Journal of Advanced Zoology
ISSN: 0253-7214
Volume 44 Issue S-7 2023 Page 180:190

The Impact of Weather Change on Honey Bee Populations and Disease

Dr. Matangi Mishra[1*], Pritam Bhunia[2], Shubham[3], Rounick Sen[4], Rittwik Bhunia[5], Jayesh Gulia[6], Titir Mondal[7], Zinedine Zidane[8], Tuhin Saha[9], Alex Chacko[10], Ritu Raj[11], Vyshak S[12], Lakshay Kaushal[13]

[1,2,3,4,5,6,7,8,9,10,11,12,13] *Department of Entomology, School of Agriculture, Lovely Professional University, Phagwara, Punjab, India.*

**Corresponding author E-mail: matangi.gaurav@gmail.com*

Article History

Received: 20 June 2023
Revised: 09 Sept 2023
Accepted: 13 Dec 2023

Abstract

This review provides an overview of the honey bee (Apis mellifera) which is one of the most important pollinators for agriculture and ecosystems, considered a critical yet fragile contributor to world biodiversity and food security among the countless species facing unprecedented challenges due to uneven climate drivers. Scientists are concerned about the impact of climate change on honey bee habitats. This review study looks at the complicated relationship between climate change and honey bees' health leading to their genetic and behavioural changes. Further, it also mentions how changes in temperature and weather patterns affect foraging, reproduction and colony survival. This study will focus on the different processes that highlight their susceptibility and emphasise the critical need for comprehensive approaches to mitigate the potential consequences through policy implementation.

Keywords: *Apis mellifera, biodiversity, genetic, climate change, pollinators*

Introduction

Climate change refers to long-term changes in global or regional temperature patterns and weather conditions caused predominantly by human activities, such as emissions of greenhouse gases, which trap heat in the Earth's atmosphere, resulting in a variety of environmental impacts such as rising temperatures, melting ice caps, and more frequent and severe weather events. The honey bee (*Apis mellifera*) is a critical yet fragile contributor to world biodiversity and food security among the countless species facing unprecedented challenges. The complicated connection between climate change and honey bee health has drawn substantial interest from experts and environmentalists alike. This review study delves into the multiple effects of climate change on honey bees, putting light on the different processes that highlight their susceptibility and emphasising the critical need for comprehensive approaches to mitigate the potential consequenceThe delicate equilibrium among honey bee ecosystems is upset as temperatures rise and weather patterns vary, severely impacting these important pollinators. Potts et al. (1) seminal work presents a comprehensive examination of the relationships between climate change and pollinator reductions, highlighting the intricate web of factors that contribute to honey bee difficulties. Furthermore, Neumann et. al. (2) conducted a study on the effects of climate-induced stress on honey bee immune systems, emphasising colonies' sensitivity to illnesses and infections under changing environmental conditions.Changing temperature regimes can cause a misalignment between honey bee foraging and the availability of floral resources, potentially leading to decreased nutrition and reduced colony expansion.Burkle et. al. (3) investigated such disruptions in their study of the temporal disjunctions between bees and plants. Rising temperatures have also been linked to altered flight patterns, decreased foraging efficiency, and heat-related mortality events among honey bee populations, as elucidated by the studies of Stabentheiner et. al. (4)

Extreme weather events, which are becoming more common as a result of climate change, intensify the challenges faced by honey bee colonies.Schweiger et. al. (5) investigates the effects of high heat events on pollinators and their habitats, indicating bees' susceptibility to such climatic stressors. Furthermore, Stabentheiner et. al. (4) highlights the complicated links between climate change, habitat loss, and changes in plant-pollinator interactions, emphasising the cascading consequences of environmental perturbations on honey bee populations.

As the review progresses, it will take you through the intricate mechanisms that link climate change and honey bee biology, demonstrating how changes in temperature and weather patterns affect everything from foraging and reproduction to disease susceptibility and colony survival. This study aims to provide a thorough picture of the issues honey bees face in the face of climate change by synthesising lessons from seminal research studies and modern findings. In doing so, it hopes to spur additional study and develop solutions that protect the resilience of honey bee populations and the vital ecosystem services they provide.

Climate change and its drivers

The complicated phenomena of climate change are influenced by both natural and man-made factors. Emissions of greenhouse gases (GHGs) such as carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) are the main anthropogenic causes of climate change. The greenhouse effect is a warming phenomenon that results from these gases trapping heat in the Earth's atmosphere.

Fossil fuel combustion, including the burning of coal, oil, and natural gas, is a major contributor to CO_2 emissions. According to the 2018 Intergovernmental Panel on Climate Change (IPCC) (7) special Report on Global Warming of 1.5°C, mostly as a result of the burning of fossil fuels, human activities have significantly increased atmospheric CO_2 concentrations since the pre-industrial era.

