Understanding the Impact of Heat Stress on Honeybee Populations: Insights into Thermoregulation, Colony Dynamics, and Environmental Interactions

1. ABSTRACT

Nowadays, heat stress is emerging as a significant issue for honeybees in apiculture due to its potential to negatively impact the honey bees' health, the bee colony, and the economic stability. This review aims to thoroughly analyze the impact of heat stress on honeybee populations by consolidating existing research to provide accurate information. The thermoregulation process in honeybees and associatedbehavioraland molecular adaptations in worker bees, specific to *Apis mellifera*. Additionally covers the various ways that individual bees respond to heat stress, including changes in their metabolic rate and feeding habits. Furthermore, the paper provides a comprehensive analysis of how heat stress affects the entire bee colony, including detrimental effects on brood development, decreased productivity, and heightened susceptibility to illnesses and parasites. Also, it investigates the correlation between heat stress and other stressors, such as pesticide exposure, nutritional stress, biotic pressures, habitat loss, and the combined effects on bee health. To safeguard these important pollinators from the negative effects of climate change, this review stresses the need of interdisciplinary research and the need of identifying health stress as a major component influencing honeybee populations.

Key words- Heat stress,thermoregulation, colony dynamics, stressors, environmental interactions.

2. INTRODUCTION

Honey bees, have an essential role in sustaining the Earth's environment. Additionally, it plays a crucial function in the process of pollination. Beekeeping is significant not only because to their vital role in pollination, but also because of the rich products they offer for human and farm animal consumption, including honey, pollen, royal jelly, propolis, wax, and bee venom [1]. Nevertheless, the population of honeybees is being impacted by external environmental stresses, which is emerging as a significant global problem. Climate change such as rise in temperature is posing a major threat to the biology as well as the behavior of honeybees. Global warming is considered as one of the primary challenges to honeybee survival. It gets even more difficult when there are huge temperature variations in the ecosystem as it makes a significant impact on the foraging behavior. High temperatures or as we can call “heat Stress” can affect the foraging habits making it more difficult as some bees become less active and adjust their foraging patterns accordingly [2, 9, 10].Given the importance of honey bees and beekeeping in the tropics, as well as the potential threat that global warming poses to them, it is a serious oversight that so little study has been performed in this area.This study focuses on the detrimental effects of increasing heat stress on honey bee populations, with a particular emphasis on Apis mellifera, the most widely used species for beekeeping in tropical regions.

Social insect colonies may modify their behavior in response to temperature fluctuations in their environment, thereby maintaining a comfortable nesting temperature [3]. Due to the detrimental effects of temperature fluctuations on colony fitness and offspring development, the ability of social insects to regulate and sustain a consistent nest temperature is considered a substantial selective pressure that drives social evolution [4]. Honeybees, on the other hand, rear their apodous offspring within hexagonal cells and are therefore unable to relocate them [5,6],so as to maintain a constant temperature within the hive, honeybees employ a variety of behavioral responses. When the heat stress affects the honeybees, it disrupts the ability to regulate the humidity and temperature in their hives. According to[7], to maintain the temperature of hive and to avoid overheating inside the hive, honeybees have to resort to thermoregulatory behavior by collecting water and fanning. Moreover, heat Stress can also affect the reproductive habits and fecundity, which leads to the decrease in colony growth and its productivity. High temperature interrupts with mating flights, decreased sperm viability and can cause in queen failures leading to the colony fecundity and genetic diversity[8]. Understanding the connection between the reproduction process and the heat stress is very crucial to ensure the long-term viability and reproductive success of the honeybee colonies.

Changes in climate can cause variety of negative effects on honeybees. It can directly affect the behaviour as well as the physiology of the honeybees. Climate change also affects the quality of flowers on which the honeybees rely on, thereby affecting the growth of the colony and harvesting capacity. It can also cause new competitions between the species and races and to define the ranges of distribution in honeybees [9]. Due to the reduction in precipitation and increase in temperature, flowers may face some adverse effects, such as making them bloomless and even reducing pollen and availability of nectar [10]. Heat stress can also hinderthe queen bee's productivity, reproduction of drone as well as brood viability of honeybees, ultimately disrupting the colony homeostasis [11]. Moreover, these negative impacts also affect the relationship between the pollinating flowers and the honeybees [12].

There are many different ways used by honeybees to deal with heat stress, such as changes in behavior, foraging tactics[13] and physiology [14]. Theseresponseshelp the colony to survive and also reducesthe negative effects of heat stress on the relations of the colony survival and reduce the negative effects of heat stress. When bees go throughstress such as heat stress, they mayconsume nectar instead of pollen. This could lead to harmful effect on the colony's nutrition and development [15]. Moreover, pollen plays an important for increasing immunity and parasite tolerance in honeybees. Bees while experiencing stress can also causeoctopamine levels to decrease.It may hamper the insect's flight and feeding behavior also. It may also reduce colony's nutritional balance [16].

