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Impact of Climate Change on Honey Bee

Research Project

Submitted to the department of (**Biology**)in partial fulfillment of the requirements of **BSc.**in (**Biology**)

By:

Halmat Nashad Zrar

Supervised by:

Dr. Wand Khalis Ali

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بسم الله الرحمن الرحيم

وَأَوْحَىٰ رَبُّكَ إِلَى النَّحْلِ أَنِ اتَّخِذِي مِنَ الْجِبَالِ بُيُوتًا وَمِنَ الشَّجَرِ وَمِمَّا يَعْرِشُونَ (٦٨) ثُمَّ كُلِي
مِن كُلِّ الثَّمَرَاتِ فَاسْلُكِي سُبُلَ رَبِّكِ ذُلُلًا ۚ يَخْرُجُ مِن بُطُونِهَا شَرَابٌ مُّخْتَلِفٌ أَلْوَانُهُ فِيهِ شِفَاءٌ
لِّلنَّاسِ ۗ إِنَّ فِي ذَٰلِكَ لَآيَةً لِّقَوْمٍ يَتَفَكَّرُونَ (٦٩)

(سورة النحل)

صدق الله العظيم

SUPERVISOR CERTIFICATE

This research project has been written under my supervision and has been submitted for the award of the degree of BSc. in Biology with my approval as a supervisor.

Signature:

Name: Dr. Wand Khalis Ali

Date: / /2024

I confirm that all the requirements have been fulfilled.

Signature:

Name:

Head of the Department of Biology

Date: / /2024

I confirm that all the requirements have been fulfilled

DEDICATION

This work is dedicated to:

To my grandfather and grandmother soul

To my Dear father

To my Dear mother and to my Dear brothers

ACKNOWLEDGEMENT

In the name of Allah. Thanks to Allah for directing me and assisting me in completing my research project. He has been a source of comfort and support for me throughout my academic career.

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ABSTRACT

This research investigates the impact of climate change on honey bees, focusing on various factors such as temperature fluctuations, altered precipitation patterns, and shifts in seasonal patterns. The study aims to understand how these climate elements may affect the behavior, health, and survival of honey bee colonies. Through a comprehensive literature review and empirical investigations, the research elucidates the multifaceted challenges posed by climate change to honey bees and explores potential strategies to mitigate these impacts. Methodologies encompass a diverse range of approaches, including observational studies, experimental manipulations, and data analysis techniques.

Keyword: Honey bees, Climate change Pollination , Bee populations , Colony, collapse disorder , Weather impacts , Stressors , Ecosystem health , Biodiversity

1. Introduction

The honey bee (*Apis mellifera* L.) plays a crucial role in the conservation of the environment, since it pollinates a myriad of wild plant species and a large number of crops which are vital for human beings (Potts *et al*., 2010). However, the honey bee is currently being affected by severe threats. In recent years the interest on bees has increased, mainly because of the high losses of bees suffering from the colony collapse disorder (CCD) and the severe repercussions that the reduction of bee populations can have on the environment and the own society (Klein *et al*., 2018). Recent interest in honeybees has been focused on mass losses of colonies and concerns about the pollination services that bees provide (Langowska *et al*., 2017). Climate change can influence honey bees at different levels. It can have a direct influence on their behavior and physiology. It can also alter the quality of the floral environment and increase or reduce colony harvesting capacity and development (Le Conte and Navajas, 2008). Honey bees will also need to adapt to a whole array of predators, parasites and pathogens surrounding them. Not only will the relationships between hosts and parasites change, honey bees will have to cope with new stresses arising from trade-facilitated transfers of pathogens among honey bee species. In such a context, climate change could create new opportunities for establishing honey bees in undreamt-of regions or habitats (Le Conte and Navajas, 2008). Climate change might affect crop pollination through its effects on managed and/or wild pollinators. The honey bee, *Apis mellifera*, is by far the most versatile and ubiquitous managed pollinator, increasing yield in 96% of animal-pollinated crops (Rader *et al*., 2013). On the individual level, when temperature rises to more than 36 °C, honey bee brood is likely to be exposed to over-heating. To better resist any passive effects, the induction of a heat shock protein is activated even during normal colony conditions in adults (Abou-Shaara *et al*., 2017). Climate change is causing temperature shifts which are leaving bees unable to pollinate in time. Bees are severely vulnerable to extreme weather and climate change has caused flowers to emerge and bloom earlier. Because bees are unable to adapt to the changing climate, they are unable to pollinate flowers and, thus, do not obtain nectar for their hives to use during the harsh winter months. As average monthly temperatures rise, flowers bloom earlier in the spring, creating a potential mismatch in seasonal timing between when flowers produce pollen and when bees are ready to feed on that pollen. Even a small mismatch of three to six days could negatively affect bees' health, making them less likely to reproduce and less resistant to predators and parasites (Abou-Shaara *et al*., 2017).

The goal of our research is to clarify the impact of climate change on honey bees and to understand how changing climate elements, such as temperature fluctuations, altered precipitation patterns, and shifts in seasonal patterns, may affect the behavior, health, and survival of honey bee colonies. so, we attempt to identify potential threats posed by climate change and develop strategies to mitigate these impacts, ensuring the sustainability of honey bee populations which play a crucial role in pollination and ecosystem health.

2. Literature Review

2.1. WEATHER, CLIMATE AND HONEY BEES

Another important trend that will likely affect honey bees is climate change. Climate is defined as the long-term average (30 years) of weather conditions in an area, whereas weather is defined as their day-to-day variations. Since the climate is changing, it is indicative that weather has been changing as well. This is important as various studies have shown weather impacts honey bees. Weather influences:

1) hive entrance activity/flight activity

2) number of eggs laid

3) honey yield

4) larvae feeding

5) swarming

6) foragers at a flower patch

7) defense behavior

8) length of foraging

Many of these studies might not have found the real relation between weather conditions and bees as they involve short-term study periods ranging from a few days to three months. Furthermore, a majority of the studies involved active disturbance of the hive to obtain data. These disturbances to the hive can cause stress and cause honey bees to react differently than normal (Le Conte and Navajas, 2008).

2.2. Honey Bee Virus

More than 20 viruses have been identified to infect honey bees worldwide. The most common are: Deformed wing virus (DWV), Black queen cell virus (BQCV), and Israeli acute paralysis virus (IAPV), Acute bee paralysis virus (ABPV) and Kashmir bee virus (KBV) often is referred to as the Acute–Kashmir–Israeli complex or AKI, and share similar characteristics (Table 1). Viruses infect all developmental stages and castes. Though always present in colonies, viruses often persist as covert asymptomatic infections. However, if colonies are under stress, virus levels can increase causing reduced worker longevity and brood survival and colony loss in winter or early spring. Viruses such BQCV also can cause colony death by preventing the development and emergence of a new queen following queen loss. A factor that has increased virus levels in managed colonies of European honey bees in the U.S. and Europe is Varroa. The mite weakens bees by feeding on hemolymph of larvae, pupae and adults. Varroa also can transmit viruses among nestmates and suppress host immunity thus leading to elevated virus replication. In colonies with large Varroa populations, brood cells are invaded by multiple foundress mites causing higher DWV levels than in singly infested cells even in Varroa-resistant stocks. Multiple infestations are common in the fall because mite populations are peaking and there are fewer cells to invade. The combination of multiply infested cells and greater virus levels in autumn ultimately causes colonies to die over winter. In addition to the threat viruses pose to honey bee colonies, recent studies indicate that the viruses can cross the species barrier and infect non-Apis species (e.g., bumble bees). Bumble bees have experienced dramatic population declines, and might acquire viruses while foraging on flowers previously visited by infected honey bees. Therefore controlling viral diseases in honey bee colonies is vital for stopping the spread of viruses among wild pollinators.(DeGrandi-Hoffman and Chen, 2015).

