Review Article

European Honey Bee (*Apis mellifera* L.) Foraging Activities, Impacts and Potential Factors of Decline- A Review

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Abstract | Honey bees pollinate various crops, fruits, vegetables, and nuts (*Apis mellifera* L.) is known to participate in foraging. Foraging behaviors in honey bees include seeking for food, recognizing and remembering the location of food sources, transporting and storing food, and interacting with other bees. The foraging activities of honey bee colonies connect them to their surroundings. As a result, several in- and out-of-colony factors impact this behavior. Foraging is advantageous not only to plants and insect colonies but also to humans. Honey bees helps preserve ecosystems as they offer pollination to many wild flowering plants. These pollinators are now under attack from a variety of sources. Pesticides, habitat degradation, genetic diversity loss, inclusion of genetically modified crops, and parasites are among the main threats to these pollinators. As a result of their decrease, there has been a significant loss of ecological activities, negatively influencing the global economy. This work covers the management of foraging activities, factors influencing this behavior, foraging preference, subspecies variations, monitoring approaches, and the need of preservation and conservation of these essential pollinators. To determine honey bee ecotypes and local species that are more resistant to pests, diseases, and pesticides, as well as to quantify the synergistic impacts of the probable causes of present colony loss, further research is required.

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Introduction

Pollination is an essential phase in the reproductive processes of the 300,000 flowering plant species on the planet since it permits seeds to be formed (Phillips *et al*., 2020). Both animals and people benefit from flowers because they provide fiber, shelter, and food (Oguh *et al*., 2021). Aside from a few vegetables and cereal crops, biotic pollination accounts for the bulk of global crop production (Das *et al*., 2018). Insect pollination boosts output by 75% in various globally important crops (Tamburini *et al*., 2019). Consequently, insect pollination benefits people both directly and indirectly (Alomar *et al*., 2018). Bees (mostly honey bees) and other pollinator insects pollinate a wide variety of fruits and agricultural commodities, and bees and other pollinators contributes $599 billion annually to comprehensive agricultural consumption (Al-Naggar *et al*., 2018). One-third of the food is provided by plant species that rely on pollinators or are pollinated byhoney bees (Ullah *et al*., 2021).

Bees are the most common pollinators (Hung *et al*., 2018). According to National Research Council statistics from 2007, published bee species worldwide are about 17,000. According to the UN Food and Agriculture Organization, bees pollinate 71 of 100 crop types that provide 90% of the world's food (FAO). The European bee (*Apis mellifera* L) is the world's most important species of bee, pollinating the world's most important crops (Neov *et al*., 2019), is also often associated with pollination tasks that are performed by other bee species (Beaurepaire *et al*., 2020). Honeybees pollinate a variety of agricultural commodities, including grapefruits, apples, almonds, soybeans, and strawberries, according to the United States Department of Agriculture (Merechal and, 2019; Pfrogner, 2019). As a result of the significant relationship between a plant variety and pollinator diversity, honey bees' activity as pollinators contributes to biodiversity conservation (Winfree *et al*., 2018; Stanley *et al*., 2020).

Honey bees take nectar and pollen from flowering plants to transport pollen to most plants. Each year, agricultural items, fruits, and vegetables pollinated by bees are worth USD 21 billion in North America (Jordan *et al*., 2021). Honey bee pollination is projected to be valued between CAD 4 billion and 5.5 billion to Canadian agriculture each year (Punko, 2021). benefits in the United States were expected to be worth roughly $40 billion per year, while benefits in Australia were predicted to be worth AUD 156 million per year.

Forager honey bees are state laborers who have been in the colony for over 21 days and are gathering nectar, tar, dust, and water outside the settlement. Colony parameters influenced labor division and the nurse bee's ability to execute foraging activities (Chen *et al*., 2021). Differences in messenger RNA quantity in the worker bee's brain are also significant (Ustaoglu *et al*., 2021).