Changes in land use and deforestation also contribute to climate change. As carbon sinks, forests take in CO_2 from the atmosphere. This carbon is released back into the atmosphere when forests are cut down for farming, urban development, or other reasons, which adds to the overall rise in GHGs.

In addition, methane and nitrous oxide are released during industrial activities like cement manufacture and some agricultural practices. Methane is produced during the digestion of livestock, especially ruminants like cattle, and fertilizers based on nitrogen increase nitrous oxide emissions.

It is significant to remember that the Earth's climate is also influenced by natural phenomena like volcanic eruptions and variations in solar radiation. However, the vast majority of scientists agree that human activities are the primary cause of the warming that has been observed since the middle of the 20th century, as evidenced by reports from organizations like the IPCC and the National Aeronautics and Space Administration [NASA]. (IPCC,2014) (8) Changing precipitation patterns and extreme weather events are part of climate change – Unquestionably, the expansion of extreme weather events and changes in the pattern of precipitation are key aspects of climate change. The scientific literature on these phenomena is well-documented, and the Intergovernmental Panel on Climate Change (IPCC) offers thorough analyses on these subjects.

Changing Precipitation Patterns:

1. IPCC Assessment: According to the IPCC's Fifth Assessment Report (AR5), there is a high probability that the patterns of precipitation around the world have changed during the past 100 years. It highlights geographical differences, noting that some regions see increases in precipitation while others see decreases.

2. Intensified Precipitation Events: According to the same report, heavy precipitation events have become more intense globally, especially in areas that are already prone to them.

Extreme Weather Events:

1. IPCC Assessment: The IPCC claims that there is evidence that some climatic extremes are changing, with more frequent and intense heat waves being recorded since the mid-20th century. The report also shows an increase in the occurrence and severity of tropical cyclones, droughts, and severe precipitation events.

2. Particular occurrences: Studies and analyses from the scientific community frequently relate particular extreme weather occurrences to global warming. For instance, the warming of the Gulf of Mexico has been linked to occurrences like Hurricane Harvey in 2017, which dumped record amounts of rain in Houston, Texas. (IPCC,2014) (8)

Impact of climate change on bee habitat

When it comes to the availability and suitability of feeding and nesting sites for both honey bees and wild bee species, climate change can have a substantial impact on bee habitat. The capacity of bees to identify acceptable sites to reside and forage for food can be disrupted by changes in temperature, precipitation, and habitat structure since they are very sensitive to environmental variables. The following are some significant ways that climate change may affect bee habitat:

Alterations to Floral Resources The timing, number, and distribution of flowering plants—which are vital for bees as sources of nectar and pollen—can be impacted by changes in temperature and precipitation patterns.

Food shortages may result from timing inconsistencies between bee foraging and the availability of floral resources brought on by climate change.

Changed Geographical Ranges: As temperatures rise, plant and flower geographic ranges may change. As temperatures rise, some plants may shift to higher altitudes or latitudes, upsetting long-standing bee-plant associations. The distribution of bees may change if they need to follow these shifts in order to find sufficient feed.

Habitat Fragmentation: As a result of increased habitat fragmentation brought on by climate change, it may be more difficult for bees to locate continuous habitat regions that are suited for them. Bee habitats can become even more fragmented as a result of increased urbanization, agricultural development, and infrastructural development, isolating populations and limiting the supply of feed.

Loss of Native Plant Species: Native plant species that are essential for bee nutrition and habitat may become extinct as a result of climate change. There may be fewer native feeding sources available to bees since these species are less likely to be able to adapt to quickly changing environmental conditions.

Predation and Competition: Habitat changes may have an impact on how some species interact with one another. For instance, as bees relocate to new places in reaction to climate change, they can come across new predators and rivals, which may have an impact on their survival and success at foraging.

Erosion of Microhabitats: Within larger ecosystems, microhabitats may degrade as a result of climate change. For instance, modifications to the vegetation brought on by changed precipitation patterns may lessen the availability of particular blooms and bee nesting locations.

Restricted Water Sources: Bees need access to water for a variety of reasons, such as hive cooling and honey dilution. Bee colonies may suffer if clean water supplies become less accessible as a result of climate change Heglandet al (2009) (9).

Climate Change Impact on bee hive construction –

Temperature and Seasonal Changes: Changes in temperature patterns brought on by climate change may make it more difficult for bees to keep the hive at its ideal temperature.

Water Availability: Bees use water for a variety of hive functions, such as controlling the temperature and thinning out honey. The capacity of the bees to locate and utilise water supplies for hive construction and maintenance may be impacted by changes in precipitation patterns and water availability brought on by climate change.

Floral Resource Availability:Flowering plant phenology is affected by climate change. Changes in flowering time may have an impact on the availability of some plant resources that bees utilize to build and maintain their hives.

