The Indirect Threats of Desert Locust Infestation on Honeybees in Ethiopia

Zemene Worku,1 Addisu Bihonegn,2 Desalegn Begna,3 Sebsib Ababor,1 and Arse Gebeyehu1

1Department of Animal Science, Faculty of Agriculture and Veterinary Medicine, Jimma University, Jimma, Ethiopia
2Andassa Livestock Research Center, Bahir Dar, Ethiopia
3Lead Researcher on Livestock Policy Related Issues, FRDE Policy Study Institute, Addis Ababa, Ethiopia

Correspondence should be addressed to Addisu Bihonegn; addbesh@gmail.com

Received 30 November 2021; Accepted 22 March 2022; Published 11 April 2022

Academic Editor: Habib Ali

Copyright © 2022 Zemene Worku et al. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

This review focuses on the potential effects of a desert locust infestation on Ethiopian honeybees. Data on the country’s infestation, locust activity, honeybee foraging behavior, pesticide kinds, and application rates were collected and analyzed in connection to honeybee life and performance. Desert locust has damaged a considerable number of plants of various kinds, possibly causing pollen and nectar loss. As a result, honeybees are likely to produce less brood, less honey, suffer from poor health, and abscond. Besides, studies suggested that the use of pesticides to control the locust could directly harm honeybees. The pesticide was used for 21 days in a row to cover a huge region infected with locusts, which could have had a severe effect on honeybees. The probability of an influence is also indicated by the overlap of pesticide administration with honeybee foraging seasons and hours. Furthermore, forager bees leave their hive 1 to 13 times per day, spending about 3 hours outside each time, indicating higher chemical exposure. Malathion is one of the pesticides that could harm honeybees, while there is no comprehensive list of the chemicals used on the internet or anywhere else. Finally, the current desert locust invasion and eradication operation in Ethiopia may have caused substantial damage to honeybees as a result of bee forage loss and pesticide hazard, emphasizing the need for future precautions. Because this is speculative work based on evidence, detailed survey research is recommended to determine the actual impact imposed on honeybees.

1. Introduction
Beekeeping (Apis mellifera) has been practiced in Ethiopia since 3500 to 3000 BC [1] times, and it has played an important role in socioeconomic issues such as churches, holidays, weddings, and other events. Ethiopia is the first and tenth honey-producing country in Africa and the world, respectively [2], which is ascribed to the suitability of the country for honeybees. Ethiopia’s suitability for beekeeping is measured by the abundance of diverse varieties of plants [3]. Honey is produced in almost all parts of Ethiopia, with distinctive types of honey coming from different regions.

Honeybees play a significant part in the livelihood of rural households and are considered an economically important insect. Honey, beeswax, and bee colony sales are vital sources of income for rural households, which are utilized for a variety of expenses such as children’s school fees and taxes. Due to its nature of low perishability, honey sales can be scheduled at any time during the year when it is needed [4]. Because beekeeping requires less initial capital, empowering poor households in general, and women in particular, is easier than with other livestock [5].

Despite the long history of beekeeping, productivity of the sector is suboptimal which is ascribed to numerous factors such as the use of traditional technology, low management practices, prevalence of pests, and indiscriminate use of agrochemicals. Traditional beekeeping characterized by the use of traditional hives (made of locally
available materials such as mud, clay, log, bark, bamboo, and others) and poor management (no supplementary feeding and less protection from enemies) of the bees accounts for more than 90% of beekeeping in the country. The prevalence of honeybee pests such as ants, spiders, birds, lizards, bee beetles, and wax moths is commonly reported by small-scale beekeepers as a major challenge to productivity. Repeated attacks by these intruders will lead the bees to abandon their beehives and move to other places. Currently, indiscriminate application of herbicides and pesticides to food crops is becoming the leading challenge to honey production in most parts of Ethiopia [6, 7], and several herbicides are used to control weeds of food crops without considering the bad effects on honeybees and their forage [8]. Agrochemicals are responsible to weaken a colony, kill the bees, and pollute the products through residues.

