stress factors is very important to reduce colony losses and improve bee health. Reports of "colony collapse syndrome" and "decline of pollinating insects" are accompanied by the conclusion that the world is experiencing a decrease in the diversity and number of insects, and this is mainly due to many human factors [5, 15]. These factors include intensification of land use, habitat loss, and urban development, the spread of invasive species and diseases, and pesticides [16].

Until recently, the types of agricultural chemicals considered dangerous to bees were mostly limited to insecticides. Fungicides were considered safe for use in the cultivation of flowering plants in the presence of bees, but unfortunately, their negative effects on bee health were confirmed. The increase in relative humidity has greatly increased the risk of agricultural pests such as aphids and yellow color in agricultural and garden lands and has caused farmers to spray their fields at least 2-3 times more than in previous years. Among the agricultural sectors that are directly affected by this chemical fight and its products suffer a qualitative and quantitative decline, is beekeeping. These effects have been shown both through increased mortality of microorganisms and direct effects on bee metabolism, including inhibition of mitochondrial respiration [17, 18].

The honey bee has endured well in the face of climate and environmental changes and has adapted to different conditions. Apart from the cold and icy regions, this insect is scattered in all parts of the world, and in addition to living naturally in its habitats, a large amount of them are cultivated in traditional or modern ways. Honeybees and other insects are cold-blooded creatures and have a strong dependence on environmental conditions, so any climatic and environmental change will have a significant impact on their life. Factors that reduce flowering plants will affect the life of bees. Environmental temperature changes, rainfall, and environmental pollutants are among the factors that strongly affect insects. Many beekeepers do not consider even micro-pollens to be ineffective in reducing the population of bee colonies, and they consider climate changes at the beginning of the breeding season to be an important factor in causing losses. Climate change is therefore affecting

honey bee populations worldwide [19]. Widespread declines of bumble bees have been reported on different continents due to such changes [20]. Climate change can also lead to the expansion of invasive species such as the small hive beetle (*Aethina tumida*) that affect bees [21].

Significant geographical differences in the creation of stressors have been reported. Honey bee populations in further parts of the world experience various mortality rates based on different factors [22]. African bees are not affected by the varroa mite and usually do not need to be controlled [23]. In some regions of the globe, pesticides have been cited as the main cause of death of honey bees and other bees [24]. Therefore, bee conservation approaches vary by geographic region. In the Middle East and Asia, Tropilaelaps, a parasitic mite of the Laelapidae family, and in some countries, such as China, the sac-borne virus is a key problem [25]. In England and Wales, the chronic bee paralysis virus is also emerging as a serious threat [26]. Invasive species, including hive mites and beetles, as well as different genotypes of honey bee viruses and their international spread, can become important challenges for honey bees.

One of the most important components for assessing the health of an ecosystem is to examine biodiversity; So that the calculation of ecological indicators in an ecosystem provides a clear picture of the environmental situation and the stability of that ecosystem. Using the monoculture model in some areas can have an inappropriate effect on the biodiversity of pollinating insects [27].

The consequence of these stressful factors is the decline of plant pollination. The investigators concluded that pollinator falls can lead to the loss of optimal pollination operations and have unfavorable ecological and economic effects that can significantly affect the conservation of wild plant diversity, broader ecosystem stability, agricultural production, Food security, and human well-being should be affected [28].

Other social or solitary bees suffer from similar and sometimes different challenges to honey bees. Researchers believe this decrease in the population of bees is a big problem for the ecosystem and biodiversity, and their absence creates additional problems by affecting agricultural production. A bee colony can guarantee pollination or biological insurance [5, 29].

Numerous of the aspects that cause honey bee colony losses also affect bumble bees [5]. Interestingly, there is often a strong positive relationship between honey bee and bumble bee diseases [30, 31]. Habitat loss, pathogens, invasive species, climate change, pollen, and pesticides that affect honey bees can negatively influence the health of bumble bees and many other species [32, 33]. Fungicides used in agriculture can affect the microorganisms that these native pollinators need to survive. Since honey bees are easier to monitor, they can be considered as an indicator to detect mortality factors in other native bees [34].

Common insecticides such as sulfoxaflor and the neonicotinoid imidacloprid severely disrupt the behavior of honey bees. These results are cause for concern because the ability of bees to respond appropriately to visual information is very important for their flight, orientation, and consequently their survival. Of course, sometimes the health issues of other bee species are different from honey bees. Investigations have revealed that pesticides sometimes affect solitary or non-Apis bees more than honey bees. Inappropriate and untimely spraying during the flowering of fruit trees, which causes the poisoning of bees, may eliminate the population of one or several colonies [35-37].