The following are the most critical foraging tasks

Scout bees hunt for the most incredible food resource, whereas hesitant bees wait for the scout bees; when they come back, they perform specific body moves called the waggle dance. Body moves notify the source location by considering the sun's directions. Reluctant bees make up about forty to ninety percent of the forager population (Begum *et al*., 2021). This body move saves the time and efforts of foragers bees. Significant differences in brain expression of genes such as y-aminobutyric acid signaling, glutamate, and catecholamine were discovered among food scouts and other foragers (Qin *et al*., 2012). A shift from foraging to sleep may happen in various ecological situations (Willart *et al*., 2012). Forager bees require a much of sleeping each night, and sleep deprivation can damage honey bee navigation systems (Wray *et al*., 2012).

Based on the resources available to forager bees, foraging activity can be divided into four categories: pollens, resins, nectars, and water. Ceroplastes species of scale insects may provide wax to these bees in rare instances (Klein, 2021). It was discovered that any form of foraging, whether for nectar or pollen, is a colony-level responsibility that involves genetic factors (Bagheri and Mirzaie, 2019). Individual forager bees are responsible for such obligations, requiring group decisions. During collective foraging, experienced bees are enthusiastic in a feeding location. Pollen foragers are likewise subjected to colony rules, and foragers utilize their trophallactic interactions to assess colony requirements (Zarchin *et al*., 2017). When pollen sources are few or of poor quality, the number of pollen foragers rises, but the pace of foraging does not (Price *et al*., 2019). The insulin receptor substrate (IRS) modulates pollen and nectar foraging decisions. Many factors appear to impact foraging behaviour, and more research into these aspects is needed.

According to studies, foragers of honey bees usually start their foraging activities with the start of day and stops in late evening. Schmutz *et al*. (2010) studied that worker of honey bees began their foraging activity about 6.10am. When atmospheric conditions are dry or arid, the high numbers of foragers leave the colonies for foraging about 8am (Alqarni *et al*., 2019). From dawn to sunset, foraging activity might change dramatically.

Pollen collection was greatest in the morning hours and low in the mid evening (Vijayan *et al*., 2018). Currie *et al*. (2010) studied that forager worked more vigorously in the noon (35 workers/min) than in the early (17.60 workers/min). From 8.20 am to 4.30 pm, honey bees visited onion buds, with high foraging activity between 11 am and 12 am (Painkra *et al*., 2021). Paul (2017) studied that forager can remember the day when the most numerous food sources are available, as shown by *Sysirinchium palmifolium* plants. Mostly bees spend a maximum of five minutes on each flower during foraging activity (Vlot *et al*., 2008), although the amount of time spent on each flower varies depending on the kind of plant. Chinese cabbage, Broccoli, and Kohlrabi spent 6.92, 6.50, and 5.54 seconds per bloom, respectively (Sushil *et al*., 2013).

The energy hypothesis, which recommends that foragers calculate feeding distances through energy lost during flights, has been discredited (Margalida *et al*., 2017). Each thought can be viewed as a mixed image because both the energy used during the flight and the motion of the ground image created by the retina are expected to measure and calculate the distance. *A. melifera's* average scrounge distance was 1527.1 meters. The rummaging distance of dust gathering honey bees was around 1.6 km in scene regions and 1.4 km in more extreme circumstances.

A. mellifera normally visits the flowers about 0.6 km in July and they can go up to 1.4 km and 2.8 km for small colonies and for large colonies (Beekman and Vastenhouw, 2004). The foraging range of honey bees is 0.04 to 6 km (Paul, 2017). To acquire water in dry regions, water foragers can fly up to 2 km to the colony. The distance of foraging for colonies seems to be influenced by food availability, colony strength, race, the month of the year, and even the time of day.

Factors influencing foraging behavior

An assortment of conditions impacts foraging conduct. The presence of a honeybee queen and the accessibility of a virgin or mated queen are among the basic groupings of these factors (in-state factors). Compared to mated queen colonies, virgin queen colonies foraged more but collected less pollen, whereas queenless colonies collected less pollen and had less searching movement than mated queen colonies. The kind of beehive impacts honey bee foraging activity (Abou-Shaara *et al*., 2013). Diseased foragers, especially parasites, cannot return to their colonies in time, taking longer. In addition to these features, the number of ovaries in the queen bee's ovaries can affect the ability of worker bees to collect nectar (Paul, 2017).