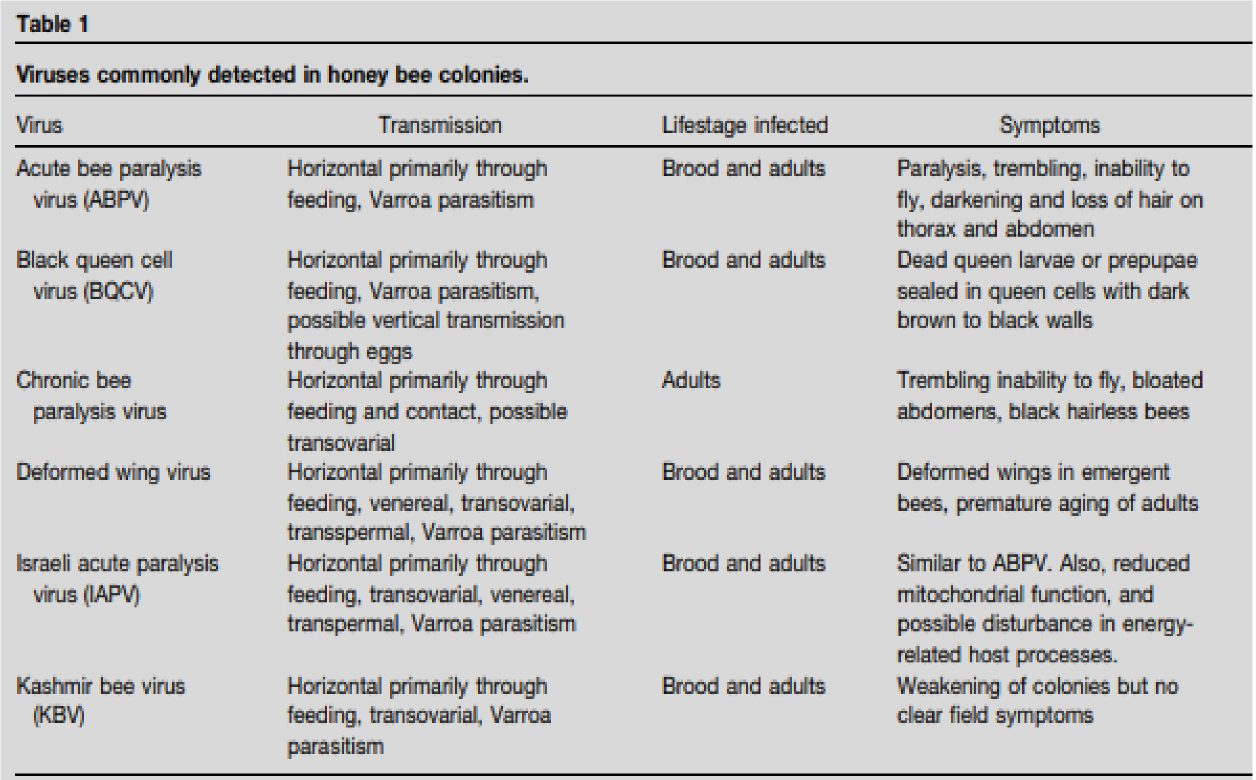


Table 1

Viruses commonly detected in honey bee colonies.

Virus	Transmission	Lifestage infected	Symptoms
Acute bee paralysis virus (ABPV)	Horizontal primarily through feeding, Varroa parasitism	Brood and adults	Paralysis, trembling, inability to fly, darkening and loss of hair on thorax and abdomen
Black queen cell virus (BQCV)	Horizontal primarily through feeding, Varroa parasitism, possible vertical transmission through eggs	Brood and adults	Dead queen larvae or prepupae sealed in queen cells with dark brown to black walls
Chronic bee paralysis virus	Horizontal primarily through feeding and contact, possible transovarial	Adults	Trembling inability to fly, bloated abdomens, black hairless bees
Deformed wing virus	Horizontal primarily through feeding, venereal, transovarial, transspermal, Varroa parasitism	Brood and adults	Deformed wings in emergent bees, premature aging of adults
Israeli acute paralysis virus (IAPV)	Horizontal primarily through feeding, transovarial, venereal, transpermal, Varroa parasitism	Brood and adults	Similar to ABPV. Also, reduced mitochondrial function, and possible disturbance in energy-related host processes.
Kashmir bee virus (KBV)	Horizontal primarily through feeding, transovarial, Varroa parasitism	Brood and adults	Weakening of colonies but no clear field symptoms

2.3. Honey Bee and Temperature

Researches indicates that most insect species exhibit a certain level of tolerance to changes in thermal conditions during their development stages. Some species are classified as temperature-tolerant (generalists), while others have a narrow tolerance for temperature changes (specialists). However, in both cases, prolonged exposure to excessively low temperatures can disrupt further development, leading to alterations in morphology and longevity or even render development impossible. Studies have shown that holometabolous insects are particularly sensitive to fluctuations in ambient temperature during metamorphosis, a critical developmental stage where adult morphology and physiology are established. Research also indicates that social insect species, such as the honey bee (*Apis mellifera*), are temperature specialists and highly stenothermic during development, requiring a very narrow temperature range for optimal growth. For instance, the egg, larvae, and pupa of honey bees necessitate a constant temperature between 33 and 36 °C for development, with 35 °C being suggested as the optimum temperature for brood rearing in healthy, genetically diverse colonies. Moreover, research highlights that maintaining a constant and elevated temperature allows honey bees to complete their development from egg to imago relatively quickly, typically within 16–24 days, depending on factors such as sex and caste. The early stages of honey bee development involve an open brood stage, with eggs present in the first three days followed by larvae that are fed by nursing bees. The duration of the open brood stage is approximately 9 days for worker bees and 10 days for drone broods. After this period, larval feeding ceases, and the cell undergoes further development (Szentgyörgyi *et al*., 2018).

2.4. Impact of Wind on Honey Bee

The research discusses how nectivorous insects like bees (Hymenoptera: Apoidea) play a crucial role in ecosystem services through pollination, with their ability to navigate complex habitats while foraging being essential. Bees typically travel between their nest sites and food sources by flying over varying distances, facing challenges such as unpredictable winds and cluttered vegetation that can make flight demanding and energetically costly. Cluttered vegetation presents mechanical challenges to flying bees but also provides visual landmarks for navigation. Bees navigate through clutter by utilizing brightness gradients within gaps and optic flow, which helps them gauge distance from obstacles, adjust flight speed, and maintain balance within flight corridors. Visual information is crucial for bees in flight, and obstacles like cluttered vegetation offer signals necessary for successful navigation. Collisions with vegetation can lead to wing damage, impacting flight performance and increasing mortality rates in bees. Wind variations, including steady wind, periodic vortices, and turbulence, also influence bee flight performance. Bees adjust their flight speed to compensate for wind and maintain stability. However, wind disturbances like vortices and turbulence can destabilize bees, requiring adjustments in wing flapping frequency and stroke amplitude, potentially increasing energy expenditure. Wind gusts and turbulence can trigger flight instabilities, leading to passive and active responses in bees to maintain orientation and speed. The study highlights the need to explore how bees navigate complex environments with obstacles and varying wind conditions, as existing research is limited to controlled experimental settings. Understanding how bees make behavioral choices in response to wind and obstacles can provide insights into their flight strategies and the trade-offs they face in balancing collision risks with enhanced visual information while foraging in natural habitats (Burnett *et al.*, 2022).