Attempts to increase the population of honey bees may result in a negative impact on native bees [38]. Honey bees or bees that are introduced for commercial purposes can transmit the disease to native bees. In some areas, experts may have problems in choosing the method of combating pests and diseases by giving priority to honey bees or bumble bees. High numbers of honey bees can be detrimental to wild bee populations, as the two groups directly compete for nectar and pollen. When flowers are abundant, this issue and competition are not a problem, but in environments with limited resources, wild bees win the competition. One of the main factors of honey bee population decline is the lack of flowers [39].

3. Challenges facing the beekeeping industry

One of the most important issues of beekeeping is their diseases. These diseases cause death or spoilage of some of the outcomes produced by bees. To meet the growing demand of providing strong hives for pollination, beekeepers had to pay more to treat diseases and pests of their bees [40]. In many parts of the world, it is considered impossible to keep bee colonies alive without disease control and treatment. With the tightening of health protocols, varroa populations have increasingly shown resistance to acaricides, which has led to an increase in bee losses, and the need for suitable alternatives such as the use of medicinal plants for pest control [41]. The latest methods that are being considered include gene silencing or RNAi methods and genetic modification of bee gut bacteria [42, 43]. These bacteria are natural microorganisms found in the bee's digestive system, which by fermenting sugars (sucrose, glucose, fructose, *etc*.) in the bee's digestive system, produce lactic acid and reduce the pH of the digestive system. In the honey bee breeding industry, several stresses such as climate changes, migration, changes in food sources, etc. cause the weakening of the immune system and the imbalance of the natural digestive microflora. Such factors make honey bees susceptible to various diseases, and as a result, we will see losses and a quantitative and qualitative drop in production. The use of probiotics in bee breeding can balance and optimize digestive microflora, improve growth, improve food digestion and absorption, improve immune system function, and resist various stresses and pathogens [44]. These changes prevent the growth and adhesion of harmful bacteria to the wall of the digestive system and the population of pathogenic agents is reduced. On the other hand, by strengthening the immune system, beneficial bacteria increase the bee's immunity against diseases and reduce the use of antibiotics.

In recent years, to meet market demand, beekeepers have significantly increased their investment in the production of protein food supplements, including food additives that supposedly help maintain bee health [45]. Beekeepers prefer that apiaries do not need to use chemicals and other control measures to survive. In addition to facilitating management and avoiding costs for controlling pests and diseases, bee products free from diseases and chemicals have a suitable and acceptable market. However, in many parts of the world, efforts are focused on breeding bees more resistant to major bee diseases and pests, such as the varroa mite, but have not yet introduced a reliable alternative [46].

Studying the genotype of African bees that are resistant to the varroa mite can help increase bee resistance through genetic modification.

Plant essential oils and their effective chemical compounds are considered suitable alternatives to chemical acaricides. The obvious feature of all these compounds is having fewer adverse effects on human health, non-target organisms, and the environment. Monoterpenoids, constituting about 90% of the total compounds in essential oils, are the most important compounds in essential oils. The tick-killing activity of essential oils of more than 150 plant species and their effective compounds have been tested on Varroa ticks, and only a few of them have obtained favorable results in hive conditions. Thymol and acaricides that contain thymol as an effective compound have brought valuable results. However, full reliance on the use of herbal bases to keep the varroa mite population below the level of economic loss is still not recommended, and the practical combination of herbal essentials with other low-risk methods is a more suitable approach [47].

4. To prevent the decline of bees and other pollinators

To tackle this problem and complement the efforts, the European Commission presented the EU Pollination Plan in 2018. It was the first comprehensive initiative at the EU level, focusing on wild pollinators. Its purpose was to promote knowledge about the reasons for the decline of pollinators, to deal with the causes, and to increase awareness in this field. They also agreed to reduce the use of dangerous agricultural pesticides and chemicals to the level of 50% [48].

Raising knowledge about insects and threats, using selective (microbial) insecticides, maintaining vegetation, using pollen and nectar sources or artificial foods, preventing deforestation, reducing greenhouse gases, and managing apiary transfer are required.