The desert locust (Schistocerca gregaria) belongs to the class Insecta and is one of a dozen grasshopper families. This desert locust belongs to the Acrididae family, which includes most short-horned grasshoppers. Although the desert locust looks like any other grasshopper, it is larger and aggressively voracious. The desert locust passes through three developmental phases, namely egg, nymph, and adult. The female locust lays eggs, and the eggs hatch into wingless larvae or nymphs called hoppers. This hopper molts five to six times, increasing in size with each molting stage it passes through. Wings develop as hoppers undergo their sixth moult. Wingless hoppers are called instars, and winged hoppers are called fledglings [9].

The desert locust is well-known for one distinct behavior that distinguishes it from other grasshoppers: it adapts its life habits to the environment it inhabits and the available resources [10]. In reaction to swarm density and environmental conditions, they can change their body color and shape. Concentration, multiplication, and grangerization are three processes that cause significant behavioral changes in desert locusts.

The desert locust can have swarms that number up to 10 billion, and these swarm move and feed in a highly organized way. The desert locust is a major threat to agricultural production [11] as it is a voracious consumer of every green plant, including leaves, fruits, shoots, flowers, barks, found on its way [12]. A plague of desert locusts, the most destructive of all locust species, could easily affect 20% of the world’s land, threatening the livelihoods of one tenth of the world’s people and seriously jeopardizing food security [13].

The impact of the locust may not only be limited to severe damage of food crops but the control operation may also result in unintended effects, as for example, toxicity to the honeybees by the pesticides applied to kill the desert locust. As a result, honeybees are likely to be harmed twice: once from a lack of food (pollen and nectar) and again from chemical toxicity. Given the difficulties of testing these impacts, collecting evidence to demonstrate their effects has been chosen as an alternative for the time being. As a result, the goal of this work was to compile relevant data that suggest the likelihood of negative impacts of the desert locust invasion on Ethiopian honeybees.

2. Methodology

This research is entirely based on a review of scientific papers and reports from international and national organizations. We aimed to compile relevant information that could indicate the possibility of a significant adverse effect of the desert locust on honeybees. Therefore, we examined evidence that is thought to suggest a trend of negative impacts. As a result, the scale of locust invasion, suitability of infested areas for honeybees, recurrence of desert locust in Ethiopia, honeybee behaviors (foraging time, frequency, and population size), and pesticide application intensity (total land treated) are all evaluated, discussed, and interpreted.

3. Results and Discussion

3.1. Desert Locust Infested Areas. In 2019/2020, Ethiopia was infested by desert locusts that have migrated from Yemen and settled in the Afar lowland. Swarms begun to migrate from the Afar region’s lowland to the semihighland Amhara regional state. While, another swarm migrated from Somaliland to the Dire Dawa city administration. Despite the fact that North East Ethiopia was the first to be confronted with the problem, the desert locust infested practically all Ethiopia’s regional states, causing varying degrees of damage. Among the regional states of the country, Tigray, Amhara, Afar, Oromia, Somalia, and SNNP regional states faced severe damage where large areas have been considerably invaded, leading to significant loss of feed and food crops (Figure 1). There was a significant reduction in pasture availability of 50 percent or more in Somali (61 percent), Afar (59 percent), Oromia (31 percent), Dire Dawa (35 percent), SNNP Region (22 percent), and Amhara (28 percent) during the outbreak of the desert locust in 2020, compared to the normal situation prior to the invasion of the locusts [14].

Following the first round of infestation, new areas were invaded, which was exacerbated by favorable conditions such as rain, wind direction, and locust speed. For example, swarms of desert locusts from Kenya infested new areas in Ethiopia as a result of a change in wind direction. The rains helped the swarms in North East Ethiopia laying eggs, which could pose a threat to Somalia, Eritrea, and Eastern Ethiopia if they hatch. Due to the pest’s tendency to travel longer distances and consume enormous quantities of plants, larger areas were readily invaded and harmed by the desert locust. The locust, assisted by the wind, can travel up to 150 kilometers, indicating how quickly it can cause damage to crops and pastures over a wider area [13].