3.1 TEMPERATURE CHANGE

The behavior and productivity of honeybees is greatly influenced by temperature. The temperature of the brood comb is maintained between 33 and 36°C, with a relative humidity of approximately 70%. Humidity levels between 30% and 75% have no significant effect on honeybee survival, but temperature changes do. Honeybees will eventually lose their ability to withstand both high and low temperatures [17, 18, 19]. For example, a previous study[20], discovered that higher temperatures significantly reduced honeybee survival. Foragers are sensitive to temperature stress caused by extreme temperatures, and they avoid collecting nectar and pollen in extreme heat or cold [16]. Honeybees regulate their head temperature by maintaining a high ambient temperature, which helps to stabilize the thoracic temperature. However, at low ambient temperatures, the thoracic temperature is controlled [17]. Honeybees can live a normal life in ideal temperature conditions. When exposed to high temperatures, they may fan their wings and gather water to create convective cooling. When exposed to cold, they may constrict and group together, producing heat.Here,**fig. 1**depicts the working of honeybees in variable temperature ranges i.e. at high, optimum and low temperature range. Optimum temperature range for working of honeybee is 25- 35 degree Celsius.

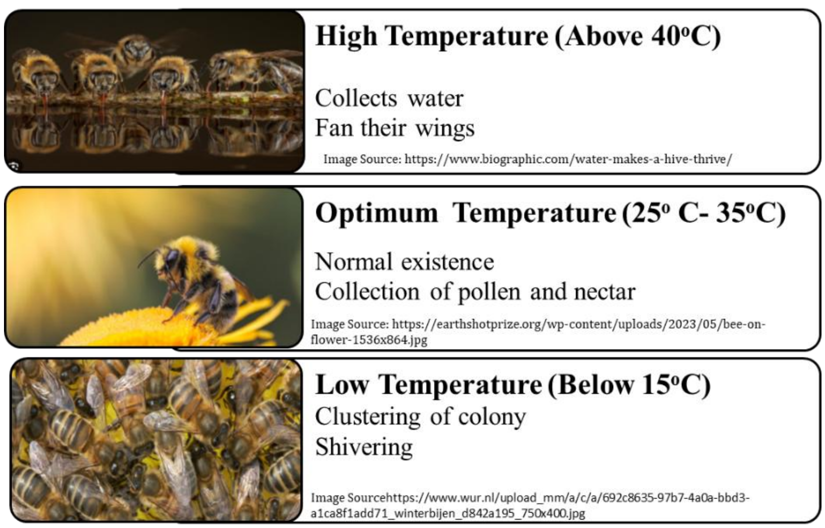

Fig .1 Workerbees' behavior at different temperature range

At higher temperature ranges, a portion of the bees first travel through the combs, fanning their wings to create air currents that cool the honeycomb convection, honeybees will collect more water and use their tongue-lashing proboscises to disperse it in a film, allowing for evaporative cooling when combined with other honeybees' fanning wings. Many honeybees will leave the hive, possibly to make room for the bees in charge of evaporative cooling. When a honeybee colony experiences high temperatures, labor is reallocated.The additional labor needed to combat heat stress can be obtained by diverting honeybees from other tasks and utilizing their reserve labor, which is found in the middle-aged caste of honeybees [21].

At low temperature ranges, when the temperature drops to 15^{o}C, the bees will clusterthemselves. The hive's air volume for heating will be reduced as a result of the bees forming a compact cluster, in which they arrange themselves in layers and clump together with their faces inward. The cluster formation reduces the surface area of the bee bodies exposed to cold air, adhering to the principle of heat transfer that increases with surface area and reducing heat loss via convection by up to 88% [18].

3.2 HEAT STRESS

When the temperature around bees increases beyond their physiological capacityi.e above 25^{o}C-35^{o}C, they suffer from heat stress.Heat stress has a negative impact on bee growth and development, immunity, task-related physiology, pollination services, foraging activity, and reproductive capacity [14]. These negative effects vary by bee species. This condition hinders their ability to regulate their body temperature and maintain optimal hive conditions[18]. Honeybees are highly vulnerable to even slight temperature changes because all the functions of their colony, including brood development, foraging, and communication, depend on the consistent interior temperature of the hive. Heat stress has various negative effects on honeybees, including risking their well-being and the survival of their colonies. Bees' dehydration, metabolic strain, and impaired immune system function are some of the consequences of heat stress. The extreme temperature disturbs their foraging routine, causing bees to spend more time collecting water to cool down or avoid foraging altogether to evade the scorching heat [22]. Heat stress can have a detrimental impact on the development of bee broods. When hive temperatures rise too high as above 40^{o}C, it can result in abnormal larval development and even death. Bees that are heat-stressed might exhibit altered behaviors like decreased activity, increased clustering, or, in severe cases, hive abandonment. Prolonged exposure to high temperatures can weaken the colony's resistance, making it more vulnerable to other stressors such as pests, illnesses, and pesticide exposure. Ultimately, heat stress poses a significant threat to honeybee populations, exacerbating pre-existing health issues and contributing to the global decline of bee populations. Therefore, it is critical to reduce heat stress in honeybee colonies to preserve ecosystem health, agricultural productivity, and pollination services.