Regarding the parameters that determine forager activity, *A. mellifera* bees have chosen to feed at 6.56°C (Tan *et al*., 2012). The high foraging behavior was recorded at 20°C (Tan *et al*., 2012), whereas the minimum was observed at 10°C, and the most increased activity followed at 42.44°C (Blayt-erekien *et al*., 2010). The relationship between foraging activity and temperature is inversely proportional (Abu-Shara *et al*., 2013). It isanticipated that the rise in temperature would have a passive impact on foraging activities. On the other hand, relative humidity had a lesser influence on flight activity (Abou-Shaara *et al*., 2017). More study is needed to comprehend these phenomena completely.

What is the importance of foraging?

Apart from the apparent consequences of honey bee foraging (collecting nectars, pollens, water, and resins), foraging for honey bee colonies has further implications, especially for plants where honey bees are the dominant pollinator (Baldock *et al*., 2019). Blueberries, apples and pears, cantaloupe, rape variations, and other species have been honey bee-pollinated plants (Khalifa *et al*., 2021). In addition, seed quality and quantity increased in the Allium cepa, onion, and Valencia cultivars (Caselles *et al*., 2019). Foragers also benefit from nitrogen deposition (in the form of excrement) on plants during visits (Mishra *et al*., 2013). A 5000-bee colony's average monthly rate of bee frass production was found to be between 2.27 and 2.69 g nitrogen. Biocontrol agents such as *Erwinia herbicola* Eh252 of fire blight may also be disseminated by forager bees on apple blossoms and nashi flowers. A new high-performance 'Triwaks' dispenser was created to give forager bees an edge when dispensing biocontrol pesticides. The activity foraging of bees is a biological indicator for indirect indication of pesticide residues available in the environment (Vijaykumar and Shivshankar, 2017). Insect infections may also be detected by bee foraging. Fruit flies, for example) (Chamberlain *et al*., 2012). Pollen traps or poison collection boards may be placed in front of hives to gather pollen or venom, respectively, to take advantage of their colonies' foraging activity (Sushil *et al*., 2013).

Honey bee loss' ecological and economic consequences

Pollinators like honey bees are essential for ecosystem preservation; when these pollinators become extinct, other ecological components suffer (van der Sluijs *et al*., 2021). Honey bees are the primarily controlled pollinators in most agricultural monocultures across the globe. Pollinator decline is associated with poorer agricultural production (Fijen *et al*., 2020), resulting in ecological and economic losses. The disappearance of honey bees throughout the globe has brought attention to the problem of global food security (Wood *et al*., 2020). In North America and Europe, crop-pollinating bees, butterflies and bumblebees have been reported to die due to low agricultural production worldwide. Honey bees provide many benefits to the plants when they visit different flowers for pollination or feeding. During this process, honey bees provide more nitrogen to plants (Mishra *et al*., 2013). They pollinate a wide range of wildflowers and help maintain biodiversity in various settings (Koyama *et al*., 2018). The International Union for Conservation of Nature (IUCN) predicts a global loss of 20,000 flowering plant species over the next few decades, decreasing pollinators like honey bees. In addition, the loss of pollinators results in a decline in plant diversity (Wu *et al*., 2018).

As shown by the dwindling honey bee population, the importance of pollinating activities has traditionally been far greater than the present market price for moneymaking fertilization (Ferrier *et al*., 2018). Consequently, they are crucial for both the economic benefits of sustainable farming and the food and nutrition security they provide. The present fall of honey bee numbers underscores the need to investigate the possible economic consequences of this trend. There will be considerable financial losses due to poorer agricultural yields and ecosystem productivity due to the decline of these pollinators. The primary reason for agricultural production reduction is a lack of pollinators, which, along with other environmental factors, results in decreasing production of yield from pollinated crops.

Elements that may cause honey bee production downfall

Honey bee numbers have been dropping in recent era, perhaps due to agricultural development, illnesses, habitat alteration or disintegration, insecticides, absence of nutrition, hereditary variation forfeiture, and shortage of food. Human disturbances have yet to be determined in relationships of honey bee numbers and species fertility (van Engelsdorp *et al*., 2010). Climate factors, availability of nest galaxy, food supplies, and long-term chemical contact may influence CCD symptoms (Li, 2021). In many regions of the globe, diseases and parasites are now regarded a danger to colony destruction. The decline of honey bees might be caused by a number of factors (Genersch *et al*., 2010).