3.2. Availability of Resources. For a number of reasons, Ethiopia is generally regarded as a good place to keep honeybees. Larger altitudinal differences, ranging from -116 meters below sea level to 4542 meters above sea level, resulted in a wide diversity of climate conditions. Besides, the rainfall varies from about 750 mm/year in Tigray and Amhara Regional States to over 1,000 mm/year in parts of Oromia Regional State [15]. As a result of the suitable
climate and weather conditions, a high plant biodiversity exists in the country. Trees, shrubs, bushes, and other types of plants are found either in forests, parks, homesteads, and other places. Besides, several crop species of cereals, legumes, vegetables, fruits, tubers, and oil seed are cultivated across the country with different degree of intensity. Moreover, specific studies at Afar [16], Amahara [17], and Tigray [18] indicate that there is abundant melliferous flora blooming during different seasons in Ethiopia. The large availability of resources and different honeybee races makes Ethiopia ideal for honeybee keeping [18, 19]. Consequently, honeybee keeping is carried out in almost all geographic locations of Ethiopia including both moist and dry areas [16, 20]. We can expect numerous honeybee colonies in desert-infested areas of Ethiopia. Actually, the Oromia region has over 50% of all bee colonies while Amhara and SNNPR together account for a further 36%.

3.3. Recurrence of Desert Locust in Ethiopia. The severity of a single occurrence, as well as the frequency with which it occurs, determines the severity of a problem. In Ethiopia, the annual probability of locust infestation is estimated to be between 30 and 40% [21]. If not on a yearly basis, periodic occurrence over a short period of time appears to be unavoidable. Ethiopia was plagued by desert locust in June of 2020, which is the biggest outbreak in twenty-five years [13]. Due to the possibility of favorable conditions associated to recurrent tropical storms and tropical depressions, there is a high risk of cyclical infestation for the next few years [22]. As a result, the number of swarms of desert locusts generated by sequential generations rapidly grows within 1-2 months, and they begin to congregate and become gregarious. The presence of immature swarms in several parts of Ethiopia until March 2021 confirms the aforesaid predictions [23]. Furthermore, given to the prevailing appropriate moisture, FAO predicted hatching and band formation in Ethiopia until mid-June 2021 [24]. If the pest appears on a regular basis, the impact on honeybees cannot be expected to be minimal.

3.4. How Could Honeybees Be Adversely Affected by the Locust?

3.4.1. Loss of Honeybee Forage Sources. Desert locusts, which are common in East Africa in general and Ethiopia in particular, may have an impact on honeybees indirectly by consuming shared resources. Honeybees collect pollen and nectar from a wide range of wild and cultivated plants and can easily learn how to exploit various and novel sources [25]. Honeybees would not be able to exist or operate at their best without these supplies. Pollen is largely employed as a protein source for the replacement generation brood and adults. Honeybees, on the other hand, use nectar as a source of energy, especially during foraging flights.

Honeybees transform excess nectar into honey for future use when there is more than enough for daily consumption. In honeybees, insufficient pollen is linked to decreased brood production [26–28], poor health [29, 30], a larger percentage of precocious foragers [27], and absconding [31]. Similarly, nectar insufficiency can lead to disease susceptibility, the inability to collect food, and the inability to secrete wax for...
longevity are the consequences of pesticides to honeybee mortality, delayed brood development, and reduced adult through spray and residues in pollen and nectar [35].

Honeybees are exposed to agrochemicals using helicopters. Of all the methods, pesticide application (spraying pesticides from vehicles and aerial application by honking motorcycle horns) or chemical application (spraying pesticides from vehicles and aerial application by using helicopters). Of all the methods, pesticide application was found to be effective regardless of the dire consequences. Agricultural pesticides are major contributors to honeybees and other pollinators decline worldwide [34] including Ethiopia [6].