2.5. Effect of CO2 on survival of honey bees

The effect of different concentrations of carbon dioxide (CO2), mixed with air or nitrogen (N_2), on the behavior and lifespan of honey bee (*Apis mellifera*) workers was studied. It was found that the workers, after being treated for three minutes with the gases entered a state of deep an aesthesia only in an atmosphere of pure CO2 and its mixtures with N_2. It was also observed that the higher the concentration Of CO2 in N_2, the quicker the bees entered a state of deep anesthesia, and they also woke up sooner. The workers treated with mixtures of gases with high concentrations of CO2 (above 80%) survived for a significantly shorter time than those treated with lower concentrations of the gases (Czekońska, 2009).

2.6. Humidity in the honeybee nest

The research highlights the limited understanding of how honeybee hygroreceptors' information is utilized within the social dynamics of a colony. While humidity-based decision-making has been observed in certain ant species, such as *Atta sexdens* and various fire ant species, evidence suggests that some social insects exhibit a collective response to nest humidity. However, studies on honeybees have shown mixed results regarding their response to humidity levels within the colony. Nest humidity plays a crucial role in the fitness of a honeybee colony for several reasons. Research has demonstrated that factors like egg survival, adult longevity, microbial activity within the hive, and susceptibility to diseases like chalkbrood are all influenced by humidity levels. For example, honeybee egg survival is dependent on relative humidity (RH), with no eggs hatching below a certain RH threshold. Moreover, the percentage of brood mummification caused by chalkbrood increases with higher RH levels. Additionally, the reproductive success of the parasitic mite *Varroa jacobsoni*, which infests brood cells, is adversely affected by higher humidity levels. Humidity also plays a role in nectar concentrating and thermoregulation processes within the hive. Honeybee workers utilize droplet extrusion behavior to regulate nest temperature through evaporative cooling, which is essential for maintaining optimal conditions within the colony. However, this evaporative cooling mechanism is impeded when the air becomes saturated with moisture. Understanding the intricate relationship between humidity levels and various aspects of honeybee colony health and behavior is essential for comprehending how these insects adapt to environmental conditions and maintain the functionality of their colonies. Further research into the specific mechanisms through which honeybees respond to and regulate nest humidity can provide valuable insights into their social dynamics and survival strategies (Ellis, 2008).

2.7. Abiotic Stressors

In modern agricultural systems, pollinators are frequently exposed to agrochemicals during periods when they heavily rely on blooming crops. Honeybees are often used as bioindicators to assess the impact of agrochemicals and land-use practices on pollinators due to their sensitivity and ability to provide detailed information about the presence of environmentally persistent agrochemicals. They can also reflect changes in agricultural landscape quality at different spatial and temporal scales. Research indicates that agrochemicals, such as pesticides, fungicides, herbicides, and acaricides, pose a significant threat to honeybee physiology and colony health. Certain agrochemicals, notably neonicotinoids, have been directly linked to colony collapse. While some highly toxic agrochemicals causing acute toxicity to pollinators are banned or restricted in various countries, the sublethal effects of medium- or low-toxicity agrochemicals can still disrupt the physiology and behavior of all caste bees within the hive. This disruption is often exacerbated by the prophylactic use of these chemicals in the surrounding environment. Understanding the impact of agrochemical exposure on pollinators like honeybees is crucial for ensuring their well-being and the sustainability of agricultural ecosystems. Efforts to mitigate the negative effects of agrochemicals on pollinators, including implementing regulations on their use and promoting alternative pest management strategies, are essential for protecting pollinator populations and maintaining ecosystem health (Lin *et al*., 2023).

2.8. Pest and Diseases Affecting Honey Bees

To comprehend the recent rise in Western honey bee colony losses across the Northern hemisphere, it is crucial to grasp the key pests and diseases that impact bee health. Honey bees face a range of challenges from pests and diseases such as mites, viruses, bacterial infections, and fungal diseases. Despite the multitude of infectious diseases and their causative agents that can lead to bee mortality, surveillance efforts have been disjointed, making it challenging to establish a comprehensive historical perspective on bee health (Castle, 2013). Only in recent times has there been an increased recognition of the significance of studying the development and interactions of these pests and diseases for a better understanding of their impact on bee populations.

2.8.1. Parasitic Mites

Varroa, a parasitic mite, is commonly found in association with honey bees. The mite is mobile and moves between bees and within the hive. They are transported by the adult bees from colony to colony through the bees' natural processes of drifting, robbing, and swarming. Varroa can spread slowly over long distances in this way; mites can be found in almost every apiary in Europe and they have spread to all continents, where honey bees are managed with the exception of Australia (Castle, 2013).

The most significant ectoparasitic honey bee mite is *Varroa destructor*. It originated from South-East Asia and was originally confined to the Eastern honey bee *Apis cerana*. After a shift to the new host the Western honey bee, Apis mellifera, during the first half of the last century, the parasite has become widespread across most continents. There are two distinct phases in the life cycle of V. destructor females; a and worker brood cells. The mite is spread by foraging and swarming bees and Varroa females are transported on adult bees to brood cells for reproduction. Shortly after leaving the brood cell on a young bee, the mites preferentially infest nurse bees for transport back to the brood cells. This may be an adaptive strategy for the Varroa females to increase their reproductive success (Rosenkranz et al. (2010). The mite feeds on the bee by injuring the cuticle of the pupae and sucking substantial amounts of haemolymph. The haemolymph is an insect's equivalent to blood, distributing nutrients throughout the bee, including immune components which form one of the primary lines of defense against invading microorganisms (Castle, 2013).

2.9. Extreme cold spells in winter

Intense and persistent cold spells in mid and late winter can disrupt the food supply inside the hive, as bees require certain minimum temperatures to break the winter cluster and move to the food. At this time of the year, food demand is increased due to the start of egg-laying and brood rearing. High frequency of occurrence and long duration of cold spells could cause increased colony loss rates. Here, we assume the correlation with honey bee colony winter mortality to be positive(Becsi et al., 2021).

3. Material and Method

Researchers have developed different methodological approaches in response to the challenge of addressing global climate change. revealing the various approaches used to understand how climate change affects the life cycle of honeybees. it is important to clarify the criteria that were used to select the studies included in this review. A rigorous selection process was in place to make sure that only studies that met specific criteria were included, ensuring that the analysis that followed was both relevant and reliable. The inclusive collection of research related to the impact of climate change on the honeybee population were been adopted. The research included in this review showcases a wide range of different methods, demonstrating the complexity of honeybee life. Scientists have used a variety of methods, including analyzing numbers, conducting experiments, and carrying out observations, for study the impact of climate change on the life cycle of honeybees, each providing different perspectives. Each phase is explained to provide a comprehensive perspective of the collaborative research efforts in the honeybee life cycle, from the complexities of literature search tactics to the complexities of data synthesis and analysis.

4.Result

4.1. Climate change impact on bees

The result indicates that climate change is likely to have a significant impact on honey bees. Weather conditions, which are influenced by climate change, have been shown to affect various aspects of honey bee behavior and productivity, such as hive entrance activity, egg laying, honey yield, larvae feeding, swarming, foraging, and defense behavior. It's important to note that many studies have been limited by short-term observation periods and hive disturbances, which can cause stress and alter the bees' normal behavior.