Extreme Weather Events:Storms and wildfires, which are becoming more frequent and more intense due to climate change, can have an immediate effect on hive structures. Bee colonies may be disrupted by strong winds or fires that damage or kill hives.

Rearing of bee brood:The brood nest needs to be maintained at the proper temperature so that bee larvae and pupae can develop. Worker bees successfully create a cluster around the brood by squeezing their wings while remaining anchored to the comb. Extremely low temperatures may upset this cluster, causing chilled brood and the potential death of growing bees (Goulson et al,2015.) (10)

Increased Pests and Pathogens: Climate change can influence the distribution and prevalence of pests and pathogens that affect bees, such as Varroa mites and Nosema. These pests can weaken bee colonies and reduce their ability to collect resources for hive construction, potentially leading to weakened hives. (C.Kremen et al,2010) (1)

Reduced Biodiversity: Climate change can lead to shifts in plant communities, favouring certain species over others. This can reduce floral diversity, potentially limiting the types of pollen and nectar available to bees. A diverse diet is essential for bee health and can impact their ability to construct and maintain hives. (Potts et al,2010) (1)

Impact of Temperature Extremes on Bee Behaviour:

Extreme weather driven by climate change can have a considerable impact on bee behaviour, impacting feeding habits, reproductive success, and colony health in general.

Foraging Patterns:Because bees are ectothermic, the atmosphere outside affects how hot or cold they are. They may be less able to forage for food in extreme temperatures, whether they are hot or cold. Foraging schedules may shift as a result of high temperatures, with bees being more active during the morning and evening hours to avoid the heat. (Reddyet al, 2012) (11)

Reproductive Success:Extremes in temperature can affect bees' ability to reproduce. For instance, high temperatures may impact the growth of larvae and pupae, affecting the colony's general health and production. (12)

Nesting and Hive Maintenance:Bees build and maintain hives to provide the best environment for their colony. Activities related to building and maintaining hives may be affected by extreme temperatures. The hive may need to make additional cooling efforts in hot weather.

Climate Change and Bee Habitats:

Flowers' capability to yield nectar and pollen, as well as their ability to grow, are all influenced by the climate (Winston, 1987) (13). Bees need to build up enough honey reserves to enable them to endure the winter. Changes in the distribution of the flower species on which honey bees depend for food (Goulson et al., 2015) (10) are one of the primary effects of climate change on honey bees. Bees in that area would suffer from an abnormally dry climate, which lowers pollen production and degrades its nutritional content (Memmott et al. 2007) (14). For the upbringing of the future workforce, a pollen diet is crucial. The lack of pollen brought on by the autumn drought will deprive bees of food in the winter, impair their defences against infections, and reduce their longevity. It's possible for tropical climates to develop into four separate seasons with dry intervals. In this situation, Asian honey bees would need to quickly intensify their honey-harvesting method in order to accumulate enough stores to endure times of scarcity. As in the instance of *Apis dorsata*, which rapidly migrates in response to seasons, flowering patterns, or interruption, they could also devise a migratory plan. To avoid starvation or predators, they abandon their nests and can travel up to 200 kilometres in the air. The same honey bee colony returns to its nests after several months of absence. The biological timing of the crop and its pollinators is essential for efficient crop pollination. Mangoes, litchi, coffee, and other crops have brief times of abundant blossoming, necessitating an enormous rise in pollinators. The timing of these events may significantly shift as a result of climate change. Pollinators that are already under stress from climate change may be severely impacted by the extreme weather events that will accompany global warming. Different responses of plants and insects to temperature changes result in temporal (phenological) and spatial (distributional) mismatches that have detrimental demographic effects on the species involved. Mismatches can cause plants to receive less pollen and insect visits, while pollinators have less access to food. Memmot et. al. (14) modelled how a network of highly resolved plant pollinators might adjust to rising temperatures. They discovered that phenological changes decreased the floral resources available to 17–50% of the pollinator species. Both pollinators and plants may suffer from a timing mismatch. Plants and pollinators might react differently depending on the temperature. For instance, warmer springtime temperatures may delay plant flowering while pollinators may not be impacted. The degree to which plants and pollinators react to the same temperature cues may vary (Hegland et al. (9). While Dormann et al. (15) predicted broad losses in future bee species richness in Europe, Williams et al. (2014) (16) identified a connection between climatic niches and declines in British bumble bees. The growth and development of colonies are closely related to flower development, nectar production, and pollen production. Bees must accumulate enough honey reserves to enable them to endure the winter. Enough pollen must be consumed by the nursing worker bees to feed the larvae through their pharyngeal glands. The distribution of the flower species on which honey bees depend for food has changed as a result of climate change, which has a significant impact on them. We are aware of how rain can affect bees' ability to collect honey. For instance, honey bees lose interest in acacia blooms when they are washed by rain because the nectar is too greatly diluted. The amount of flower nectar available for honey bees to collect will also decrease in an excessively dry climate; for example, when the weather is extremely dry, lavender blossoms don't produce any nectar, making honey bee gathering entirely speculative. In dire circumstances, honey bees may starve to death if the beekeeper is not watchful. We are aware of how rain can affect bees' ability to collect honey. It is challenging to foresee the direct impact of increased atmospheric carbon dioxide concentrations on honeybees and their plant hosts. Indirectly, increased atmospheric CO_2 is anticipated to alter carbon-to-nitrogen ratios in plant tissues, potentially changing the composition of nectar (17)