3.4.2. Pesticide Hazard. Since there is no way of early warning on locust spread and invasion, reactions to these sudden events are varied but can be grouped as mechanical disturbance (banging on cans and pans, blowing whistles, and honking motorcycle horns) or chemical application (spraying pesticides from vehicles and aerial application by using helicopters). Of all the methods, pesticide application was found to be effective regardless of the dire consequences. Agricultural pesticides are major contributors to honeybees and other pollinators decline worldwide [34] including Ethiopia [6].

Pesticides affect all developmental stages and casts of honeybees. Honeybees are exposed to agrochemicals through spray and residues in pollen and nectar [35]. Mortality, delayed brood development, and reduced adult longevity are the consequences of pesticides to honeybee colonies [36]. Some chemicals (for example 2, 4-D) can kill 95% of the exposed adult bees [37]. Similarly, exposure of future queen bees to pesticides during developmental stage results in reduced capped queen cells and queen emergence [38]. The problem during the developmental phase extends to adult hood performance expressed in terms of reduced egg laying rate and reduced capacity to attract attendant worker bees [39]. Lower sperm viability is caused by pesticides exposure during developmental stage in drones [40]. Presence of disease [41, 42], cocktails of pesticides [43], and developmental stages are factors that exacerbate pesticide impact on honeybees. Furthermore, exposure to chemicals increases the susceptibility of bees to disease [44]. The ultimate result of these adverse effects on the honeybee community is a decrease in the number of honeybee colonies, as well as reduced performance of the survivor’s ones.

Impact of pesticide application to control locusts (like the present situation) may be greater than the customary manual application method to crops lands due to wider area coverage and application method of the former. Unlike the use of pesticide to control crop pests, which is applied to specific acre of land (containing the crop only), the use of pesticide to control locusts is applied wherever the pest exists. Unfortunately, locusts are found on every green plant including grasses, crops, trees, shrubs, and even on residence homes. Spraying on surfaces increases the probability of exposure of the bees to the pesticides. Besides, aerial application is assumed to be dangerous compared to land-based application methods.

The probability of bee exposure to pesticide determines the level associated to the risk. The exposure to pesticides depends on crop-related factors (overlap between the presence of bees in the crop area and the flowering of the crop or weeds, overlap between bee activity on the flowering crop and pesticide application, or the presence of extra floral nectaries, insects producing honeydew, or drinking water in the crop area), bee biology factor (period, duration and range of foraging, nest location, and nectar and pollen consumption), and pesticides use and application practice (types and rate of use) [45]. These facts lead to hypothesize a higher probability of bee exposure to pesticides when these are applied to control the desert locust in Ethiopia. Evidences of our hypothesis are explained below.

Desert locusts infested Ethiopia towards the end of June 2019 and following months [24] with great loss to crops and pastures. Ethiopia has been battling the locusts since the infestation. About 1.5 million hectare of land has been treated since its prevalence in the country except the first two months. This means 72,487 ha of land has been treated monthly for 21 successive months (Table 1). In other words, no month was pesticide-free for almost two years, confirming the overlap between flowering times and pesticide application. Most of the honeybee floras of the country are in bloom from September-November [46] followed by second shorter season in April-May. Honeybees are actively foraging during these periods because pollen and nectars are linked to flowering stage of plants; therefore, they certainly got into contact with sprayed pesticides for a long period of time.

Table 1: Pesticide treated areas since August 2019 up to May 2021.