4 RESPONSES TO HEAT STRESS

It is worth noting that climate change is happening at a faster rate than anticipated, according to [23]. However, several studies have indicated that bees use a range of physiological and behavioral methods to enhance their heat tolerance [6]. Variations in species responses to climatic conditions can be observed. For instance, *A. cerana* demonstrates greater tolerance to exceedingly high temperatures than *A. mellifera* does to high temperatures [24]. Furthermore, compared to *A. mellifera carnica*, *A. mellifera ligustica* exhibits greater tolerance to high temperatures in terms of thermal limits and metabolic rates [25]. In this review, the research on the harmful impacts of heat stress on various bee colonies, including stingless bees, bumblebees, and honeybees (especially *A. mellifera)*isdone. This study also highlights the protective measures that bees employ to counteract heat stress. It is worth mentioning that different bee species or subspecies exhibit varying reactions to heat stress and have distinct defense mechanisms.

4.1HEAT STRESS DURING FORAGING

The forager bees are worker bees in the bee hive, that are at least 21 days old. At this point, they transition to carrying out activities outside of the colony, such as collecting water, nectar, pollen, or resin. The maximum activity was observed at ambient temperatures of around 20 °C [26], the lowest foraging activity was discovered at 43 °C [27], and the lowest activity was observed at or below 10 °C [28]. Furthermore, [29] discovered a substantial negative association (r =-0.09) between temperature and foraging activity. Elevated temperature is therefore predicted to passively alter foraging behavior, as seen by [30] with pollen foragers.Bees face heat stress during their foraging activities, which can particularly affect their thorax, a crucial part of their ability to fly. This stress is not limited to the temperature inside their colonies. However, bees have developed mechanisms to regulate their thoracic temperature and prevent overheating. For instance, bumblebees *(B. vosnesenskii)* can transfer heat from their thorax to their abdomen to avoid overheating. Interestingly, this ability is lost when their heart stops beating [14].During flight, the air temperature gradually increased from 33 to 45 °C, and in response, *A. mellifera*exhibited an increased rate of evaporative heat loss and a decreased rate of metabolic heat synthesis to prevent thorax overheating. These findings suggest that behavioral treatments can be helpful in assisting bees in coping with heat stress [31].

4.2THERMOREGULATION

The strength of a colony is determined by the number of workers. Since honey bees are scattered across different continents and climates, they are vulnerable to extreme weather conditions, especially sudden temperature changes. Hence, an efficient thermoregulation system is required to regulate the temperature of both the colony and the bees' bodies. As the broods are very sensitive to temperature variations, it is crucial to maintain the ideal temperature for the comb to allow the colony to grow and develop. Honey bees are known for their capability to engage in intense endothermy while performing various tasks such as foraging, guarding, and self-defense [32, 33]. Similar to human structures, *Apis mellifera* utilize a variety of heating and ventilation methods to maintain the ideal temperature in their hives.

Thermoregulation is the process through which organisms regulate their internal body temperature within a specific range, irrespective of the external environment. In the case of honeybees, thermoregulation is essential for their survival and wellbeing. Honeybee colonies work collectively to keep the temperature inside the hive stable, especially during extreme temperatures such as excessive heat or cold, to ensure that they can survive and thrive. The primary source of heat production is the energy released during the metabolism of carbohydrates. The thoracic muscles that shiver use hexose sugars (82%) which they metabolize [34]. Here, **fig. 2** demonstrates that when outside temperature lowers down below 15℃, worker bees tend to retain heat inside beehive by cluster formation and by shivering thermoregulation technique. And when outside temperature exceeds above 35℃, worker bees tend to cool the hive by fanning and evaporative cooling thermoregulation technique.