Diseases infections and parasites

Bees are infected by twenty positive-strand RNA viruses, the majority of which are members of the Iflaviridae and Dicistroviridae family (Genersch and Aubert, 2010). Until the bee mite *Verruva destroyer* was developed, the disease was thought to be harmless (Evans and Schwarz, 2011). Nevertheless, they are now considered to be the cause of colony extinction. The Israeli severe paralysis virus, the Kashmir bee virus (KBV), and the acute bee paralysis virus all seem to have *V. Destroyer*as a viral transmitter and activation (Berthoud *et al*., 2010). The deformed wing virus (DWV) of Iflaviridae family appears to have been not only vectorized by Varroa but also mimicked within a mite (Genersch and Aubert, 2010). The DWV is moved vertically by drones and queens and horizontally by larval feeding. When the *V. distructor* infects the pupae, it causes poor feathers and other signs, including a tiny and swollen belly (Tej *et al*., 2017). As a result, bees die within 67 hours of their first appearance (Guichard *et al*., 2020). DWV has been identified as a probable reason of gathering loss since it may work self-sufficiently of Varroa mites (Roberts *et al*., 2017). According to the researchers, low winter temperatures aided virus-related contagion in bees, and the severity of DWV contagion was linked to *V. distructor* population. They also discovered that the host atmosphere impacts the outcomes of the DWV bee integrities trial.

Bacterial pathogens of honeybee

Honey bees have two main bacterial illnesses, European Fulbroad and American Foulbrood are caused by *Melissococcus plutonius* and *Paenibacillus* larvae, respectively (Joczyk-Matysiak *et al*., 2021; Grossar *et al*., 2020). *Paenibacillus* larvae produce spores, making it more challenging to maintain than

M. plutonius larvae, which do not generate spores. Bacteria may enter the larvae's midgut and proliferate there, consuming most of the larvae's food has been taken away from them, forcing them to die (Leska *et al.*, 2021).

European foulbrood

European foulbrood has been found everywhere in the world where honey bees reside, and it is quickly spreading in the UK and Switzerland. Initially, bacteria induce undetected colonisation of honey bees until the bees begin to exhibit signs of illness. Bee larvae die as a result of the disease (Pasho *et al.*, 2021). As it hasn't been recorded in many countries, so EFB isn't regarded as a critical role in colony losses (Teixeira *et al.*, 2020).

American foulbrood

The American foulbrood (AFB) has an impact on the bee brood. In many countries, it is a sickness that must be recorded. American foulbrood very infectious and quickly spreads both inside and across colonies. To prevent the illness from spreading further, such AFB colonies should be destroyed. The apiary sector has been the most affected by AFB. The yearly economic loss in the United States due to AFB infection was projected to be more than $50 million in the year 2000 (Eischen *et al.*, 2005).

Pesticides

Pesticides and other pollutants may poison honey bees. These compounds affect pollinator nectar supplies and honey bee nesting materials are being reduced (Barbosa *et al.*, 2015). Pesticides, particularly neonicotinoids, are likely the main cause of honey bee extinction (Hashimi *et al.*, 2020). Poisonous neonicotinoids interact synergistically to spread infectious illnesses such as Neonicotinia ceranae, resulting in colony loss (Tsvetkov *et al.*, 2017). Despite this, there is no known link among neonicotinoids and Colony Collapse Disorder (CCD). Furthermore, nutritional neonicotinoids have minimal impact on reducing honey bees (Van der Sluijs *et al.*, 2013).

Other chemicals, in addition to neonicotinoids, have been discovered as harming honey bee survival. There was a greater frequency of nosema infection in bees that ate pollen with a higher fungicide load (Belsky and Joshi, 2019). Similarly, large pesticide imidacloprid residues in nectar and pollen might kill bees (Lentola *et al.*, 2017). Other pesticides, such as acaricides, have also been shown to be hazardous to the health of bees. The most prevalent pesticide pollutants detected in hives are beekeepers' pesticides, and residues have been related to a variety of sub-lethal consequences. Pesticides with sublethal effects may have unexpected repercussions, such as lowering foraging activity (Lämsä *et al.*, 2018).