| Fiscal year | Months     | Treated areas (ha) | References |
|-------------|------------|--------------------|------------|
| 2019        | June       | —                  | 4 July 2019, no 489 |
| 2019        | July       | —                  | 2 July 2019, no 490 |
| 2019        | August     | 11                 | 3 September 2019, no 491 |
| 2019        | September  | 4,636              | 3 October 2019, no 492 |
| 2019        | October    | 4,064              | 4 November 2019, no 493 |
| 2019        | November   | 10,822             | 4 December 2019, no 494 |
| 2019        | December   | 8,410              | 6 January 2020, no 495 |
| 2020        | January    | 22,550             | 3 February 2020, no 496 |
| 2020        | February   | 50,350             | 5 March 2020, no 497 |
| 2020        | March      | 51,633             | 4 April 2020, no 498 |
| 2020        | April      | 99,948             | 4 May 2020, no 499 |
| 2020        | May        | 57,058             | 4 June 2020, no 500 |
| 2020        | June       | 79,574             | 3 August 2020 no 502 |
| 2020        | July       | 44,883             | 3 August 2020 no 502 |
| 2020        | August     | 54,703             | 2 September 2020, no 503 |
| 2020        | September  | 57,457             | 5 October 2020, no 504 |
| 2020        | October    | 335,453            | 2 November 2020, no 505 |
| 2020        | November   | 160,580            | 3 December 2020, no 506 |
| 2020        | December   | 210,673            | 4 January 2021, no 507 |
| 2021        | January    | 166,158            | 4 February 2021, no 508 |
| 2021        | February   | 73,838             | 3 March 2021, no 509 |
| 2021        | March      | 15,066             | 3 May 2021, no 511 |
| 2021        | April      | 14,370             | 3 May 2021, no 511 |
| Total       |            | 1,522,237          |            |

Source: [24].
Furthermore, honeybees are diurnal insects that forage during the day time, which is concurrent to spray time, particularly aerial application which is impossible during the night. Africanized honeybees are reported to be active during the whole day with early morning and late evening being the two peak periods [47]. A forager bee move out of hive 1 to 13.5 time per day [33]. In general, a honeybee is reported to be outside the hive for 0.95–3.0 h per day for multiple purposes but commonly for pollen and nectar collection. The probability of bees to be sprayed by pesticides is 100% if the bee or the hive is found within the range of the spray [35]. This may be damaging a large number of honeybee individuals, foragers in particular.

Other than forager bees, house bees are also affected by pesticides through infected pollen and nectar. Forager bees collect and deposit nectar and pollen from pesticide-treated fields into the hives, therefore spreading toxic substances to bees in the hives and to hive products, a threat also for consumers [48]. Bees are not repelled by pesticides and thus collect contaminated pollen and nectar [49]. Scientific reports indicated that a single worker honey bee may cause disruption to the casts in the hive with possible death of large numbers bees [50].

Exhaustive list of applied pesticides to control desert locusts is not available from reports online. However, Malathion, Diazinon, and other environmentally friendly pesticides are used to control the pest in Ethiopia [Formating Citation]. However, scientific reports indicated that Malathion is among toxic chemicals for honeybees [51, 52]. Malathion reduces the life of worker bees by 80% under higher concentration [52]. Genetic variation to Malathion sensitivity is reported by [53] implying that some groups of honeybees might have been affected more than others. No research finding is reported regarding the effect of diazinon on honeybees.

4. Conclusion and Recommendation

The long-lasting desert locust invasion in Ethiopia is expected to have a detrimental influence on honeybee colonies, honey yield, and quality, due to the loss of honeybee resources (pollen and nectar) and chemical spray hazards. Pesticide poisoning could be avoided by keeping the colony in the hive through internal feeding during intensive pesticide application periods or by moving hives away from pesticide application sites. Supplemental nutrition should be provided to honeybees so that the colony can survive the dearth period when locusts destroy the surrounding flora. Furthermore, we would suggest raising awareness about the need of using predominantly mechanical techniques and safe insecticides while eradicating the desert locust.

Data Availability

The data that support the findings of this study are available from the corresponding author, Bihonegn, upon reasonable request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