4.2. Honey Bee Temperature

Workers developing in cold were heavier (mean ± SD: 112.0 ± 8.41 mg) than workers developing in warm (mean ± SD: 102.6 ± 12.64 mg). When each colony was analyzed 8 separately, this difference was statistically significant in two of them, while, in one, both groups were of similar mass (Fig. 1). Both rearing temperature and colony origin significantly affected worker body mass, and an interaction between these factors was significant (Tab. 1). Drones from all four colonies were heavier when developing in cold (mean ± SD: 233.5 ± 19.57), than in warm (mean ± SD: 222,4 ± 19.20 mg) (Fig. 1.). Similarly, as in the case of workers, the maternal colony and temperature significantly affected the body mass of drones, and these two factors also interacted with each other (Tab.1). The head mass of drones was smaller, the thorax mass similar, while the abdomen mass was larger in drones reared in cold (Fig. 2, Tab. 1). Body part masses also differed significantly between colonies. The interaction between temperature and maternal colony was significant in the case of thorax and abdomen masses, but not in the case of head mass (Tab. 1). The proportion of body parts in drones changed with developmental temperature. Drones reared in cold had proportionally smaller heads (Fig. 3a, Tab.1) also smaller thoraxes (Fig. 3b, Tab. 1) but proportionally larger abdomens (Fig. 3c, Tab.1) than drones reared in warm. Moreover, the effect of maternal colony was statistically significant for all body part proportions (Tab. 1). The proportion of all body parts also showed a significant interaction between rearing temperature and maternal colony (Tab. 1).The life span of worker bees varied depending on their maternal colony (F(2, 2384) = 52.9, $p < 0.001$), but not on rearing temperature (F(1, 2384) = 1.2, $p = 0.178$), which also showed significant interaction between these two factors (F(2, 2384) = 107.8, $p < 0.001$). However, in one colony (W2), a large number of bees (28 - 59% / cage, total of 186 bees) developing in cold died suddenly during a 48 hours period between their 8th and 9th day of life. These deaths were most probably caused by an unknown pathogen and therefore did not represent the natural life span of these individuals. We have omitted these bees from further analysis of life span and found that, after their exclusion, the life span of worker bees developing in cold was longer (19.2 ± 0.21 days in war vs. 22.1 ± 0.24 days in cold)(F(1, 2198) = 41.7, $p < 0.001$) and further also differed between colonies (F(1, 2198) = 180.0, $p < 0.001$) and also showed an interaction between rearing temperature and maternal colony (F(2, 2198) = 19.0, $p < 0.001$). The life span of drones was significantly different between bees developing in warm and cold (17.8 ± 0.59 days vs. 23.9 ± 0.54 days, respectively (F(1, 701) = 102.3, $p < 0.001$), and life span in various maintaining colonies also differed between each other (F(1, 701) = 107.3, $p < 90.001$), and a significant interaction of these two factors was revealed (F(3, 701) = 28.1, $p < 0.001$) (Tab. 2). Survival curves of both workers (Fig. 4a) and drones (Fig. 4b) reared in cold or warm differed significantly from each other ($C = -9.77$, $p < 0.001$; $C = 7.57$, $p < 0.001$, respectively). In both cases, individuals reared in cold were living longer. Survival curves between workers (Fig. 5a) from various maternal families also differed ($\chi2 = 236.33$, $p < 0.001$), similarly as survival curves of drones reared after emergence in various maintaining families ($\chi2 = 190.00$, $p < 0.001$) .

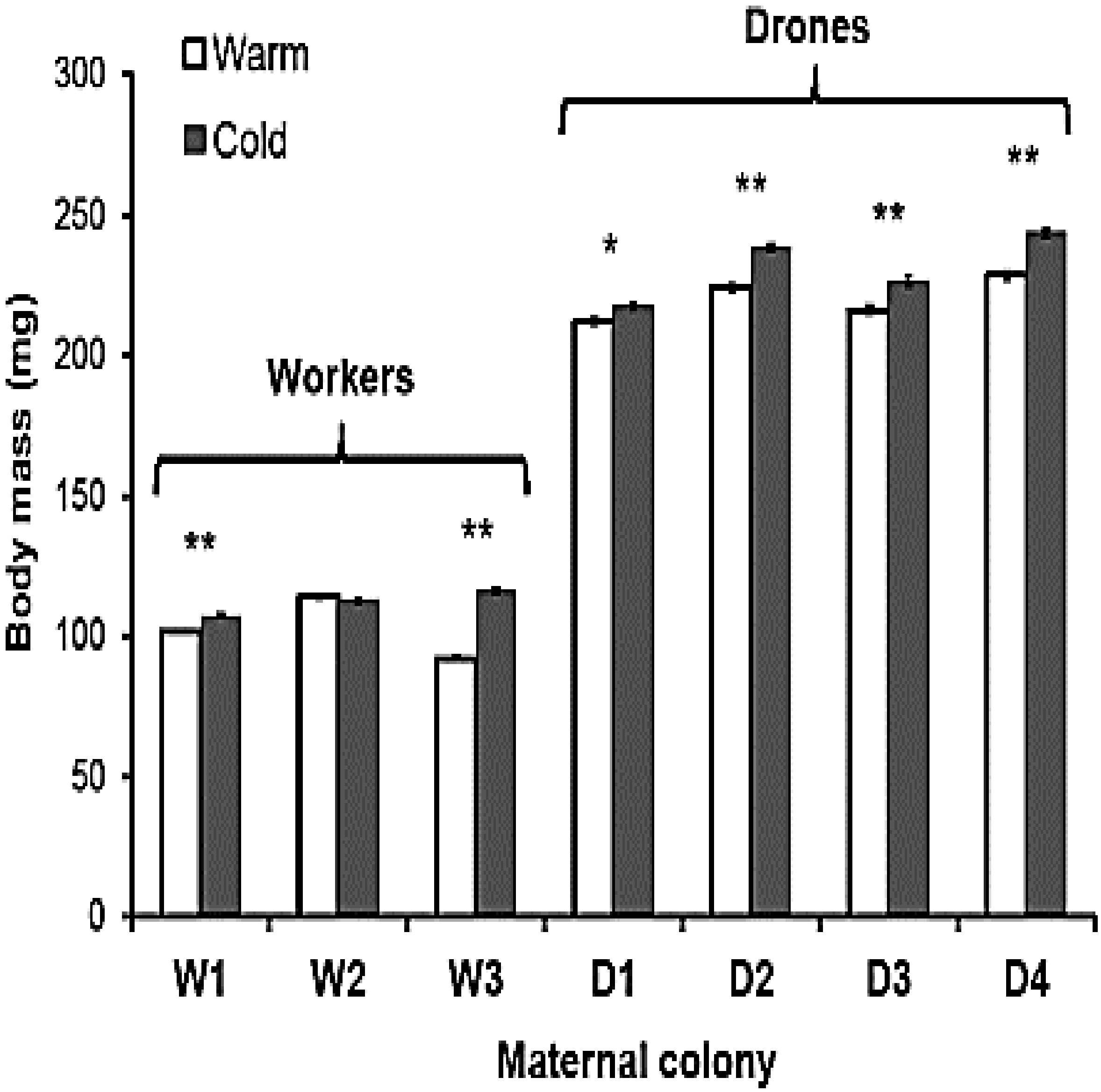
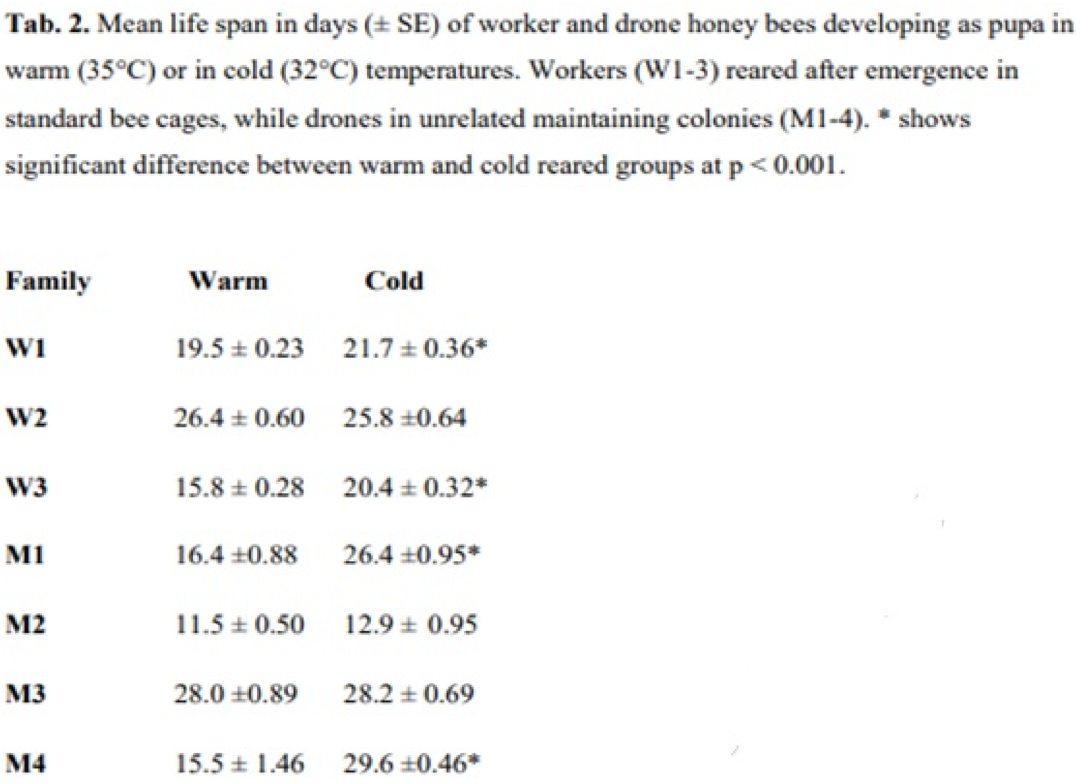