5. Conclusion

There are many challenges to improve the health of honey bees and the joint efforts of beekeepers, scientists, and research institutions are needed to protect bees. The goal of the researchers is that the "Honey Bee Health and Protection" section will be an effective means of helping the survival of honey bee species and other pollinators so that they can continue their vital role in ecosystems and agriculture around the world.

References

1. Klein AM, Vaissière BE, Cane JH, Steffan-Dewenter I, Cunningham SA, Kremen C, Tscharntke T. Importance of pollinators in changing landscapes for world crops. Proceedings of the royal society B: biological sciences. 2007 Feb 7;274(1608):303-13.https://doi.org/10.1098/rspb.2006.3721
2. Aizen MA, Harder LD. The global stock of domesticated honey bees is growing slower than agricultural demand for pollination. Current biology. 2009 Jun 9;19(11):915-8. https://doi.org/10.1016/j.cub.2009.03.071
3. Gallai N, Salles JM, Settele J, Vaissière BE. Economic valuation of the vulnerability of world agriculture confronted with pollinator decline. Ecological economics. 2009 Jan 15;68(3):810-21. https://doi.org/10.1016/j.ecolecon.2008.06.014
4. Holden C. Report warns of looming pollination crisis in North America. 2006: 397-397. https://doi.org/10.1126/science.314.5798.397
5. Goulson D, Nicholls E, Botías C, Rotheray EL. Bee declines driven by combined stress from parasites, pesticides, and lack of flowers. Science. 2015 Mar 27;347(6229):1255957. https://doi.org/10.1126/science.1255957
6. Moritz RF, Härtel S, Neumann P. Global invasions of the western honeybee (*Apis mellifera*) and the consequences for biodiversity. Ecoscience. 2005 Jan 1;12(3):289-301. https://doi.org/10.2980/i1195-6860-12-3-289.1
7. Engel MS, Rasmussen C, Gonzalez VH. Bees: Phylogeny and classification. In Encyclopedia of Social Insects 2021 Jan 31 (pp. 93-109). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-030-28102-1_14
8. Vereecken NJ. Wallace's Giant Bee for sale: implications for trade regulation and conservation. Journal of insect conservation. 2018 Dec;22(5-6):807-11. https://doi.org/10.1007/s10841-018-0108-2
9. Morandin LA, Laverty TM, Kevan PG. Bumble bee (Hymenoptera: Apidae) activity and pollination levels in commercial tomato greenhouses. Journal of economic entomology. 2001 Apr 1;94(2):462-7. https://doi.org/10.1603/0022-0493-94.2.462
10. Brittain C, Williams N, Kremen C, Klein AM. Synergistic effects of non-Apis bees and honey bees for pollination services. Proceedings of the Royal Society B: Biological Sciences. 2013 Mar 7;280(1754):20122767. https://doi.org/10.1098/rspb.2012.2767
11. Brown MJ, Dicks LV, Paxton RJ, Baldock KC, Barron AB, Chauzat MP, Freitas BM, Goulson D, Jepsen S, Kremen C, Li J. A horizon scan of future threats and opportunities for pollinators and pollination. PeerJ. 2016 Aug 9;4:e2249. https://doi.org/10.7717/peerj.2249/table-1

