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Beehive Microclimate Significantly Influences the Activity and Productivity of Honey Bee (*Apis mellifera* L.) Colonies

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Abstract

Environmental conditions, particularly temperature, significantly influence a honey bee colony, affecting its behavior, physiology, and performance. This study aimed to investigate the effects of shaded and unshaded environments on colony growth and performance. The experiments were conducted in shaded and unshaded colonies in the same apiary, and data were collected on the temperature inside and outside the brood nest, foraging activity, stored pollen area, sealed brood area, bee population size, and honey yield. The unshaded colonies exhibited higher brood nest temperatures and enhanced colony performance during cooler months, with a significantly greater number of foragers and pollen foragers, a larger stored pollen area, sealed brood areas, a larger colony population size, and a higher honey yield than shaded colonies. Conversely, shaded colonies outperformed unshaded colonies during hotter months, as unshaded colonies experienced stress from elevated temperatures, leading to reduced foraging activity, pollen collection, colony growth, and honey production. These findings highlight the crucial role of microclimatic conditions in honey bee colony management, underscoring the importance of providing optimal environmental conditions to support colony performance and sustainability, particularly in fluctuating climatic conditions. It is recommended to shade the beehives in the summer and remove the shading in the winter and spring.

Introduction

Honey bees are among the most economically significant insects due to their critical role as pollinators (Taha et al., 2016; Al-Kahtani et al., 2017; Chabert et al., 2024). Also, beehive products play a crucial role in increasing income, particularly in rural communities (Taha et al., 2021a; Eissa & Taha, 2023). The health and performance of colonies are crucial for achieving optimal productivity, which requires proper management practices, including controlling environmental factors and providing adequate nutrition. This approach significantly enhances colony strength and productivity (Taha et al., 2025).

Maintaining a stable brood nest temperature between 33 °C and 36 °C is vital for colonies, as this range supports proper brood growth and development (Jones & Oldroyd, 2006; Taha & Al-Kahtani, 2019). Deviations from this temperature range due to external ambient conditions can disrupt brood development, reduce emergence rates (Tautz et al., 2003), and negatively impact colony productivity (Taha & Al-Kahtani, 2019). Low temperatures are particularly detrimental, leading to colony losses (Minaud, 2024) and destabilizing the hive's heat center (Stabentheiner, 2003). These fluctuations can also affect critical colony activities, such as brood rearing and foraging activity (Jarimi et al., 2020).

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Honey bees possess remarkable thermoregulation strategies. For instance, they can elevate brood temperatures to reinforce brood health and activities that mitigate threats (Li et al., 2016; Gounari et al., 2022). Worker bees in the colony can detect temperature changes as small as 0.25 °C using their antennal receptors (Jarimi et al., 2020). When the brood temperature drops below 30 °C, and the hive is infected with pathogens such as *Ascosphaera apis* (chalkbrood disease), bees may raise the hive temperature to prevent the spread of the disease (Starks et al., 2000). Several other factors could also influence colony activity and productivity, among them, floral nectar and pollen availability (Taha et al., 2019; Balvino-Olvera et al., 2024), honey bee race (Taha & Al-Kahtani, 2019), seasonal variations (Shawer et al., 2021), colony strength (Sihag & Rawal, 2025), feeding colonies (Amera et al., 2024; Khanal et al., 2024; Taha et al., 2025), and the surrounding environmental factors (Khanal et al., 2024). Beekeepers have adopted various strategies to mitigate colony losses by regulating hive temperatures across different seasons.

In the summer, colonies are shaded, and clean water sources are provided to mitigate the effects of high temperatures. During autumn and winter, colonies are exposed to sunlight and provided with proper nutrition to sustain them. Previous studies have explored several approaches to improve hive conditions, such as heat-insulating materials (e.g., nylon or foam; Abd-Elmawgood et al., 2015) and solar heaters (Wineman et al., 2003). Additionally, foam hives have been shown to increase sealed brood and pollen stores (Flores et al., 2020), while electric heating has been found to significantly enhance brood and honey production (Omran, 2011). From this perspective, the current study aimed to test the hypothesis that shading affects the monthly fluctuations in worker and drone sealed brood areas, foraging activity, stored pollen area, colony population size, and honey yield.