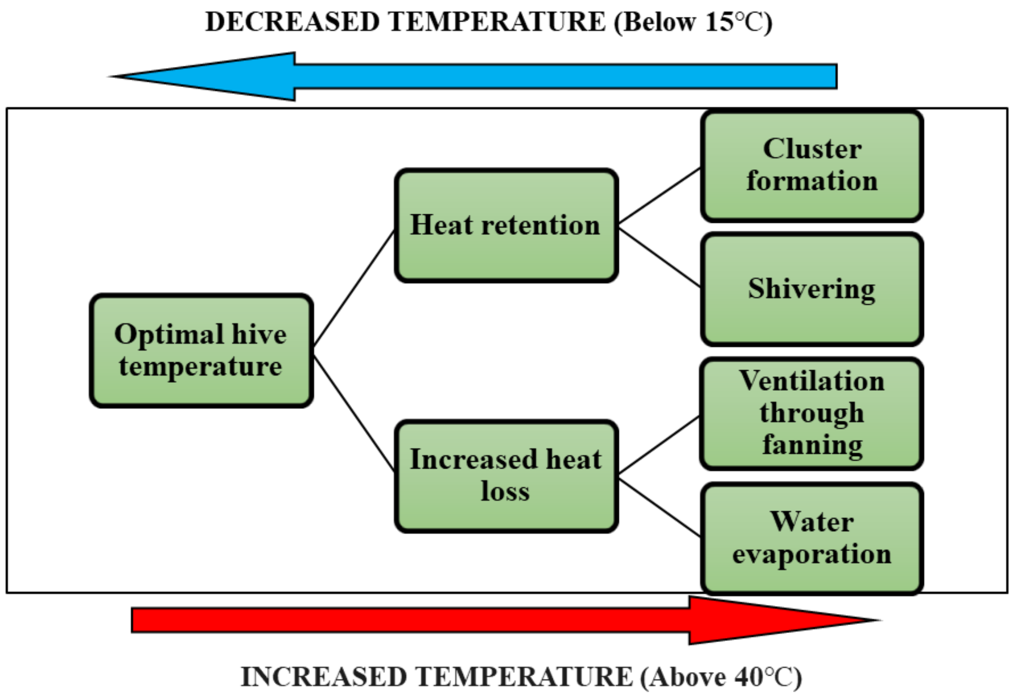

Fig. 2, Mechanism of thermoregulation inside the bee's hive at different temperature ranges.

TABLE 1, Thermoregulation methods employed by worker bees within the beehive in response to elevated temperatures outside of the optimal range:

Thermoregulation technique	Beehive status	References
Strengthened insulation	Using propolis for the purpose of temperature regulation and sealing cracks, worker bees absorbs heat or store as heat	[6,24,42]

	shield.	
Increased volume of air	Vigorously beating of wings by positioning themselves at the hive entrance.	[42]
Effective ventilation and cooling	Bees spread water droplets on the surface of hive materials and fan their wings over the moistened areas, promoting evaporation and lowering the temperature inside the hive	[22,40]
Humidity and temperature control	Under specific temperature circumstances, side wall bees function similarly to a heat exchanger, in which worker bees absorb heat by pressing their ventral sides against hot surfaces	[42]
Increased Air circulation and hygiene control	Fanners, help to force airflow throughout the hive, positioning themselves left, right, top, and bottom in the beehive.	[22]

4.3 STRESS SIGNALING PATHWAY

Both [6] and[35] found that heat stress significantly affects the development of bees at all stages of their life cycle, from larvae to pupae to nursing adults, and even the entire colony. Furthermore, heat stress might impact each bee individually as they forage for nectar and pollen [36]. According to [6], bees have evolved a variety of biochemical and behavioral compensatory mechanisms to deal with heat stress. These mechanisms allow bees to endure high temperatures. Honeybees' molecular and behavioral stress signaling system against heat stress is illustrated in **Fig. 3**. Some genes in the heat shock protein (Hsp) and nuclear factor Y (NF-Y) families show an upregulation of expression at the molecular level. Fanning their wings, passively absorbing heat, and increasing the number of water-collecting foragers are some of the behavioral adaptations that bees use to protect themselves from heat stress [14]. Bees' molecular and behavioral responses to heat stress are interdependent.