Fig. 1 Workers developing in cold and worm conditions

Tab. 1 Statistical differences in the body mass of workers (three maternal colonies) and drones (four maternal colonies), in the mass of body parts (head, thorax, and abdomen) of drones and their ratio to the total body mass of individuals developing as pupa in warm (35°C) and in cold (32°C) temperatures. All comparisons were done using two-way ANOVA with temperature and maternal colony as factors.

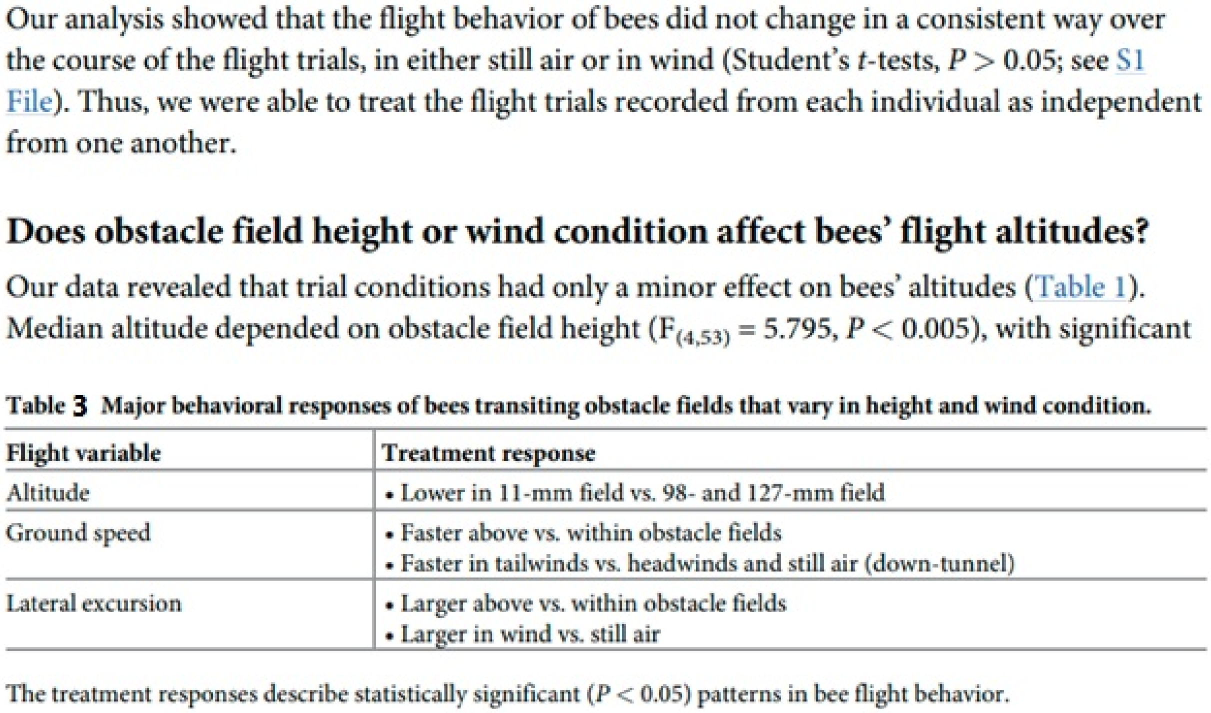
	Temperature	**Maternal Colony**	**Temperature*Colony**
Body mass of workers	F(1, 894) = 295.9 p < 0.001	F(2, 894) = 129.5 p < 0.001	F(2, 894) = 195.4 p < 0.001
Body mass of drones	F(1, 790) = 54.5 p < 0.001	F(3, 790) = 78.5 p < 0.001	F(3, 790) = 4.3 p = 0.005
Head mass of drones	F(1, 392) = 4.38 p = 0.037	F(1, 392) = 26.9 p < 0.001	F(3, 392) = 2.0 p = 0.109
Thorax mass of drones	F(1, 392) = 0.13 p = 0.716	F(1, 392) = 13.7 p < 0.001	F(3, 392) = 2.6 p = 0.048
Abdomen mass of drones	F(1, 392) = 163.91 p < 0.001	F(1, 392) = 69.1 p < 0.001	F(3, 392) = 24.6 p < 0.001
Head ratio of drones	F(1, 392) = 124.4 p < 0.001	F(3, 392) = 5.2 p = 0.002	F(3, 392) = 15.0 p < 0.001
Thorax ratio of drones	F(1, 392) = 308.5 p < 0.001	F(3, 392) = 100.8 p < 0.001	F(3, 392) = 33.3 p < 0.001
Abdomen ratio of drones	F(1, 392) = 329.6 p < 0.001	F(3, 392) = 82.8 p < 0.001	F(3, 392) = 33.1 p < 0.001



Tab. 2. Mean life span in days (± SE) of worker and drone honey bees developing as pupa in warm (35°C) or in cold (32°C) temperatures. Workers (W1-3) reared after emergence in standard bee cages, while drones in unrelated maintaining colonies (M1-4). * shows significant difference between warm and cold reared groups at p < 0.001.

Family	Warm	Cold
W1	19.5 ± 0.23	21.7 ± 0.36*
W2	26.4 ± 0.60	25.8 ±0.64
W3	15.8 ± 0.28	20.4 ± 0.32*
M1	16.4 ±0.88	26.4 ±0.95*
M2	11.5 ± 0.50	12.9 ± 0.95
M3	28.0 ±0.89	28.2 ± 0.69
M4	15.5 ± 1.46	29.6 ±0.46*

4.3. Impact of Wind on Honey Bee



Our analysis showed that the flight behavior of bees did not change in a consistent way over the course of the flight trials, in either still air or in wind (Student's *t*-tests, $P > 0.05$; see S1 File). Thus, we were able to treat the flight trials recorded from each individual as independent from one another.

Does obstacle field height or wind condition affect bees' flight altitudes?

Our data revealed that trial conditions had only a minor effect on bees' altitudes (Table 1). Median altitude depended on obstacle field height ($F_{(4,53)} = 5.795$, $P < 0.005$), with significant

Table 3 Major behavioral responses of bees transiting obstacle fields that vary in height and wind condition.