Extreme Weather Events and Colony Survival

Climate change is a universal phenomenon that is not limited by geography. The two main forces driving this process appear to be industrialization and deforestation, which together are causing the ozone layer to thin and the atmospheric concentration of carbon dioxide to rise. A significant alteration in the statistical distribution of weather patterns over timescales ranging from decades to millions of years is referred to as global climate change. It could be a shift in the distribution of weather events around the average or in the average weather conditions themselves (e.g., more or fewer extreme weather events). According to the Intergovernmental Panel on Climate Change (IPCC), global temperatures are expected to rise by 1.1–6.4°C by the end of the century. Climate change can have multiple kinds of effects on honey bees. It can have an immediate impact on their behaviour and physiology. It can also affect the development cycle by changing the quality of the floral environment and increasing or decreasing colony harvesting capacity and development (18). It is well known that each race of honey bees develops at its unique rate. Any type of climate change or movement of a honey bee race from one geographical place to another is certain to have quantifiable impacts. The impact of climate change on insects is determined by their thermal tolerance and adaptability to temperature variations. Rising global temperatures have caused more frequent and extended heat waves, which can harm honey bee hives. High temperatures can cause bees to become stressed, impair their foraging effectiveness, and shorten their lifetime. Heat stress-related losses in the hive can also result from prolonged exposure to severe heat (19). Droughts caused by climate change can diminish the availability of floral resources, affecting honey bee foraging. Water scarcity can also be a problem for honey bees, as they need water to regulate their body temperature and to dilute nectar for hive storage (20). Food shortages and heat stress caused by drought can weaken colonies and limit their ability to survive other stresses such as diseases and insecticides. Floods and storms can have a direct influence on honey bee colonies, destroying colonies and causing colony losses. Floods can severely affect colonies, disrupting the natural hive habitat and making them more susceptible to disease (4). Floodwaters may also carry pollutants including pesticides and toxins from agricultural runoff, which can harm bee health (21). Furthermore, the disruption of foraging patterns caused by flooded landscapes can add to the stress of honey bee colonies by limiting their access to food sources. Heatwaves may impact the thermoregulation of honey bees, resulting in heat stress and perhaps colony collapse (4). Temperature rises can also affect the availability of nectar and pollen, as some plant species may fail to produce blooms or nectar during periods of excessive heat (22). Heat stress can shorten foraging bees' lives and limit their foraging efficiency, lowering colony productivity. Storms like hurricanes and tornadoes can physically harm beehives and shift colonies from their established positions Such interruptions can result in the loss of both bees and resources, making recovery difficult for beekeepers. Severe winds and heavy rains might restrict the availability of floral resources, hampering foraging activity (23).

Pollinator-Plant Relationships under Climate Change for Honey Bees

Pollinator-plant interactions are essential for preserving biodiversity and environmental stability. Honey bees (*Apis mellifera*) are among the most important pollinators, supporting the reproduction of countless plant species, including many of our main crops. However, climate change is putting these vital interactions in jeopardy. The timing of flowering in plants can change as a result of variations in temperature and precipitation patterns. Plants that bloom sooner or later than when honey bee populations are active may interfere with their foraging patterns, resulting in a lack of food for colonies. Bees must accumulate enough honey reserves to enable them to endure the winter. Changes in the distribution of the flower species on which honey bees depend for food (29) have a significant impact on honey bee populations. Bees in that area would suffer from an abnormally dry climate, which lowers pollen production and degrades its nutritional content (24). For the upbringing of the future workforce, a pollen diet is crucial. Due to the pollen deficit brought on by the autumn drought, bees will suffer in the winter, losing strength and becoming more vulnerable to infections. The growth and foraging activity of colonies are directly influenced by flower development, nectar and pollen output, and climate (13) Bees must accumulate enough honey reserves to enable them to endure the winter. Changes in the distribution of the flower species on which honey bees depend for food (9) have a significant impact on honey bee populations. Bees in that area would suffer from an abnormally dry climate, which lowers pollen production and degrades its nutritional content (25). For the upbringing of the future workforce, a pollen diet is crucial. Due to the pollen deficit brought on by the autumn drought, bees will suffer in the winter, losing strength and becoming more vulnerable to infections. Effective pollination of crops is greatly influenced by the biological timing of the crop and its pollinators. Mangoes, litchi, guava and other crops have phases of mass blossoming over very brief times, necessitating a huge rise in pollinators. The timing of these events may be significantly impacted by climate change. Pollinators already under stress from climate change could be severely impacted by the extreme weather events that will accompany global warming. Changes in temperature affect insects and plants in various ways, leading to temporal (phenological) and spatial (distributional) mismatches that have negative demographic effects on the species involved. Mismatches can cause plants to endure decreased insect visits and pollen deposition, while pollinators encounter decreased food availability. The impact of rising temperatures on a finely detailed plant-pollinator network was modelled by (14). Honey bees may find it increasingly challenging to synchronise their foraging activities with blossoming plants when temperature and weather patterns become more unpredictable. This may lead to decreased pollination efficiency, which could impact plant reproduction. A temporal mismatch can be harmful to pollinators as well as plants. Plants and pollinators might react differently depending on the temperature.