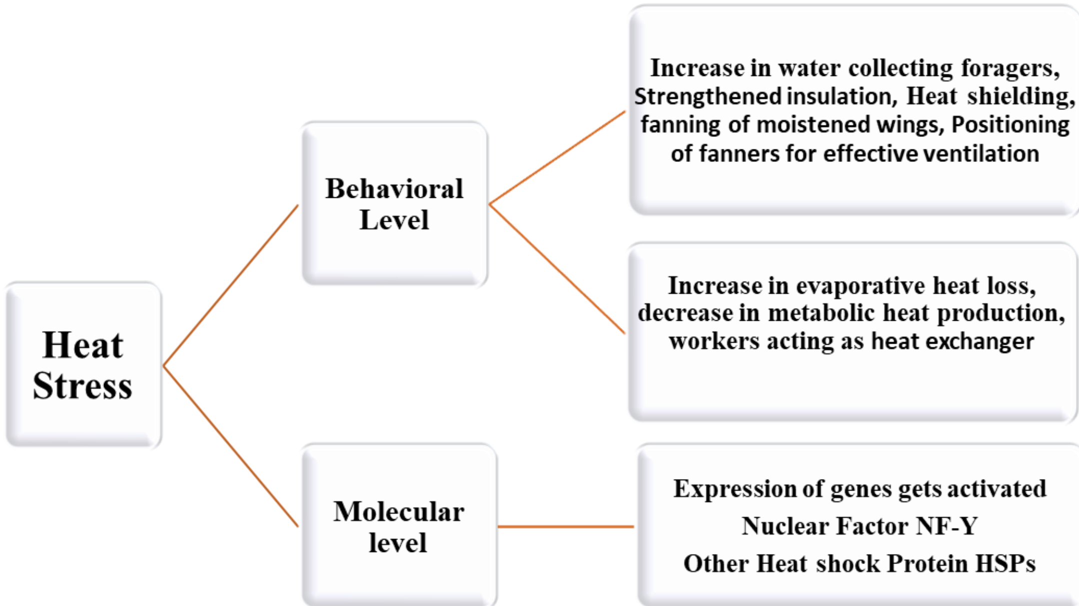

Fig3, Defense mechanisms against heatstress

Bee defense mechanisms against heat stress involve both molecular and behavioral adaptations.

(a)Behavioral level - Bees possess diverse adaptation methods to safeguard themselves against heat stress. *Apis mellifera* workers employ multiple strategies to dissipate heat when the temperature exceeds the optimal range. These strategies include fanning their wings, adopting passive heat-absorbing behavior, and increasing the number of water-collecting foragers [22]. When foragers experience heat stress during their search for food, *A. mellifera* decreases the amount of heat it produces through metabolism and increases the amount of heat it loses through evaporation. In addition, *Bombus vosnesenskii* and *Melipona subnitida* have the ability to transmit heat from their thorax to their belly [17].

(b)Molecular level - At the molecular level, when bees are exposed to extreme temperatures, their bodies initiate certain protection mechanisms. In response to heat stress, certain genes, including those from the heat shock protein (Hsp) and nuclear factor Y (NF-Y) families, have been found to alter their expression [37,38].More precisely, the transcription of some genes associated with nuclear factor Y (NF-Y) and heat shock protein (Hsp) family is enhanced. Consequently, the synthesis of Hsp and NF-Y proteins induces the transcription of many genes that assist bees in adapting to high temperatures. The expression these genes enhance the bees' ability to combat oxidative stress and increase their tolerance to high temperatures [14]. Additional research has also validated this occurrence, since heat shock genes have the ability to stimulate the creation of heat shock proteins (HSPs) in insects when exposed to heat shock

[39]Hsp70 exhibited broad expression in the hemolymph of forager bees [40]. Hsp70 was detected in all anatomical regions of *A. mellifera* (brain, thorax, and head) in response to temperatures varying from 33 °C to 50 °C [41].

4.4 DECREASING HIVE TEMPERATURE

According to[22], *A. mellifera* has more water-collecting foragers. The workers fan their wings within the hive or near the entrance to keep it cool. Honeybees can also cool themselves by evaporating a thin layer of water in their proboscis. When the cooling measures are not enough, a large number of honeybees exit the hive and gather outside the entrance. To maintain ventilation and evaporation, a sufficient number of bees are kept inside the nest. Bee workers use asocial homeostatic heat-shielding behavior to protect their hives from extreme local heat fluctuations. Within 10 minutes, they lower the temperature of the brood comb to a safe level [6].The next step for a worker bee that has absorbed heat is to release it. According to [6],there are two documented mechanisms for heat dissipation - pattern-rich dissipation and pattern-free dissipation. Pattern-rich dissipation is characterized by a directed movement of hot bees away from the heated region of the hive to other parts, such as pollen stores and honey, or even outside the hive. In contrast, when heat dissipation is pattern-free, there is no identifiable trend in the direction of heated workers' movement within the hive.

4.5 MAINTAINING IN-HIVE TEMPERATURE

The ideal in-hive temperature of 35 °C also applies in warm environments. Bees have evolved a cooling system to help them survive in warm climates. At temperatures above 15 °C, the clusters of bees naturally disperse to reduce heat insulation. Overcrowding during the day is unlikely to cause overheating when the ambient temperature is high, as it is in the summer when worker bees are out foraging and drones are not present in the colony. Furthermore, if the hive becomes overcrowded at night, the bees will naturally spend the night outside to stay cool. This behavior happens in front of the hive's entrance[42]. However, to ensure that the brood nest is kept at the optimal temperature, variety of cooling strategies have been employed by worker bees in the beehive.