Flight variable	Treatment response
Altitude	• Lower in 11-mm field vs. 98- and 127-mm field
Ground speed	• Faster above vs. within obstacle fields • Faster in tailwinds vs. headwinds and still air (down-tunnel)
Lateral excursion	• Larger above vs. within obstacle fields • Larger in wind vs. still air

The treatment responses describe statistically significant ($P < 0.05$) patterns in bee flight behavior.

4.4. Effect of CO2 on survival of honey bees

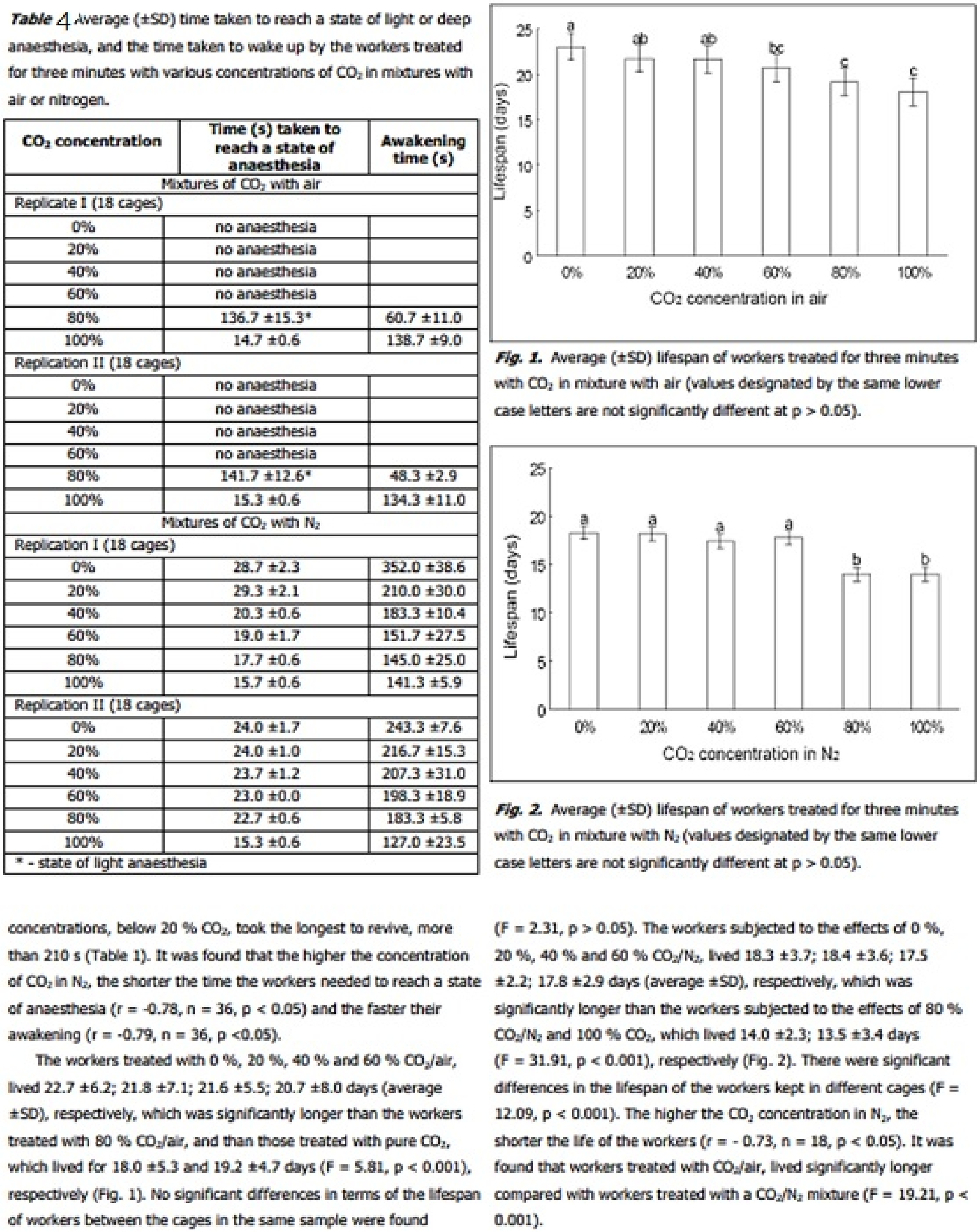


Table 4 Average (±SD) time taken to reach a state of light or deep anaesthesia, and the time taken to wake up by the workers treated for three minutes with various concentrations of CO_2 in mixtures with air or nitrogen.

CO_2 concentration	Time (s) taken to reach a state of anaesthesia	Awakening time (s)
Mixtures of CO_2 with air		
Replicate I (18 cages)		
0%	no anaesthesia	
20%	no anaesthesia	
40%	no anaesthesia	
60%	no anaesthesia	
80%	136.7 ±15.3*	60.7 ±11.0
100%	14.7 ±0.6	138.7 ±9.0
Replication II (18 cages)		
0%	no anaesthesia	
20%	no anaesthesia	
40%	no anaesthesia	
60%	no anaesthesia	
80%	141.7 ±12.6*	48.3 ±2.9
100%	15.3 ±0.6	134.3 ±11.0
Mixtures of CO_2 with N_2		
Replication I (18 cages)		
0%	28.7 ±2.3	352.0 ±38.6
20%	29.3 ±2.1	210.0 ±30.0
40%	20.3 ±0.6	183.3 ±10.4
60%	19.0 ±1.7	151.7 ±27.5
80%	17.7 ±0.6	145.0 ±25.0
100%	15.7 ±0.6	141.3 ±5.9
Replication II (18 cages)		
0%	24.0 ±1.7	243.3 ±7.6
20%	24.0 ±1.0	216.7 ±15.3
40%	23.7 ±1.2	207.3 ±31.0
60%	23.0 ±0.0	198.3 ±18.9
80%	22.7 ±0.6	183.3 ±5.8
100%	15.3 ±0.6	127.0 ±23.5
* - state of light anaesthesia		

Fig. 1. Average (±SD) lifespan of workers treated for three minutes with CO_2 in mixture with air (values designated by the same lower case letters are not significantly different at $p > 0.05$).

Fig. 2. Average (±SD) lifespan of workers treated for three minutes with CO_2 in mixture with N_2 (values designated by the same lower case letters are not significantly different at $p > 0.05$).

concentrations, below 20 % CO_2, took the longest to revive, more than 210 s (Table 1). It was found that the higher the concentration of CO_2 in N_2, the shorter the time the workers needed to reach a state of anaesthesia ($r = -0.78$, $n = 36$, $p < 0.05$) and the faster their awakening ($r = -0.79$, $n = 36$, $p < 0.05$).

The workers treated with 0 %, 20 %, 40 % and 60 % CO_2/air, lived 22.7 ±6.2; 21.8 ±7.1; 21.6 ±5.5; 20.7 ±8.0 days (average ±SD), respectively, which was significantly longer than the workers treated with 80 % CO_2/air, and than those treated with pure CO_2, which lived for 18.0 ±5.3 and 19.2 ±4.7 days ($F = 5.81$, $p < 0.001$), respectively (Fig. 1). No significant differences in terms of the lifespan of workers between the cages in the same sample were found ($F = 2.31$, $p > 0.05$). The workers subjected to the effects of 0 %, 20 %, 40 % and 60 % CO_2/N_2, lived 18.3 ±3.7; 18.4 ±3.6; 17.5 ±2.2; 17.8 ±2.9 days (average ±SD), respectively, which was significantly longer than the workers subjected to the effects of 80 % CO_2/N_2 and 100 % CO_2, which lived 14.0 ±2.3; 13.5 ±3.4 days ($F = 31.91$, $p < 0.001$), respectively (Fig. 2). There were significant differences in the lifespan of the workers kept in different cages ($F = 12.09$, $p < 0.001$). The higher the CO_2 concentration in N_2, the shorter the life of the workers ($r = -0.73$, $n = 18$, $p < 0.05$). It was found that workers treated with CO_2/air, lived significantly longer compared with workers treated with a CO_2/N_2 mixture ($F = 19.21$, $p < 0.001$).