References

[1] W. Abebe, “Identification and documentation of indigenous knowledge of beekeeping practices in selected districts of Ethiopia,” Journal of Agricultural Extension and Rural Development, vol. 3, pp. 82–87, 2011.
[2] T. Nega, “Review of Ethiopia’s global position in honey and other bee products production and marketing: analysis of sectoral opportunities and limitations,” Biomedical Journal of Scientific & Technical Research, vol. 10, no. 3, pp. 7879–7883, 2018.
[3] T. B. Kifle, “Screening of potential herbaceous honey plants for beekeeping development,” Agriculture, Forestry and Fisheries, vol. 3, no. 5, p. 386, 2014.
[4] Y. Gebremeskel and B. Tamir, “Characterization of beekeeping systems and honey marketing in eastern zone Tigray, Ethiopia,” Livestock Research for Rural Development, vol. 26, 2014.
[5] Y. M. Belete and Z. A. Ayele, “Bee-keeping for women empowerment: case of new business model in honey value chain development project’s beneficiaries in Amhara regional state, Ethiopia,” Livestock Research for Rural Development, vol. 32, 2020.
[6] D. Begna, “Assessment of pesticides use and its economic impact on the apiculture subsector in selected districts of Amhara region, Ethiopia,” Journal of Environmental & Analytical Toxicology, vol. 5, pp. 2–5, 2014.
[7] M. Girma, S. Ballo, A. Tegegne, N. Alemayehu, and L. Belayhun, “Approaches, methods and processes for innovative apiculture development: experiences from Ada’a-Liben Woreda Oromia regional state, Ethiopia,” in Improving Productivity and Market Success (IPMS) of Ethiopian Farmers Project, Working Paper 8. ILRIInternational Livestock Research Institute, Nairobi, Kenya, 2008.
[8] B. Negatu, H. Kromhout, Y. Mekonnen, and R. Vermeulen, “Use of chemical pesticides in Ethiopia: a cross-sectional comparative study on knowledge, attitude and practice of farmers and farm workers in three farming systems,” Annals of Occupational Hygiene, vol. 60, no. 5, pp. 551–566, 2016.
[9] WMO, Weather and Desert Locusts: WMO-No. 1175, World Meteorological Organization, Geneva, Switzerland, 2016.
[10] P. M. Symmons and K. Cressman, Desert Locust Guidelines, Biology and Behaviour, Food and Agriculture Organization of the United Nations, Rome, Italy, 2nd edition, 2001.
[11] L. Brader, H. Djibo, F. G. Faya et al., “Towards a more effective response to desert locusts and their impacts on food security, livelihood and poverty,” Multilateral Evaluation 2003–05 Desert Locust Campaign, FAO, Rome, Italy, 2006.
[12] S. Shrestha, G. Thakur, J. Gautam, N. Acharya, M. Pandey, and J. Shrestha, “Desert locust and its management in Nepal: a review,” Journal of Agriculture and Natural Resources, vol. 4, no. 1, pp. 1–28, 2021.
[13] FAO, Desert Locust Crisis-Appeal for Rapid Response and Anticipatory Action in the Near East and North Africa January–December 2020, FAO, Rome, Italy, 2020.
Advances in Agriculture

[14] FAO, *Impact of Desert Locust Infestation on Household Livelihoods and Food Security in Ethiopia: Joint Assessment Findings*, FAO, Rome, Italy, 2020.

[15] D. Tibebe and L. Tamene, *Biophysical and Socioeconomic Geodatabase for Land Productivity Dynamic Assessment in Ethiopia*, Centro Internacional De Agricultura Tropical, Cali, Colombia, 2016.

[16] G. K. Reda, S. Girmay, and B. Gebremichael, "Beepkeeping practice and honey production potential in afar regional state, Ethiopia," *Acta Universitatis Sapientiae, Agriculture and Environment*, vol. 10, no. 1, pp. 66–82, 2018.

[17] H. Adal, Z. Asfaw, Z. Woldu, S. Demissew, and P. van Damme, "An iconic traditional apiculture of park fringe communities of Borena Sayint national park, north eastern Ethiopia," *Journal of Ethnobiology and Ethnomedicine*, vol. 11, no. 1, 2015.

[18] H. Gebremedhin, Z. Tesfay, G. Murutse, and A. Estifanos, "Seasonal honeybee forage availability, swarming, absconding and honey harvesting in Debrekidan and Begasheka water-sheds of Tigray, northern Ethiopia," *Livestock Research for Rural Development*, vol. 25, 2013.

[19] T. Bareke and A. Addi, "Honeybee flora resources of Guji zone, Ethiopia," *Biology Agriculture and Healthcare*, vol. 8, 2018.