4.6QUEEN'S RESILIENCE TO HEAT STRESS

Heat stress can impact the physiology of both the queen's eggs and her offspring, which can ultimately result in a reduction of the queen's fertility. It is worth noting that thermal stress may have effects on queens that are not related to her stored sperm. In fact, some short-term effects of cold stress have already been discovered [43]. The viability of the sperm stored by the queen may be reduced in certain circumstances despite her overall resistance to temperature stress[44],observed that the viability of stored sperm is reduced by exposure to cold temperatures. Interestingly, this phenomenon was not observed in response to heat stress.

4.7EFFECT ON OCTOPAMINE

Octopamine is a neurotransmitter that plays a crucial role in helping honeybees cope with heat stress. When honeybees experiences heat stress, their levels of octopamine increases, which aids in regulating several physiological functions, including thermoregulation. Octopamine improves the bees' ability to gather water and use evaporative cooling to maintain optimal body temperature. It also stimulates the activity of "fanner" bees, which helps improve evaporative cooling and air circulation within the hive. Moreover, octopamine may affect honeybees' foraging behavior and metabolic activity during heat stress. In summary, octopamine is vital in coordinating adaptive reactions that ensure colony survival by maintaining optimal body temperature and preventing heat stress [45].

4.8CONCEPT OF EVAPORATIVE COOLING

Evaporative cooling is a fundamental method used to reduce body temperature. It combines the cooling effect of evaporation with water's thermal conductivity. Evaporative cooling causes heat loss in both deuterostomia and protostomia, and helps in the process of acclimatization. The honeybee uses this method to cool the entire hive as well as to lower its own body temperature. This is crucial for the survival of the colony, as the primary goal of hive thermoregulation is to promote proper progeny development. The honeybee cools itself by a mechanism similar to panting. During this process, liquid is vomited and evaporates as it is caught on the extended proboscis [42]. Worker bees are responsible for controlling the air quality in their hive through coordinated fanning. This process helps in the exchange of heat, gases, and moisture as well as air circulation [46, 47, 48]. The use of fans by worker bees is determined by abiotic factors in the hive, such as humidity and temperature. Moreover, the bodies of worker bees are capable of absorbing and transferring heat from nearby hotspots.

4.9 VENTILLATION AND COOLING

Bees actively fan their wings to help ventilate and cool the hive[22]. As the temperature inside the brood nest approached 35°C, several hundred bees took on the fanning role in the ventilation process, positioning themselves left, right, top, and bottom in the beehive. These bees, known as fanners, help to force airflow throughout the hive. However, 20-30 bees moved to the outside of the tiny entrance into the screened landing platform and began fanning as soon as the temperature reached around 40°C. Furthermore, these fanning bees used a ventilation strategy in which they divided areas of continuous inflow and outflow at the hive entrance into groups.It is also crucial to note that proper gaseous exchange of oxygen and CO_2, as well as humidity control, will occur during the air exchange [42].

4.10 HEAT SHIELD

Another way honey bees protect their young is through "heat shielding," in which worker bees absorb heat by pressing their ventral sides against hot surfaces [6]. Later, the bees will disperse the heat they have absorbed or stored by flying to a cooler part of the hive other than the brood area.When the temperature inside the hive rises too high, bees collect water droplets and place them there. By absorbing the excess heat, this layer of water acts as a heat sink for keeping the hive cool. Bees may also use propolis, a resin-like material collected from plants, to seal cracks and aid in temperature regulation [42].

5 IMPACTS ON HONEY BEE HEALTH AND COLONY DYNAMICS

5.1 Immune function

Heat stress can have a severe impact on honey beesimmune systems, making them more vulnerable to infections and illnesses[49].High temperatures can disrupt various physiological processes, including cellular stress responses and protein denaturation, which are essential for immune function. This disruption can compromise the bee's ability to mount a successful immune response against pathogens, leading to higher mortality rates and lowering the overall health of the colony. Additionally, heat stress can worsen pre-existing environmental stressors, further reducing honeybee immunity and contributing to colony collapse disorder. Overall, heat stress poses a significant threat to honeybee populations by weakening their disease resistance and increasing colony vulnerability.

5.2 Honey Production

Heat stress can be detrimental to honey production in honeybees. When temperatures rise, honeybees prioritize thermoregulation and water collection to keep the hive cool, which can lead to reduced foraging activity [50].Heat can have a significant impact on bee foraging and pollination services. For instance, in hot desert conditions, high temperatures can negatively affect pollen gathering and foraging. Bees belonging to the *Apis mellifera* species tend to reduce their activities during hot, dry, and windy weather. However, if the hive is located in nectar-rich acacia trees, the negative effects of the weather on *A. mellifera*‘sforaging activity can be reduced [14]. This indicates that providing *A. mellifera* with high-quality diets and adequate nectar sources can help maintain their foraging activity during heat stress. However, heat stress can diminish a colony's overall productivity, which could have a negative impact on beekeeping operations by reducing the amount of honey produced and the overall profitability.