During the three-minute exposure of workers to 20 %, 40 % and 60 % CO2/air, no anesthesia was observed. The locomotor activity of bee workers declined with the increase in CO2 concentration from 20 % to 60 %. The workers stayed in one place, making only single movements with their heads, antennae or legs and showed accelerated breathing movements. With less than 80 % CO2 concentration in air, workers entered a state of light anesthesia after an average (±SD) of 139.2 ±12.8 s in both replicates (Table 1). Only workers treated with 100 % CO2reached a state of deep anesthesia, after an average (±SD) of 15.0 ±0.6 s (Table 1). Deep anesthesia was also observed in all workers treated with various concentrations of CO2 in N2, where the workers reached a state of deep anesthesia in a progressively shorter time (Table 1). In pure CO2, workers entered a phase of deep anesthesia after an average (±SD) of 15.5 ±0.6 s in both replicates, whereas in pure N2 this was after 26.3 ±3.8 s (Table 1). The swiftest arousal from the anesthesia occurred in workers treated with an 80 % CO2/air, and with 100 % CO2, on average (±SD) after 54.5 ±9.9 s and 136.5 ±9.3 s (Table 1). Among the workers treated with a CO2/N2, the quickest to awake from their anesthesia, i.e., after 183 s, were those kept in atmospheres with high CO2 concentrations (80 - 100 %), whereas those kept in low concentrations, below 20 % CO2, took the longest to revive, more than 210 s (Table 1). It was found that the higher the concentration of CO2 in N2, the shorter the time the workers needed to reach a state of anesthesia ($r = -0.78$, $n = 36$, $p < 0.05$) and the faster their awakening ($r = -0.79$, $n = 36$, $p <0.05$). The workers treated with 0 %, 20 %, 40 % and 60 % CO2/air, lived 22.7 ±6.2; 21.8 ±7.1; 21.6 ±5.5; 20.7 ±8.0 days (average ±SD), respectively, which was significantly longer than the workers treated with 80 % CO2/air, and then those treated with pure CO2, which lived for 18.0 ±5.3 and 19.2 ±4.7 days ($F = 5.81$, $p < 0.001$), respectively (Fig. 1). No significant differences in terms of the lifespan of workers between the cages in the same sample were found Effect of CO2 on survival of honey bees 69 ($F = 2.31$, $p > 0.05$). The workers subjected to the effects of 0 %, 20 %, 40 % and 60 % CO2/N2, lived 18.3 ±3.7; 18.4 ±3.6; 17.5 ±2.2; 17.8 ±2.9 days (average ±SD), respectively, which was significantly longer than the workers subjected to the effects of 80 % CO2/N2 and 100 % CO2, which lived 14.0 ±2.3; 13.5 ±3.4 days ($F = 31.91$, $p < 0.001$), respectively (Fig. 2). There were significant differences in the lifespan of the workers kept in different cages ($F = 12.09$, $p < 0.001$). The higher the CO2 concentration in N2, the shorter the life of the workers ($r = - 0.73$, $n = 18$, $p < 0.05$). It was found that workers treated with CO2/air, lived significantly longer compared with workers treated with a CO2/N2 mixture ($F = 19.21$, $p < 0.001$). Table 1. Average (±SD) time taken to reach a state of light or deep anesthesia, and the time taken to wake up by the workers treated for three minutes with various concentrations of CO2 in mixtures with air or nitrogen.

4.5. The effect of humidity on fanning behavior and worker mobility

The distribution of fanning workers was not dependent on the position of the chamber in the linear setup since their number was not significantly different between the five 55% RH chambers (Friedman ANOVA x2 = 5.17, d.f. = 4, N.S). This number was consistently low in 70 all chambers with a mean (±SD) of 0.3±0.1 workers fanning per chamber during an observation time.

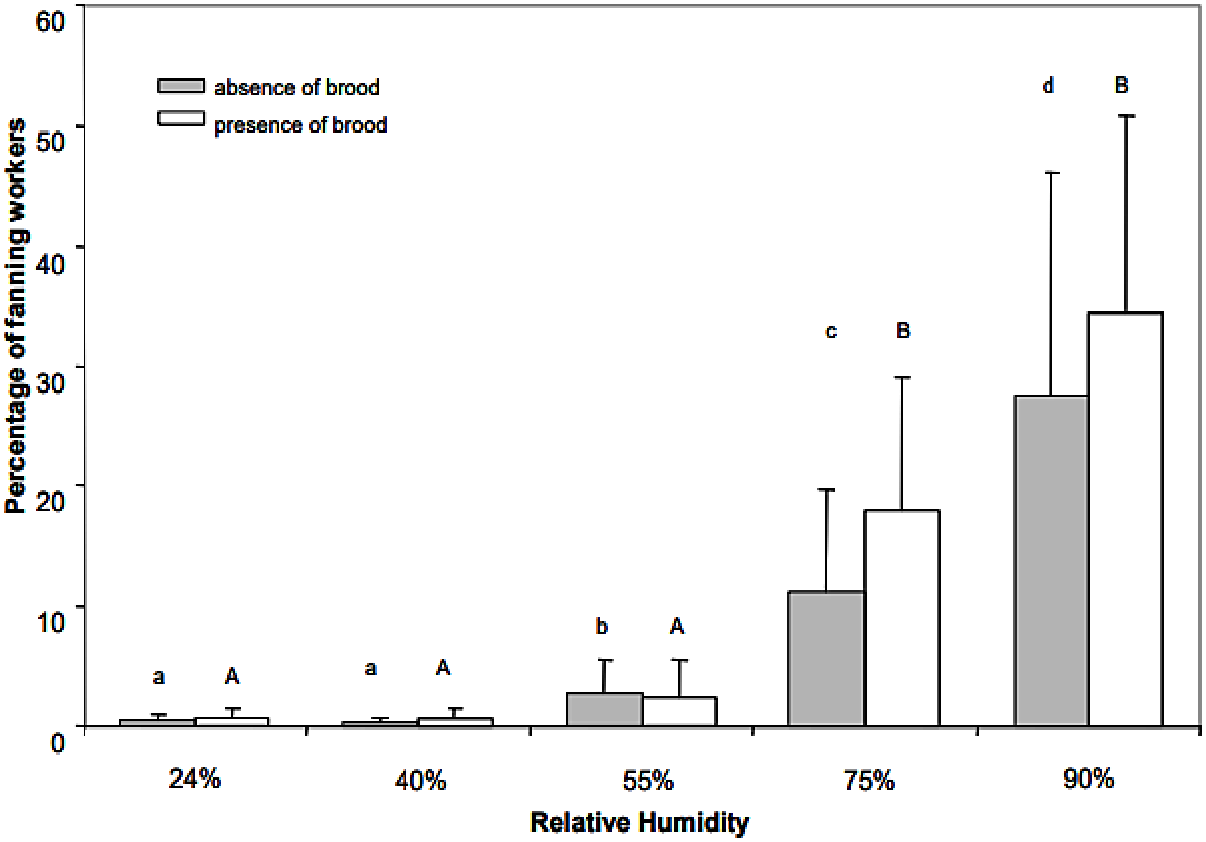


Fig. 3.3 Percentage of fanning workers given as mean (±SD) per chamber in a RH gradient (24 to 90% RH). Letters a - d indicate significant differences in the presence (6 day old workers) of brood and letters A - B indicate differences when in the absence (3 & 6 day old workers) of brood ($p<0.05$, Wilcoxon Matched Pairs test).