Bee Health and Disease Dynamics

Temperatures have increased as a result of climate change, changing the dynamics of bee health and disease. Changes in temperature can have an impact on bee pathogens like Nosema and certain viruses. Warmer temperatures may boost these diseases' chances of survival and reproduction, which could increase the likelihood that bee populations will become infected (26). The geographic distribution of viruses and pests that affect bees could vary as a result of changes in the climate. Parasites like the *Varroa destructor* mite may spread into areas that were previously unsuitable for their existence when temperatures rise. This may raise the incidence of these pests overall and expose previously unaffected bee populations to fresh dangers (27). The dynamics of disease may be intensified by new contacts between bee species and their parasites brought on by range expansion. The shift in flowering patterns in plants due to climate change disrupts the synchrony in bees foraging activities and floral resources this results in nutritional stress which weakens their immune systems and makes them more susceptible to pathogens (28). The potential effect of climate change could have a significant impact on the virulence and spread of these illnesses and parasites. These diseases typically exhibit a variety of virulence-varying haplotypes. These haplotypes may spread to honey bee populations as a consequence of climate change (18). Honey bees of various kinds and races might encounter illnesses with which they have never co-evolved as a result of climate change-induced movements. One such example is the situation between *Varroa destructor* and *Apis mellifera*. *Varroa destructor* clings to bees and feeds on their bodily fluids, spreading viruses that can weaken and kill bee colonies. Varroa mites are now present in previously inhabited places as a result of climate change. *Nosema ceranae* infects honey bee stomachs with this microsporidian parasite resulting in diarrhoea, decreased foraging effectiveness, and impaired immune systems. *Nosema ceranae* infections may become more common as temperatures rise. A harmful virus spread by Varroa mites is called the Deformed Wing Virus (DWV), higher temperatures may facilitate the virus's multiplication and spread inside bee colonies. American foulbrood is a bacterial infection brought on by *Paenibacillus larvae* that can completely destroy bee brood. The frequency of American Foulbrood outbreaks can be impacted by variations in temperature and humidity patterns. Climate change impacts bee health by influencing the prevalence and distribution of diseases and pests. To mitigate these risks, it is critical to continue researching the interactions between climate change and bee health and to begin implementing honey bee population protection strategies.