[20] K. Ejigu, T. Gebey, and T. R. Preston, "Constraints and prospects for apiculture research and development in Amhara region, Ethiopia," *Livestock Research for Rural Development*, vol. 21, 2009.

[21] P. Bartel, "Horn of Africa natural hazard probability and risk analysis," *Humanitarian Information Unit*, vol. 1–17, 2007.

[22] L. Wang, W. Zhuo, Z. Pei, X. Tong, W. Han, and S. Fang, "Using long-term earth observation data to reveal the factors contributing to the early 2020 desert locust upsurge and the resulting vegetation loss," *Remote Sensing*, vol. 13, pp. 1–19, 2021.

[23] USAID, "East Africa—desert locust crisis," pp. 1–6, USAID, Washington, DC, USA, 2020.

[24] FAO, *Desert Locust Bulletin: General Situation during May 2021 Forecast Until Mid-July 2021*, FAO, Rome, Italy, 2021.

[25] M. Giovanetti, M. Mariotti Lippi, B. Foggi, and C. Giuliani, "Exploitation of the invasive Acacia pycnantha pollen and nectar resources by the native bee apis mellifera," *Ecological Research*, vol. 30, no. 6, pp. 1065–1072, 2015.

[26] R. Brodschneider, K. Crailsheim, K. C. Nutrition, B. Robert, and C. Karl, *Nutrition and health in honey bees*, *Apidologie*, vol. 41, 2010.

[27] M. Corona, B. Branchicella, S. Madella, Y. Chen, and J. Evans, "Decoupling the effects of nutrition, age and behavioral caste on honey bee physiology and immunity," 2019.

[28] F. Requier, J.-F. Odoux, M. Henry, and V. Bretagnolle, "The carry-over effects of pollen shortage decrease the survival of honeybee colonies in farmlands," *Journal of Applied Ecology*, vol. 54, no. 4, pp. 1161–1170, 2017.

[29] B. Branchicella, L. Castelli, M. Corona et al., "Impact of nutritional stress on the honeybee colony health," *Scientific Reports*, vol. 9, pp. 10156–10211, 2019.

[30] G. Di Pasquale, M. Salignon, Y. Le Conte et al., "Influence of pollen nutrition on honey bee health: do pollen quality and diversity matter?" *PLoS One*, vol. 8, no. 8, pp. 1–13, Article ID e72016, 2013.

[31] A. G. Dolezal, J. Carrillo-Tripp, T. M. Judd, W. Allen Miller, B. C. Bonning, and A. L. Toth, "Interacting stressors matter: diet quality and virus infection in honeybee health," *Royal Society Open Science*, vol. 6, Article ID 181803, 2019.

[32] R. Pudasaini, B. Dhital, and S. Chaudhary, "Nutritional requirement and its role on honeybee: a review," *Journal of Agriculture and Natural Resources*, vol. 3, no. 2, pp. 321–334, 2020.

[33] S. Rodney and J. Purdy, "Dietary requirements of individual nectar foragers, and colony-level pollen and nectar consumption: a review to support pesticide exposure assessment for honey bees," *Apidologie*, vol. 51, no. 2, pp. 163–179, 2020.

[34] E. Crema, O. Jollivet, E. Collina, S. Sala, and P. Fantke, "Characterizing honey bee exposure and effects from pesticides for chemical prioritization and life cycle assessment," *Environment International*, vol. 138, Article ID 105642, 2020.

[35] F. Sanchez-Bayo and K. Goka, "Pesticide residues and bees—a risk assessment," *PLoS One*, vol. 9, no. 4, Article ID e94482, 2014.

[36] J. Y. Wu, C. M. Anelli, and W. S. Sheppard, "Sub-lethal effects of pesticide residues in brood comb on worker honey bee (apis mellifera) development and longevity," *PLoS One*, vol. 6, no. 2, Article ID e14720, 2011.