5.3 Colony survival and Growth

Heat stress is a significant threat to the survival of honeybee colonies, as it can negatively impact their health and disrupt essential physiological processes. Elevated temperatures can weaken honeybee’s immune systems, reduce their honey production, and affect their foraging behavior.

Additionally, heat stress can exacerbate other environmental stressors, leading to an increase in colony mortality rates. The cumulative effects of heat stress pose a significant risk to honeybee populations, underscoring the need for mitigation strategies to address the effects of climate change on pollinator health. In a study conducted by[51], honeybees' physiological responses to heat stress were investigated; shedding light on how these reactions affect colony survival.
To maintain bee'scolony,worker bees display various behaviors to regulate the temperature of their nest when the surrounding temperature rises. These behaviors include fanning air, spreading water, dissipating heat, and even evacuating the nest. The bees can maintain nest homeostasis up to a temperature of 60°C as long as they have access to water. Despite the need to collect water for cooling, bees do not compromise their nectar intake rate. While task-switching is crucial for coping with heat stress, the role of inactive workers, or 'reserve labor,' is yet to be understood. The findings suggest that colonies can adapt to environmental stressors without disrupting other colony processes. While different behavioral responses to heat stress are well documented, it remains unclear how colony-scale reorganization occurs during heat stress. The roles and distributions of task specialists, generalists, and reserved labor are still unknown, as is the effect of the bee's previous roles on their response to heat stress. Furthermore, it is not known whether there are distinct behavioral groupings structured by age or experience across the entire colony [52].