12. Darnhofer I, Bellon S, Dedieu B, Milestad R. Adaptiveness to enhance the sustainability of farming systems. A review. Agronomy for sustainable development. 2010 Sep;30:545-55. https://doi.org/10.1051/agro/2009053
13. Steinhauer N, Kulhanek K, Antúnez K, Human H, Chantawannakul P, Chauzat MP. Drivers of colony losses. Current opinion in insect science. 2018 Apr 1;26:142-8. https://doi.org/10.1016/j.cois.2018.02.004
14. Nearman A, VanEngelsdorp D. Water provisioning increases caged worker bee lifespan and caged worker bees are living half as long as observed 50 years ago. Scientific Reports. 2022 Nov 14;12(1):18660. https://doi.org/10.1038/s41598-022-21401-2
15. Goulson D. The insect apocalypse, and why it matters. Current Biology. 2019 Oct 7;29(19):R967-71. https://doi.org/10.1016/j.cub.2019.06.069
16. Vanbergen AJ, Initiative TI. Threats to an ecosystem service: pressures on pollinators. Frontiers in Ecology and the Environment. 2013 Jun;11(5):251-9. https://doi.org/10.1890/120126
17. Motta EV, Raymann K, Moran NA. Glyphosate perturbs the gut microbiota of honey bees. Proceedings of the National Academy of Sciences. 2018 Oct 9;115(41):10305-10. https://doi.org/10.1073/pnas.1803880115
18. Yoder JA, Jajack AJ, Rosselot AE, Smith TJ, Yerke MC, Sammataro D. Fungicide contamination reduces beneficial fungi in bee bread based on an area-wide field study in honey bee, *Apis mellifera*, colonies. Journal of Toxicology and Environmental Health, Part A. 2013 May 1;76(10):587-600. https://doi.org/10.1080/15287394.2013.798846
19. Giannini TC, Acosta AL, Garófalo CA, Saraiva AM, Alves-dos-Santos I, Imperatriz-Fonseca VL. Pollination services at risk: bee habitats will decrease owing to climate change in Brazil. Ecological Modelling. 2012 Oct 10;244:127-31. https://doi.org/10.1016/j.ecolmodel.2012.06.035
20. Soroye P, Newbold T, Kerr J. Climate change contributes to widespread declines among bumble bees across continents. Science. 2020 Feb 7;367(6478):685-8. https://doi.org/10.1126/science.aax8591
21. Cornelissen B, Neumann P, Schweiger O. Global warming promotes biological invasion of a honey bee pest. Global change biology. 2019 Nov;25(11):3642-55. https://doi.org/10.1111/gcb.14791
22. De la Rúa P, Jaffé R, Dall'Olio R, Muñoz I, Serrano J. Biodiversity, conservation and current threats to European honeybees. Apidologie. 2009 May 1;40(3):263-84. https://doi.org/10.1051/apido/2009027
23. Dias de Freitas C, Oki Y, Resende FM, Zamudio F, Simone de Freitas G, Moreira de Rezende K, Amaro de Souza F, De Jong D, Quesada M, Siqueira Carvalho A, Silvia Soares Pires C. Impacts of pests and diseases on the decline of managed bees in Brazil: a beekeeper perspective. Journal of Apicultural Research. 2022 Jul 8:1-4. https://doi.org/10.1080/00218839.2022.2099188
24. Castilhos D, Dombroski JL, Bergamo GC, Gramacho KP, Gonçalves LS. Neonicotinoids and fipronil concentrations in honeybees associated with pesticide use in Brazilian agricultural areas. Apidologie. 2019 Oct;50:657-68. https://doi.org/10.1007/s13592-019-00676-x
25. Ai H, Yan X, Han R. Occurrence and prevalence of seven bee viruses in *Apis mellifera* and *Apis cerana* apiaries in China. Journal of invertebrate pathology. 2012 Jan 1;109(1):160-4. https://doi.org/10.1016/j.jip.2011.10.006
26. Budge GE, Simcock NK, Holder PJ, Shirley MD, Brown MA, Van Weymers PS, Evans DJ, Rushton SP. Chronic bee paralysis as a serious emerging threat to honey bees. Nature Communications. 2020 May 1;11(1):2164. https://doi.org/10.1038/s41467-020-15919-0
27. Cléments DR, Weise SF, Swanton CJ. Integrated weed management and weed species diversity. Phytoprotection. 1994;75(1):1-8. https://doi.org/10.7202/706048ar
28. Potts SG, Biesmeijer JC, Kremen C, Neumann P, Schweiger O, Kunin WE. Global pollinator declines: trends, impacts and drivers. Trends in ecology & evolution. 2010 Jun 1;25(6):345-53. https://doi.org/10.1016/j.tree.2010.01.007