Diet

Nutrition is critical for honey bee numbers and health (Lawson *et al.*, 2021). Honey bees that don't get enough pollen to acquire all of the amino acids may grow feeble, leaving them more vulnerable to diseases and illnesses. To avoid nutritional deficiencies, build immune systems, and stay healthy, foraging bees need a variety of natural pollen and nectar (Alaux *et al.*, 2010). Plant variety preservation and improvement activities might help provide better feed for honey bees, reducing the risk of starvation.

Colony collapse in genetically modified crops

The primary goal of developing genetically modified crops was to protect crops from pests and pesticides. Crops with pesticide properties that have been genetically engineered may have a negative, influence on bees but the not lethal. This concern regarding genetically modified crops negative impacts, on the other hand, has not been proven (Arpaia *et al.*, 2021). Pollen from *Bacillus thuringiensis,* Bt. maize had no effect on worker bee or colony death. There is no conclusive evidence that GMO crops cause severe poisoning in honey bees (Hristov *et al.*, 2020).

Weather and climatic factors contribute to honey bee colony decline

Climate change has an important influence on bee populations. In the past, prolonged spells of hot, cold, and rainy weather have been connected to large, often unexplainable, honey bee mortality (Neov *et al.*, 2019). According to beekeepers, unembellished winter time is also accountable for winter death in the United States. Due to decreased metabolic demands on foragers, higher temperatures improve colony output, making climatic conditions beneficial for colony development (Stanimirovi *et al.*, 2019). More outstanding nectar production is linked to frequent periods of severe temperatures and enough rainfall, which leads to increased colony output (Applegate, 2021). The harsh winter weather is mostly to blame for the colony's demise.

Other causes of colony collapse in honey bees

In addition to the reasons listed above, there are others such as parasites, pathogens, and competition from invading non-native animals and plants in a specific location. *Crithidia mellificae* is a parasite that impacts colony mortality throughout the winter months (Gómez-Moracho *et al*., 2020). In certain circumstances, environmental variables may play a role in honey bee decline. Exotic plants and land use negatively influence the connections between pollinators and specialized plants (Grass *et al*., 2013). Invasive plant and insect species can threaten native honey bee populations across the globe. There is a need of investigation impact of invading wildlife, vegetation, pathogens, and diseases on native honey bees.

Conclusions and Recommendations

Honey bees are the most essential pollinators, but their foraging activities have been disrupted due to various reasons, especially climate fluctuations and certain weather conditions. Pathogen and disease attacks on honey bees have grown due to changes in the environment, resulting in a population drop. Pollinator declines, particularly among bees, have been linked to several humanitarian causes, including pesticide exposure, habitat loss owing to industrialization, and forest degradation. GMOs created with cutting-edge technology have also impaired bees' ability to pollinate. Numerous steps are necessary to offset the loss of these important pollinators and the problems that come with it, as a result of their sudden absence. Understanding the economic and pollination requirements of each species is critical for minimizing environmental harm and loss. A country must provide pollination services (like awareness and training activities for honey bee foraging to farmers) in order to maintain a sustainable level and reduce greenhouse gas emissions. To protect honey bees from the negative effects of pesticides, farmers may employ non-toxic weed and pest management techniques. There is always a need of research on creating a disease prone environment for honey bee ecotypes.

Both natural and anthropogenic factors can reduce honey production by evenly or proportionately reducing bee foraging activity of honey bees. Natural factors cannot be controlled, but man-made factors such as GMO production, pesticide use, and deforestation can be controlled so as not to disrupt bee foraging activities.

Novelty Statement

This study provides bee keepers with crucial information of of foraging activities, factors influencing this behavior, foraging preference, subspecies variations, monitoring approaches, and the need of preservation and conservation of these essential pollinators.

Author's Contribution

Tariq Mahmood: Conceptualization, Visualization, methodology, investigation, field work, perform experiment data curation, data analysis, software, writing.
Mamoona Wali Muhammad: Field work, data curation.
Akbar Hayat: Data curation, perform experiment.
Adan Fatima: Proposal development.
Areej Kashaf: Paper write up.
Rida Tanveer: Analysis.
Rana Usama Iqbal: Study design, review, field work.
Sami Ullah, Muhammad Shahzaib Tariq and Muhammad Ali Raza: Data collection in field
Samia Zain: Critical review

Conflict of interest

The authors have declared no conflict of interest.

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