[37] G. Yeebyo, A. Bezabeh, and A. Tassew, "Acute toxicity effects of agrochemicals on honeybees (apis mellifera jenemtica) in Tigray region of Ethiopia," *Livestock Research for Rural Development*, vol. 32, 2020.

[38] J. P. Milone and D. R. Tarpy, "Effects of developmental exposure to pesticides in wax and pollen on honey bee (apis mellifera) queen reproductive phenotypes," *Scientific Reports*, vol. 11, pp. 1–12, 2021.

[39] E. M. Walsh, S. Sweet, A. Knap, N. Ing, and J. Rangel, "Queen honey bee (apis mellifera) pheromone and reproductive behavior are affected by pesticide exposure during development," *Behavioral Ecology and Sociobiology*, vol. 74, 2020.

[40] A. Fisher and J. Rangel, "Exposure to pesticides during development negatively affects honey bee (apis mellifera) drone sperm viability," *PLoS One*, vol. 13, no. 12, Article ID e0208630, 2018.

[41] R. Martin-Hernández, C. Bartolomé, N. Chejanovsky et al., "Nosema ceranae in apis mellifera: a 12 years post detection perspective," *Environmental Microbiology*, vol. 20, no. 4, pp. 1302–1329, 2018.

[42] J. S. Pettis, D. Vanengelsdorp, D. Johnson, and G. Dwely, "Pesticide exposure in honey bees results in increased levels of the gut pathogen nosemia," *Naturwissenschaften*, vol. 99, no. 2, pp. 153–158, 2012.

[43] S. Tosi and J. C. Nieh, "Lethal and sublethal synergistic effects of a new systemic pesticide, flupyradifluro (sivantos), on honeybees," *Proceedings of the Royal Society B: Biological Sciences*, vol. 286, 2019.

[44] T. Tesovnik, M. Zorc, M. Ristanić et al., "Exposure of honey bee larvae to thiamethoxam and its interaction with nosemia ceranae infection in adult honey bees," *Environmental Pollution*, vol. 256, Article ID 113443, 2020.

[45] H. Van, D. Valk, and I. Koomen, "Aspects determining the risk of pesticides to wild bees: risk profiles for focal crops on three continents," in *Pollination Service for Sustainable Agriculture*—FAO, Roma, Italy, 2013.

[46] E. Gebru, A. Berhanu, L. Hayal, A. Solomon, and A. Tsehaye, "Honey bee flora diversity and their impact on honey production in Tigray region of Ethiopia," *Livestock Research for Rural Development*, vol. 28, 2016.

[47] J. Woyke, "Diurnal flight activity of African bees apis mellifera adansonii in different seasons and zones of Ghana," *Apidologie*, vol. 23, no. 2, pp. 107–117, 1992.

[48] H. V. V. Tomé, D. R. Schmeh, A. E. Wedde et al., "Frequently encountered pesticides can cause multiple disorders in..."
developing worker honey bees,” Environmental Pollution, vol. 256, Article ID 113420, 2020.

[49] I. Naiara Gomes, K. Ingred Castelan Vieira, L. Moreira Gontijo, and H. Canto Resende, “Honeybee survival and flight capacity are compromised by insecticides used for controlling melon pests in Brazil,” Ecotoxicology, vol. 29, no. 1, pp. 97–107, 2020.

[50] A. Jivan, “The impact of pesticides on honey bees and hence on humans,” Scientific Papers Animal Science and Biotechnologies, vol. 46, pp. 272–277, 2013.

[51] D. Melisie and T. Damte, “Effects of some insecticides on foraging honeybees on onion flowers under field condition,” Recent Research in Science and Technology, vol. 9, pp. 13–17, 2017.

[52] R. Salari, R. Salari, and C. Medicine, “Investigation of the best saccharomyces cerevisiae growth condition,” Electronic Physician, vol. 9, no. 1, pp. 3592–3597, 2017.

[53] F. D. Rinkevich, J. W. Margotta, J. M. Pittman et al., “Genetics, synergists, and age affect insecticide sensitivity of the honey bee, apis mellifera,” PLoS One, vol. 10, no. 10, Article ID e0139841, 2015.