29. Winfree R, Williams NM, Dushoff J, Kremen C. Native bees provide insurance against ongoing honey bee losses. Ecology letters. 2007 Nov;10(11):1105-13. https://doi.org/10.1111/j.1461-0248.2007.01110.x
30. Cornman RS, Tarpy DR, Chen Y, Jeffreys L, Lopez D, Pettis JS, Vanengelsdorp D, Evans JD. Pathogen webs in collapsing honey bee colonies. 2012. https://doi.org/10.1371/journal.pone.0043562
31. Piot N, Schweiger O, Meeus I, Yañez O, Straub L, Villamar-Bouza L, De la Rúa P, Jara L, Ruiz C, Malmstrøm M, Mustafa S. Honey bees and climate explain viral prevalence in wild bee communities on a continental scale. Scientific Reports. 2022 Feb 3;12(1):1904. https://doi.org/10.1038/s41598-022-05603-2
32. Cameron SA, Sadd BM. Global trends in bumble bee health. Annual review of entomology. 2020 Jan 7;65:209-32. https://doi.org/10.1146/annurev-ento-011118-111847
33. Talebi, E., Haghighat Jahromi, M., Khosravi Nezhad, M., Rowghani Haghighi Fard, E. Herbal plants as an appropriate stimulus with prophylactic potential in livestock: A review. Safe Future and Agricultural Research Journal (SFARJ), 2022; 1(1): 11-19. https://doi.org/10.22034/sfar.2022.158473
34. Wood TJ, Michez D, Paxton RJ, Drossart M, Neumann P, Gerard M, Vanderplanck M, Barraud A, Martinet B, Leclercq N, Vereecken NJ. Managed honey bees as a radar for wild bee decline?. Apidologie. 2020 Dec;51:1100-16. https://doi.org/10.1007/s13592-020-00788-9
35. Menezes C, Colleto-Silva A, Gazêta GS, Kerr WE. Infestation by Pyemotes tritici (Acari, Pyemotidae) causes death of stingless bee colonies (Hymenoptera: Meliponina). 2022 https://doi.org/10.1007/s13592-022-00913-w
36. Arena M, Sgolastra F. A meta-analysis comparing the sensitivity of bees to pesticides. Ecotoxicology. 2014 Apr;23:324-34. https://doi.org/10.1007/s10646-014-1190-1
37. Capela N, Sarmento A, Simões S, Azevedo-Pereira HM, Sousa JP. Sub-lethal doses of sulfoxaflor impair honey bee homing ability. Science of The Total Environment. 2022 Sep 1;837:155710. https://doi.org/10.1016/j.scitotenv.2022.155710
38. Banaszak J. Strategy for conservation of wild bees in an agricultural landscape. Agriculture, ecosystems & environment. 1992 May 1;40(1-4):179-92. https://doi.org/10.1016/0167-8809(92)90091-O
39. Cane JH, Tepedino VJ. Gauging the effect of honey bee pollen collection on native bee communities. Conservation Letters. 2017 Mar;10(2):205-10. https://doi.org/10.1111/conl.12263
40. Oglu KS, Qizi KB. Measures for the prevention of diseases caused by disorders of bee nutrition and feeding conditions. Academicia Globe. 2022;3(03):5-8. https://dx.doi.org/10.17605/OSF.IO/YKPU8
41. VanEngelsdorp D, Evans JD, Saegerman C, Mullin C, Haubruge E, Nguyen BK, Frazier M, Frazier J, Cox-Foster D, Chen Y, Underwood R. Colony collapse disorder: a descriptive study. PloS one. 2009 Aug 3;4(8):e6481. https://doi.org/10.1371/journal.pone.0006481
42. Leonard SP, Powell JE, Perutka J, Geng P, Heckmann LC, Horak RD, Davies BW, Ellington AD, Barrick JE, Moran NA. Engineered symbionts activate honey bee immunity and limit pathogens. Science. 2020 Jan 31;367(6477):573-6. https://doi.org/10.1126/science.aax9039
43. Moran NA, Sloan DB. The hologenome concept: helpful or hollow?. PLoS biology. 2015 Dec 4;13(12):e1002311. https://doi.org/10.1371/journal.pbio.1002311
44. Mishukovskaya G, Giniyatullin M, Shelekhov D, Khabirov A, Smolnikova E, Naurazbaeva A. The use of probiotics in spring supplementary feeding of bee colonies. Bulgarian Journal of Agricultural Science. 2023 Jan 1;29(1).
45. Ricigliano VA, Williams ST, Oliver R. Effects of different artificial diets on commercial honey bee colony performance, health biomarkers, and gut microbiota. BMC veterinary research. 2022 Dec;18(1):1-4. https://doi.org/10.1186/s12917-022-03151-5
46. Spivak M, Gilliam M. Hygienic behaviour of honey bees and its application for control of brood diseases and Varroa: Part II. Studies on hygienic behaviour since the Rothenbuhler

era. Bee world. 1998 Jan 1;79(4):169-86. https://doi.org/10.1080/0005772X.1998.11099408

47. Rosenkranz P, Aumeier P, Ziegelmann B. Biology and control of Varroa destructor. Journal of invertebrate pathology. 2010 Jan 1;103:S96-119. https://doi.org/10.1016/j.jip.2009.07.016

48. https://www.europarl.europa.eu/news/en/headlines/society/20191129STO67758/what-s-behind-the-decline-in-bees-and-other-pollinators-infographic