Materials and Methods

Experimental location

The experiments were carried out at the apiary of the Faculty of Agriculture, Kafrelsheikh University (31° 5′ 54″ N, 30° 57′ 0″ E) in two periods. The first period was from October 2022 to May 2023, while the second period took place from June to September 2023. At the beginning of each period, 12 hybrid Carniolan honey bee (*Apis mellifera carnica* Pollmann × *A. m. lamarkii* Cockerell) colonies (7 combs for each) headed by newly open-mated sister queens were used. All colonies were relatively equal in terms of strength and the number of combs covered with bees. Six colonies were kept in a shaded area, while the other six colonies were kept in an open area (unshaded) in the same apiary.

Brood nest temperature

Each colony was equipped with a digital thermoelectric thermometer with two sensors to measure the temperature inside and outside the brood nest. One sensor was placed inside the brood nest, and the other in the empty part of the brood chamber to record the temperature inside and outside the brood nest, respectively. Temperature measurements were recorded weekly at the same times as foraging activity measurements (8:00-9:00 during June-September and at 12:00 –13:00 during October-May). A digital thermometer was kept outside the colony to record the ambient temperature. The monthly mean of temperatures outside and inside the brood nest was calculated for all colonies.

Colony activity

The foraging activity was estimated at the peaks of flight activity, which occurred between 8:00 and 9:00 hrs during June-September and between 12:00 and 13:00 hrs during October-May. Foraging activity was determined by weekly counts of foragers and pollen foragers using a tally counter. The areas (inches^2) of stored pollen, worker-sealed brood, and drone-sealed brood were calculated at 12-day intervals using an unoccupied standard frame divided into square inches. Colony population size was determined by counting the number of combs covered with bees, which totaled 2,000 bees (Taha, 2007). Honey yield was harvested by the end of the Egyptian clover (*Trifolium alexandrinum* L.) flow season at the beginning of June and by the end of the cotton (*Gossypium herbaceum* L.) flow season at the end of August. The mean honey yield of each colony was estimated by calculating the difference between the weight of honeycombs before and after honey extraction.

Statistical analysis

The variances between shaded and unshaded colonies during the two experimental periods were examined using a two-way analysis of variance (ANOVA) for all parameters, except honey yield, which was examined using a one-way ANOVA. The Shapiro-Wilk normality test confirmed that the data were normally distributed. The evaluation was conducted using the original statistics. The ANOVA was performed using the PROC GLM procedure in SAS version 9.1 (SAS, 2003). Tukey's HSD post-hoc test was used to compare the treatment means.

Results

The data presented in Table 1 illustrate that the monthly averages of the temperatures outside and inside the brood nest were significantly ($P<0.01$) influenced by shading. During the 1st experimental period (October to May), the brood nest temperatures of shaded colonies were consistently lower than those of unshaded colonies by 0.68, 0.69, 0.74, 0.75, 0.67, 0.71, 0.89, and 0.43 °C from October to May, respectively. Similarly, the outside brood nest temperatures of shaded colonies were lower than those of unshaded colonies by 0.99, 1.27, 1.33, 1.14, 1.33, 0.70, 1.72, and 3.75 °C, respectively, during the same period. On the contrary, during the 2nd experimental period (June to September), the brood nest temperatures of unshaded colonies were consistently higher than those of shaded colonies by 0.36, 0.42, 0.65, and 0.52 °C from June to September, respectively. Also, the temperatures outside the brood nest in unshaded colonies exceeded those of shaded colonies by 2.13, 0.78, 1.48, and 2.08 °C during the same period.

Data illustrated in Figs (1-6) display that the number of forager bees/colony/min., the number of pollen foragers/colony/min., stored pollen area (sq. inches)/colony/month, worker sealed brood area (sq. inches)/colony/month, drone sealed brood area (sq. inches)/colony/ month, and colony population size (No. bees/colony)/month in unshaded colonies were significantly ($P < 0.01$) higher than those in shaded colonies during the 1st experimental period (October to May), and the inverse trend was observed during the 2nd experimental period (June-September). Compared with the unshaded colonies, the number of forager workers and pollen foragers in shaded colonies decreased by 5.02 & 10.07, 26.82 & 45.68, 44.48 & 43.75, 24.85 & 25.61, 32.02 & 27.60, 39.60 & 45.31, 36.50, and 29.87 & 39.24% during the months from October to May, respectively. On the contrary, the number of forager workers and pollen foragers in shaded colonies increased by 0.92 & 14.82, 18.58 & 25.48, 20.11 & 26.13, and 24.05 & 14.18% from June to September, respectively. In addition, the stored pollen areas in shaded colonies were lower than those in the unshaded colonies, by 18.82%, 8.22%, 10.64%, 21.88%, 8.38%, 25.19%, 18.11%, and 17.33% during the months from October to May, respectively. On the contrary, stored pollen areas in shaded colonies increased by 0.60%, 34.81%, 33.46%, and 20.47% from June to September, respectively compared to the unshaded colonies. Similarly, Compared with the unshaded colonies, the worker sealed brood areas in shaded colonies decreased by 1.47%, 3.53%, 4.92%, 12.04%, 19.84%, 29.02%, 46.68%, and 39.35% during the months from October to May, respectively. On the contrary, worker sealed brood areas in shaded colonies increased by 4.95%, 17.56%, 17.53%, and 34.14% from June to September, respectively. Also, drone sealed brood areas in shaded colonies showed a marked decrease, reducing by 206.45%, 67.46%, 73.03%, and 42.31% compared with the unshaded colonies during the months from February to May, respectively.