6 INTERACTIONS WITH OTHER STRESSORS

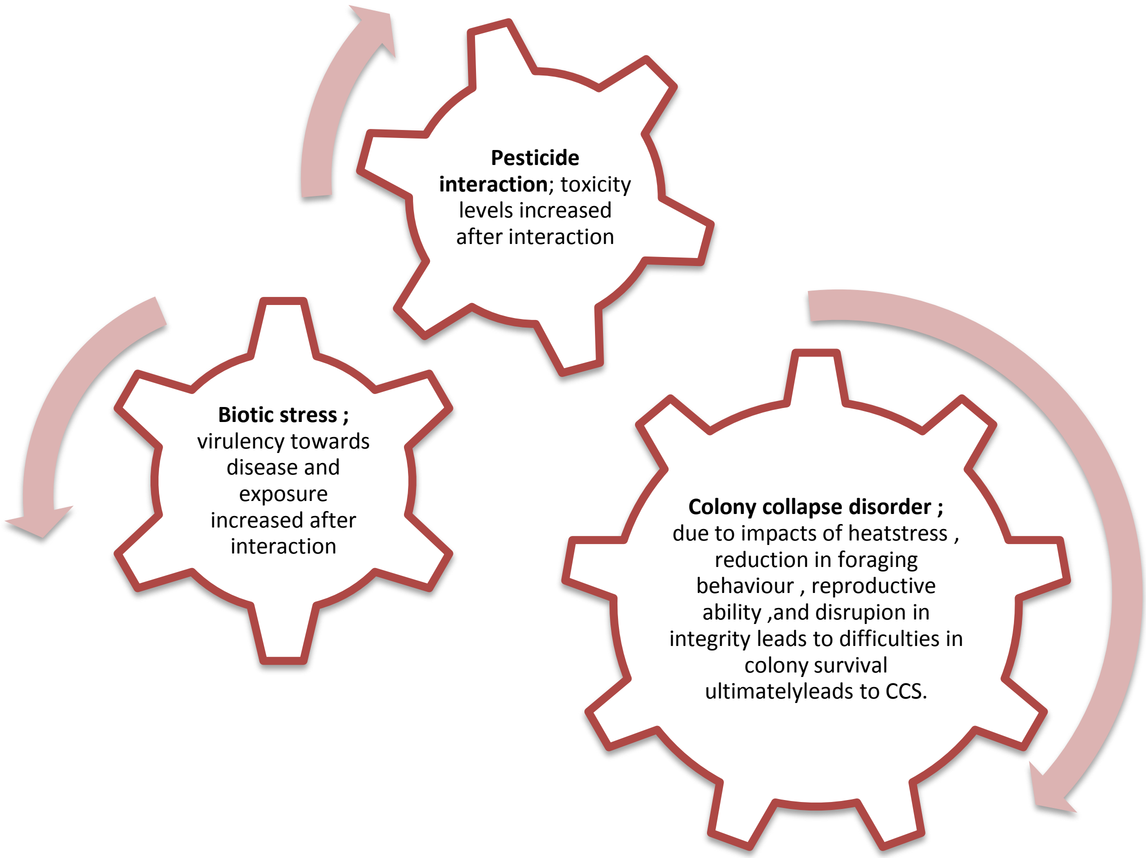

Fig 4 , Interaction of heat stress with other stressors

6.1Colony collapse disorder

Heat stress and high temperatures are believed to be major contributors to colony collapse disorder (CCD) in honeybee populations. Studies have shown that high temperatures can worsen the various stressors that lead to CCD, such as pesticide exposure, nutritional deficiencies, and pathogens [53]. It can cause nutritional stress in honeybee colonies by increasing their metabolic demands, reducing their foraging effectiveness, and altering the quality of floral resources. Besides, heat stress can interfere with a hive's thermoregulation systems, which can affect brood development and colony balance [50]. It can also weaken bee's immune systems, making them more susceptible to infections and illnesses linked to CCD. The combined impact of high temperatures on honeybee physiology and colony dynamics highlights the intricate relationship between temperature stress and the vulnerability of bee populations to collapse. To mitigate the effectsof CCD and enhance honeybee health and resilience to climate change, heat stress needs to be addressed through management techniques such as hive insulation and access to water sources.

6.2 Pesticide interaction

Pesticide exposure is a type of abiotic stress that affects the regulation of antioxidant genes in honeybees. Summer bees are more vulnerable to the harmful effects of pesticides than winter bees [54]. Imidacloprid, a neonicotinoid insecticide commonly used in agriculture to control pests, has been associated with the decline of bees. Even at low doses, it impairs honeybee performance[55]. Exposure to Imidacloprid, can have a significant impact on the antioxidant system and gene regulation in honey bees. Insect's antioxidant system can be disrupted by thermal stress, which can exacerbate the effects of pesticide exposure. Honey bee survival may be influenced by synergistic interactions between environmental temperature and pesticide toxicity due to their unique and stable thermobiology. A recent study discovered that bees exposed to sublethal doses of the neonicotinoid insecticides;acetamiprid and imidacloprid had increased heat tolerance and survival rates[56].

Heat stress can negatively impact the ability of bees to efficiently metabolize and detoxify pesticides, which can make them more susceptible to the harmful effects of chemical residue. Pesticide exposure can aggravate heat stress by interfering with physiological processes, such as immune response and thermoregulation [51]. The combined effect of both stressors, known as synergistic effects, can have a greater impact on honeybee health than if either stressor acted alone. Studies have shown that heat-stressed honeybees exposed to pesticides have higher mortality rates, poorer foraging behavior, and smaller colonies compared to bees living in normal conditions. Therefore, to prevent a decline in bee populations and ensure the long-term health and survival of honeybees, it is essential to address both heat stress and pesticide exposure.

6.3 Biotic stress

Bees and other pollinators regularly face various stressors due to their interactions with the environment. When exposed to multiple stressors, bees may experience intensified negative effects due to additive or synergistic interactions[57]. Honeybee populations are susceptible to biotic stressors in high temperatures. The growth and activity of various pathogens and parasites that live in the hive can be affected by high temperatures, which can exacerbate biotic stress in honeybee colonies. For instance, the incidence of disease in honeybees may increase as high temperatures promote the growth and spread of pathogens like bacteria, fungi, viruses, and microsporidia. Additionally, some parasites like Varroa mites, which are already causing a decline in honeybee health, may benefit from warmer weather [58]. This could lead to an increase in the parasites' rate of reproduction and the severity of infestation within hives. High temperatures can also weaken the honeybee immune system, compromise individual bee health, and ultimately result in colony losses.

7CONCLUSION

Heat stress affects the development and growth of honeybees by inhibiting foraging activities,fecundity, body thermoregulation, and other normal functions in their bodies. Effects of heat stress on honeybees poses significant challenges to their health, physiological behaviors, and overall colony survival. Warm temperature encourages parasites and diseases to migrate more easily. The complex interaction between heat stress and other stressors emphasizes the difficulties in mitigating its effects on honeybee populations. Addressing this issue requires an extensive approach, encompass both short term management strategies and long-term climate change mitigation efforts. The use of pesticides and insecticides in agriculture causes bee poisoning and death, so it is critical to research and use natural, bee-friendly alternatives to synthetic chemicals while managing them. It is critical that honey bees have access to nectar, clean water, and pollen; thus, pollution that harms the environment or the bees should be avoided or controlled.As global temperatures rise due to climate change, it's crucial to anticipate potential impacts and take early efforts to protect these essential species.

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