Genetics and Behavioral changes

In the world, 73% of the crops grown are dependent on honey bee pollination. The environment's temperature affects the honey bees' activities since they are ectothermic. Considering this, bee biology, behaviour, and distribution may be impacted by climate change, which is characterized by increased temperatures. A change in temperature could lead to significant population implications by creating temporal (phenological) and spatial (distributional) mismatches. Asynchrony may cause plants to receive fewer insect visits and pollen deposits, while bees have less food available to them. There are very few thorough studies measuring the effects of climate change, whether they are detrimental or not.The beekeepers voiced concern about the increased effort and time spent by honey bees in pursuit of these two vital inputs due to the drop in local food and water supplies, which can harm the hive's health and honey production.*Apis mellifera*, the European honey bee, has the capacity to adapt to hot environments. For instance, *Apis mellifera*sahariensis is a plant that grows in the Sahara's oases and has adapted to the region's severe heat and local bloom, such as palm blooms. Honey bees can grow in the Arizona Desert in the United States.These bees need water to survive, which they use in copious amounts to develop their larvae and keep the temperature of the brood between 34 and 35 degrees Celsius. Deserts are found in arid climates. The bees perish because flowers are unable to supply them with enough water. Climate change projections state that even more arid conditions will result in the loss of the oasis and the honey bees that lived there. *Apidium mellifera* It is extremely improbable that sahariensis will move naturally to greater because oases are secluded and advantageous desert regions poorly suited for swarming or long-distance migration. it is crucial to think about conservation strategies to move this bee to areas that will promote its development. The life cycle of honey bees may be impacted by climate change. Everyone agrees that honey bee races mature at different rates. Therefore, any type of climate change or the relocation of a race of honey bees to a foreign geographic area is sure to have observable effects. In cold climates, honey bees spend the winter bundled up tightly and rely on their honey reserves for the energy they require to make it till April.Significant adaptive pressure is exerted by the honey bee's capacity to store energy and control the colony's growth. The colony grows and the worker population rises in the spring when the weather is more agreeable and the queen begins to lay eggs. The honey bees might be unable to produce during a cold spell that lasts for several weeks. The enormous honey bee population quickly depletes its food supplies, which puts the colony in danger of starvation. Justbecause they grow so quickly in the spring, hybrid bees—bee breeders' crosses of several races—can easily experience it. Local ecotypes that are more acclimated to the local environment, on the other hand, are more circumspect and grow more slowly in the spring until after this cold snap when they reproduce quickly. They avoid endangering the colony's life in this way. Therefore, it is necessary to draw a distinction between local ecotypes, which must adapt their growth and stores to the climate, and hybrid bees chosen by bee breeders. The result is that hybrids have not been bred to increase food reserves, the queen does not alter her egg-laying, and the workers do not alter their larvae-rearing, making it impossible for the bees to survive without the help of a beekeeper who can supply them with an endless supply of sugar solution. The plasticity and genetic diversity of the honey bee's life history features in relation to temperature and the environment suggests that this could lead to the selection of development cycles appropriate for novel climatic circumstances.

Impact on pollination services

Except for grains, many food crops are entomophilous, meaning that they rely on insects for pollination. Bees pollinate 19% over 73% of the world's crops (Abrol, 2009). The removal of resources from flowers, such as nectar, pollen, or both, benefits pollinators in return. This reciprocity has developed over the years, benefiting both natural terrestrial ecosystems and agroecosystems that humans have created. The impact of climate change on insects relies on how adaptable they are to temperature changes and changes in temperature. Investigating the variations in heat tolerance among subspecies is urgently necessary. The highest daily temperature, the number of days (the number of days with an average temperature within a given range), and the duration of the day are the environmental signals that control the bee phenomenon. Feverish bees need a high body temperature to fly. Their level of exploration is influenced by their surrounding temperature (12). Small bees quickly absorb heat at high ambient temperatures because of their high surface-to-volume ratios. All bees weighing more than 35 mg (Apis, Bombus, Xylocopa, and Megachile) may be heated endothermically. Foraging is hampered by the time needed for thermoregulation at higher temperatures. Pollinators are susceptible to overheating when temperatures rise, especially in regions with high ambient temperatures and consistent weather patterns. Pollen removal and deposition efficiency will also change.The lack of local vegetation is not the only food-related problem that climate change is causing for honey bees. Honey bees have been finding less nectar in nearby wildflowers, such as bluebells (*Campanula patula*), per A5. The honey bee's capacity for storing energy and controlling colony growth places considerable adaptive pressure. For instance, when the weather starts to warm up in the spring, the queen starts to produce eggs, the colony expands, and the number of workers rises. It is possible for a cold wave to linger for several weeks during which honey bees are unable to leave their hives to go foraging. The honey bee population is so large that food supplies are depleted so quickly that the colony may starve to death. Nectar and pollen production are directly impacted by climate, as well as flower productivity.A honey bee colony can starve to death because of the high number of the population, which causes a rapid depletion of stores. According to Winston (1987), the production of pollen, nectar, and flowers is closely tied to colonial growth and the generation of food. In order to stay warm, bees must gather enough honey. The distribution of flower species, from which bees obtain their food, is what has the greatest effect of climate change on bees (29). Extremely dry environments can harm home bees by lowering pollen output and nutritional quality (14). Future workers must consume pollen for proper development.Bees are deprived in winter, their immune systems are compromised, they are more vulnerable to diseases, and their lifetime is reduced due to pollen deficit brought on by autumn drought. Dry seasons allow for the development of tropical climates with more pronounced seasons. In this situation, Asian honeybees must act swiftly to improve their honey collection method in order to build up sufficient stocks to withstand the period of shortage.

Conservation and management strategies

All climatic variations influence honey bees' local livelihoods, which in turn affects their health and well-being.The beekeepers shared the primary strategies for reducing the effects of climate change. According to beekeepers, providing the colonies with extra food is the most crucial response to the absence of nectar. In addition to cold temperatures and no flowering seasons, such as late Autumn and winter, syrup or sweets must be available for their survival throughout harvest seasons.As there is insufficient protein nutrition for honey bees, there is no workable remedy to the paucity of pollen caused by climate change. As a result, intensive transhumance emerged as a need, necessitating the summertime relocation of bee hives to hilly regions. The farm's financial stability and the absence of resources can be compensated for by new blooms and locations.