Table 1. The monthly ambient temperature, temperature outside and inside the brood nest in shaded and unshaded colonies in 2022/2023.

Months	Ambient temperature °C	Inside brood nest		Outside brood nest	
		Unshaded colony	Shaded colony	Unshaded colony	Shaded colony
1st experimental period					
October 2022	32.25	35.40 ± 0.07^{a}	34.72 ± 0.10^{cd}	33.40 ± 0.08^{a}	32.40 ± 0.04^{b}
November	29.20	35.35 ± 0.06^{a}	34.66 ± 0.07^{d}	27.32 ± 0.14^{d}	26.50 ± 0.10^{e}
December	23.00	35.29 ± 0.06^{a}	34.55 ± 0.06^{e}	22.28 ± 0 .04^{i}	20.86 ± 0. 12^{k}
January 2023	17.75	35.24 ± 0.06^{a}	34.48 ± 0.07^{e}	22.72 ± 0.09^{h}	21.72 ± 0.05^{j}
February	19.75	35.43 ± 0.06^{a}	34.75 ± 0.04^{b}	23.07 ± 0.07^{g}	21.84 ± 0.07^{j}
March	21.50	35.60 ± 0.06^{a}	34.89 ± 0.05^{b}	23.17 ± 0.10^{g}	22.32 ± 0.05^{i}
April	25.75	35.79 ± 0.07^{a}	34.89 ± 0.04^{b}	25.13 ± 0.05^{f}	23.15 ± 0.05^{g}
May	31.25	35.87 ± 0.07^{a}	35.10 ± 0.05^{b}	30.03 ± 0.11^{c}	25.03 ± 0.04^{f}
2nd experimental period					
June	31.00	35.49 ± 0.02^{c}	35.20 ± 0.03^{d}	32.37 ± 0.05^{c}	31.77 ± 0.02^{e}
July	36.25	35.86 ± 0.03^{a}	35.44 ± 0.03^{c}	32.87 ± 0.04^{a}	32.09 ± 0.06^{d}
August	35.75	35.85 ± 0.02^{a}	35.20 ± 0.02^{d}	32.94 ± 0.09^{a}	31.45 ± 0.07^{f}
September	34.50	35.60 ± 0.04^{b}	35.09 ± 0.02^{e}	32.63 ± 0.07^{b}	30.49 ± 0.11^{g}

Values are the mean ± standard error. The means of each parameter followed by the different letters are significantly different at $P<0.01$.

Table 2. Analysis of variance of temperature inside and outside brood nest, forager workers, brood area, colony population size, and honey yield.

Variable	DF	SS	MS	F- value	*P*- value
1st experimental period					
Temperature outside the brood nest	15	2144.96	142.99	1880.54	< 0.001
Temperature inside the brood nest	15	22.02	1.46	33.83	< 0.001
No forager bees/colony/min	15	3133.59	208.90	260.60	< 0.001
No pollen foragers/colony/min	15	18.94	1.26	99.47	< 0.001
Stored pollen area/colony/month	15	11.00	0.73	14.99	< 0.001
Worker sealed brood area/colony/month	15	4782089.68	318805.97	69.44	< 0.001
Drone sealed brood area/colony/month	15	527563.11	35170.87	47.52	< 0.001
Colony population size/colony/month	15	77582436.71	5172162.45	62.21	< 0.001
Egyptian honey yield (kg)/colony	1	5.21	5.21	1775.81	< 0.001
2nd experimental period					
Temperature outside the brood nest	7	44.96	6.42	145.14	< 0.001
Temperature inside the brood nest	7	5.93	0.84	85.99	< 0.001
No forager bees/colony/min	7	907.95	129.70	167.31	< 0.001
No pollen foragers/colony/min	7	8.94	1.27	49.51	< 0.001
Stored pollen area/colony/month	7	2.84	0.40	37.22	< 0.001
Worker sealed brood area/colony/month	7	984120.99	140588.71	18.12	< 0.001
Drone sealed brood area/colony/month	7	75500.22	10785.74	17.54	< 0.001
Colony population size/colony/month	7	17761435.90	2537347.99	15.56	< 0.001
Cotton honey yield (kg)/colony	1	2.79	2.79	1645.44	< 0.001

Source of variation = shading and months, SS = sum of squares, MS = mean squares.