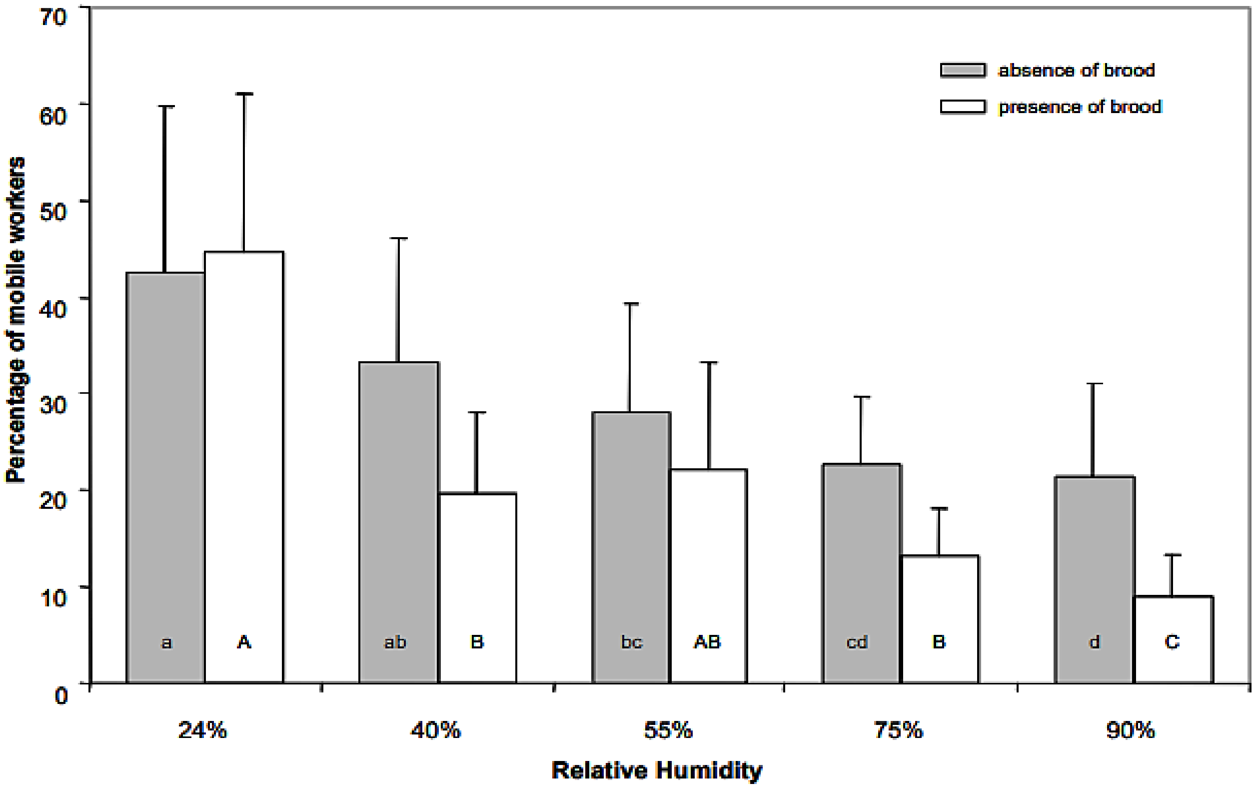


Fig. 3.4 Mean percentage (±SD) of mobile workers in a humidity gradient of 24 to 90% RH when in the absence (3 & 6 day old workers) of brood and in the presence (6 day old workers) of brood. Letters a - d indicate significance at $p < 0.05$ in absence of brood and letters A – C in the presence of brood (Wilcoxon Matched Pairs test)

4.6. Pest and Diseases Affecting Honey Bees

The impact of pests and diseases on honey bee colonies, particularly focusing on Varroa destructor, a parasitic mite. Varroa is identified as a significant threat to honey bee health, having originated from South-East Asia and later spreading to Western honey bees, Apis mellifera. The mite has two distinct phases in its life cycle: one attached to adult bees and another reproductive phase within sealed drone and worker brood cells. Varroa is spread through foraging and swarming bees, with females transported to brood cells for reproduction. The mite feeds on bees by injuring their cuticle and sucking hemolymphs, the insect equivalent of blood, thereby impacting the bee's immune system. This paragraph highlights the critical role of understanding and managing such pests and diseases for the health and survival of honey bee colonies.

5. Discussion

The timing of flowering plants can be affected by climate change, which has an impact on the availability of nectar and pollen, which are honey bees' main food sources. Bees may experience food shortages as a result of changes in flowering patterns, particularly during crucial periods like the brood-rearing season. Foraging activity is regulated by honey bees based on cues from their surroundings, such as lighting and temperature. These cues may become less reliable due to climate change, which might alter foraging habits. As environmental circumstances change, bees may choose to graze at various times or in other places. Foraging activity is regulated by honey bees based on cues from their surroundings, such as lighting and temperature. These cues may become less reliable due to climate change, which might alter foraging habits. As environmental circumstances change, bees may choose to graze at various times or in other places. Environmental change is related with additional successive and serious outrageous climate occasions, Environmental change can prompt living space misfortune and discontinuity through elements, for example, changes in land use, deforestation, and adjusted precipitation designs. Loss of reasonable scrounging environments and settling destinations can lessen honey bee populaces and breaking point their capacity to lay out new settlements.

Environmental change can likewise influence the hereditary variety of honey bees populaces. Natural stressors related with environmental change, like outrageous temperatures and territory misfortune, can diminish the genetic supply inside honey bees populaces, making them less versatile to future difficulties like vermin, infections, and ecological changes. the impacts of environmental change on honey bees are perplexing and diverse, with both immediate and aberrant effects on their way of behaving, natural surroundings, and endurance. Moderating these effects requires deliberate endeavors to address the underlying drivers of environmental change and to execute systems to help honey bees wellbeing and versatility.

The findings underscore the urgent need for proactive measures to address the impacts of climate change on honey bees. Integrated pest management strategies, including monitoring and controlling *Varroa mite* infestations, are crucial for maintaining colony health. Furthermore, efforts to minimize exposure to agrochemicals and mitigate habitat loss can help mitigate additional stressors on bee populations. Collaboration between researchers, beekeepers, policymakers, and agricultural stakeholders is essential for implementing adaptive management practices and promoting bee-friendly agricultural policies ,continued research into the complex interactions between climate variables, bee physiology, and ecosystem dynamics is necessary for developing targeted interventions. By prioritizing honey bee conservation and sustainability, society can safeguard the vital pollination services provided by bees and ensure the resilience of agricultural systems in the face of climate change.

6. Conclusion

Climate change poses significant challenges to honey bee populations, affecting various aspects of their life cycle and behavior. Weather conditions influence hive activity, egg laying, honey yield, foraging, and defense behavior, highlighting the interconnectedness between climate and bee productivity. Temperature fluctuations impact bee development, with colder temperatures leading to heavier workers and longer lifespans, but also posing risks of sudden mortality due to unknown pathogens. Additionally, exposure to high levels of carbon dioxide affects bee behavior and lifespan, with implications for colony dynamics. Varroa mites and other pests further exacerbate bee health issues, leading to colony losses. However, the research emphasizes the importance of understanding these dynamics for developing effective mitigation strategies. Through interdisciplinary approaches, such as monitoring weather indicators and implementing hive management practices, it is possible to enhance honey bee resilience to climate change and ensure the sustainability of pollination services.

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