Beekeepers have called attention to the critical issue of V. destructor parasitism. Because of the expansion of the queen's oviposition in the winter due to climate change, the mite reproduces continuously. As a result, the efficiency of control is reduced, necessitating additional measures (such as completely removing all brood and intentionally halting brood production by seasonal and winter queen caging). Beekeepers noted that in order to reduce varroa, a variety of treatments, including synthetic acaricides, and oxalic and formic acids, must be used. Additionally, the treatment time must be delayed owing to the weather.

The necessity to frequently replace queens, due to poor fertilization, was noted by an apiarist. Beekeepers had to boost the output of nuclei in order to preserve the bee stock and, consequently, the viability of the farm. In addition, they had to make sure that the most recent honey stock was available so that they could equalize the colonies even during seasons other than fall and have stronger colonies.

Modelling and future predictions

Due to climate change, proper steps and initiatives should be taken to preserve the bee population. Considering the importance of honey bees in the environment, the right approach should be taken and below are some of the steps which can be considered (30)

Climate change models-Climate change mitigation models: Emission Reduction Models: Reducing greenhouse gas emissions is one of the best methods to safeguard honey bee populations. Different emission reduction scenarios and their effects on the future climate can be simulated using climate models. Reduced emissions can lessen the severity of climate change's effects on bee habitats and food sources.

Renewable Energy Transition Models: Reduce carbon emissions and slow down climate change by switching to renewable energy sources like wind and solar energy. Climate models can be used to evaluate the possible advantages of adopting renewable energy on bee populations.

Land Use Planning Models: To find places that are favourable for the preservation and restoration of bee habitat, climate models can be combined with land use planning models. Bee populations can find sanctuary in shifting climates by preserving and increasing bee-friendly habitats.

Habitat Modelling: Habitat modelling involves predicting changes in vegetation and flowering patterns using climate data. With the use of these models, conservation efforts can be directed at places where bee forage may be declining as a result of climate change.

Species Distribution Models: Climate information is used in species distribution models to forecast how the range of honey bee subspecies may change in response to changing conditions. The choice of bee stocks that are better suited to upcoming climates and conservation efforts can both be influenced by this information.

Crop and Pollination Modelling: Models that predict how crop yields and pollination services will be impacted by changing climatic circumstances might help guide agricultural practises and regulations. With the use of this knowledge, farmers and beekeepers may take proactive steps to preserve pollination services while protecting bee numbers.

Integrated Assessment Models (IAMs): IAMs incorporate economic, environmental, and climatic models to assess the trade-offs and interdependencies between various policies. They can assist decision-makers in deciding on mitigation and adaptation strategies for climate change that will benefit both honey bee populations and human communities.

Monitoring and Early Warning Systems: Climate Monitoring Systems: Systems for monitoring the climate in real time can offer useful information for determining how climate change will affect the habitats of honey bees. Satellite images, weather stations, and remote sensing are some examples of these systems.

Early Warning Systems: Early warning systems can forecast extreme weather conditions, such as droughts and heatwaves, which can have a detrimental effect on honey bee numbers. These details can be used by conservationists and beekeepers to take preventative measures.

Citizen Science Models: Through citizen science initiatives, the general public can be involved in monitoring and conservation efforts, which can help us better understand how climate change affects honey bee populations. To analyse the data gathered by citizen scientists, models might be created.

Policy Models: Models can evaluate the efficacy of regulations meant to curtail pesticide usage, protect pollinator habitats, and advance sustainable agriculture. They can assist decision-makers in protecting honey bees by assisting them in doing so.

Management Models: The location of hives, the timing of hive splits, and beekeeping techniques can all be altered to accommodate changing climatic circumstances with the use of beekeeping management models.

As the effects of climate change alter over time, ongoing monitoring and adaptation are crucial. Implementing successful solutions to safeguard honey bee populations in a changing environment requires cooperation between scientists, decision-makers, beekeepers, and communities.

Collection of historical data- Collecting the historical data of the honey bee population in the region should be done to track the record of the declining population and proper measures should be taken. In addition to details on hive counts, colony health, and environmental factors (such as temperature, precipitation, and vegetation), this data should span several years or decades.

Habitat analysis- Evaluation should be done on how climate change might affect honey bee habitats. Bee populations can be strongly impacted by changes in vegetation, flowering cycles, and the availability of foraging resources. To evaluate habitat changes, employ land-use models and remote sensing data. (30)

Adaptation strategies- Create adaptation methods to lessen the effects of climate change on honey bees based on the findings of our modelling. Changes in land use, conservation initiatives, and beekeeping techniques may all be part of these plans.

Habitat Restoration and Enhancement: Plant Native Bee-Friendly Flora: Encourage the cultivation of native plants that provide nectar and pollen for honey bees, as well as wildflowers. These local species are frequently better adapted to the climate there.

Create Pollinator-Friendly Landscapes: Encourage local governments and landowners to create landscapes that benefit pollinators. This may entail establishing meadows, pollinator gardens, and a decrease in the usage of perfectly trimmed lawns. (31)

Preserve Natural Habitats: The meadows, woodlands, and wetlands that offer honey bees vital forage and places to nest should be preserved and protected.

Adaptive Hive Management: Based on the climate in their area, beekeepers can modify their management techniques. To take into account changes in blooming patterns and weather, they might need to adjust the schedule of hive inspections, hive splitting, or extra feeding.

Bee Stock Selection: Choose bee stocks that are better able to adapt to changing climatic conditions, such as those with greater foraging and disease-resistance skills.

Reduced Pesticide Use: Encourage people to use fewer pesticides, especially when flowers are blooming. Encourage the use of integrated pest management (IPM) techniques that put pollinator protection first.Andrews et al., (2022). (32)

Diversify Cropping Systems: To guarantee a constant supply of forage materials for honey bees, encourage the development of diversified agricultural landscapes that include a variety of crops and flowering plants.

Research and Monitoring: Keep an eye on honey bee populations, forage availability, and weather patterns to determine how well adaptation tactics are working and to make any necessary corrections.

Research on Climate-Resilient Bees: Encourage studies on choosing and developing honey bee strains that are more tolerant of shifting climatic circumstances.

Monitoring and feedback- Monitoring climate variables and honey bee numbers over time can help us validate and improve our models. In order to increase the precision of our forecasts and modify our techniques as necessary, this feedback loop is essential.

Policy Implications and Future Directions

A multifaceted strategy involving research, policy, and conservation efforts is required due to the vulnerability of honey bee populations to the effects of climate change. Adopting energy-saving measures, sustainable land-use practises, and renewable energy sources are all crucial steps in the mitigation of climate change (30). Strong policies are also needed to reduce greenhouse gas emissions. Policies protecting bee habitats—such as wildflower meadows and diverse landscapes—are essential, and promoting sustainable farming practises like organic farming and integrated pest management can reduce the need for chemical pesticides. Honey bee health, physiology, behaviour, and susceptibility to stressors induced by climate change should be the focus of increased research and monitoring efforts.A strong monitoring program's establishment and upkeep are essential for tracking honey bee populations and identifying trends over time. Engaging farmers and decision-makers requires educational outreach, such as public awareness campaigns about the importance of honey bees and the dangers of climate change (32). These initiatives are strengthened further by offering tools and instruction on efficient management and conservation techniques for honey bees. In order to increase populations' resistance to stressors related to climate change, breeding programmes that promote genetic diversity are crucial. Research and development of resilient honey bee strains that can adjust to shifting environmental conditions should be the main focus of these efforts. In summary, the implementation of adaptive management strategies is imperative to maintain successful conservation efforts for honey bees in the face of climate change. These strategies involve flexible policies that adjust to new scientific discoveries and threats. (33)

Conclusion

Since the effects of climate change have only recently come to light, it is important to comprehend how this global phenomenon affects bee activity and its interactions with crop plants before developing specific mitigation strategies. Despite concerns about the potential negative effects of climate change, there is a dearth of scientific research on the precise effects pollinators will have, particularly on crop plants. Particularly in the tropics, where the diversity of entomophilous crops is anticipated to be highest, there is a lack of knowledge regarding the temperature sensitivity of crop plants and their pollinators.

Despite the fact that numerous studies have been presented regarding the toxicity of pesticides to honey bees, a proper management strategy to reduce honey bees' exposure is still lacking. However, all pesticide applications should be carried out in a way that minimises their contact with honey bees in order to stop the global decline of honey bee populations. In order to make the current management strategies more effective in the future, farmers and beekeepers must educate themselves about the harmful effects that various agrochemicals have on honey bees. This can be done through an extension programme.

Since *Apis mellifera* can be found almost everywhere in the world and in a wide range of climates, it has demonstrated a remarkable capacity for adaptation and can make use of its genetic variability to adapt to climate change. (30) (31). The Asian species, on the other hand, have persisted in Asia, which may indicate a lower level of environmental adaptability and fragility in the face of climate change. Therefore, human intervention in the form of beekeeping is crucial for maintaining the various ecotypes of the two domestic species, *A. cerana* and *A. mellifera*. More research is required to improve our understanding of the fundamental ecology of crop pollination in the context of climate change.

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