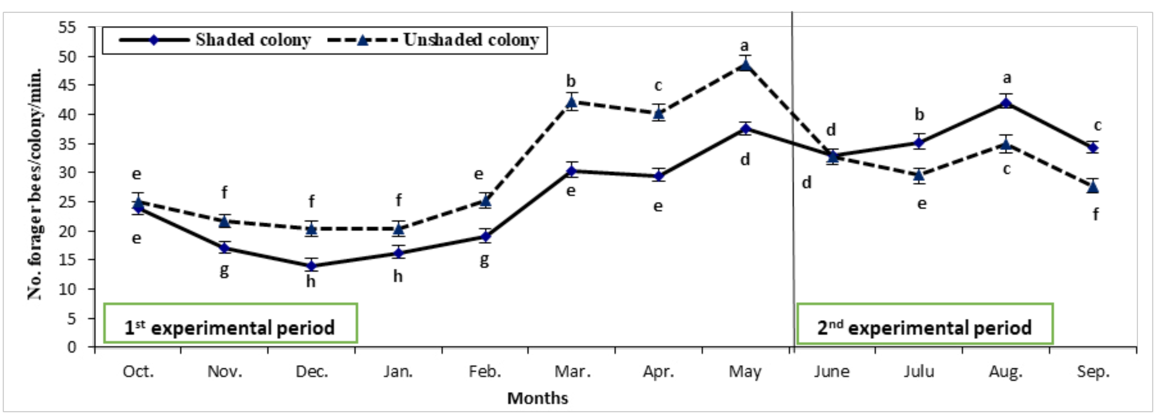

Fig 1. Monthly fluctuation of the number of forager bees/colony/min in shaded and unshaded Carniolan hybrid bee colonies in Kafrelsheikh province during 2022/2023. Different letters above the bars within each experimental period indicate a significant ($p<0.05$) difference.

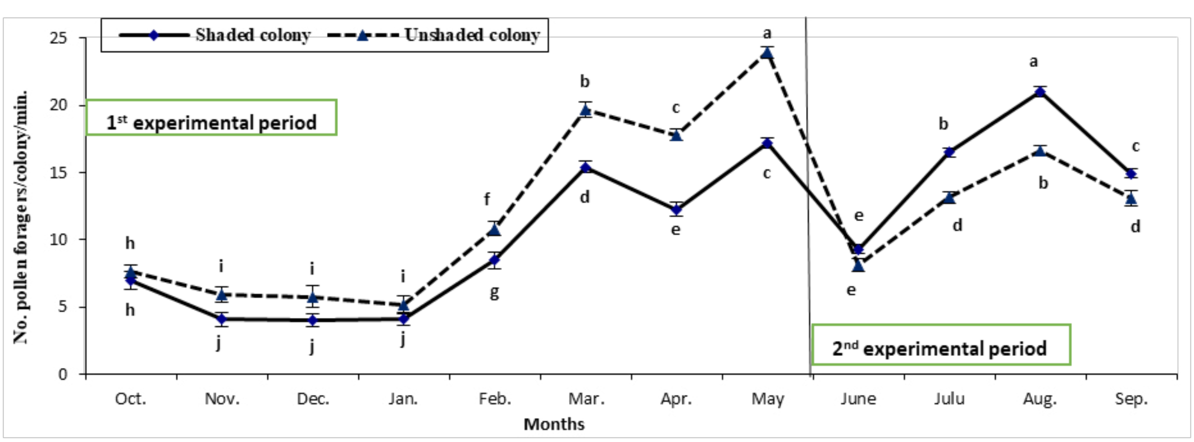

Fig 2. Monthly fluctuation of the number of pollen foragers/colony/min in shaded and unshaded Carniolan hybrid bee colonies in Kafrelsheikh province during 2022/2023. Different letters above the bars within each experimental period indicate a significant ($p<0.05$) difference.

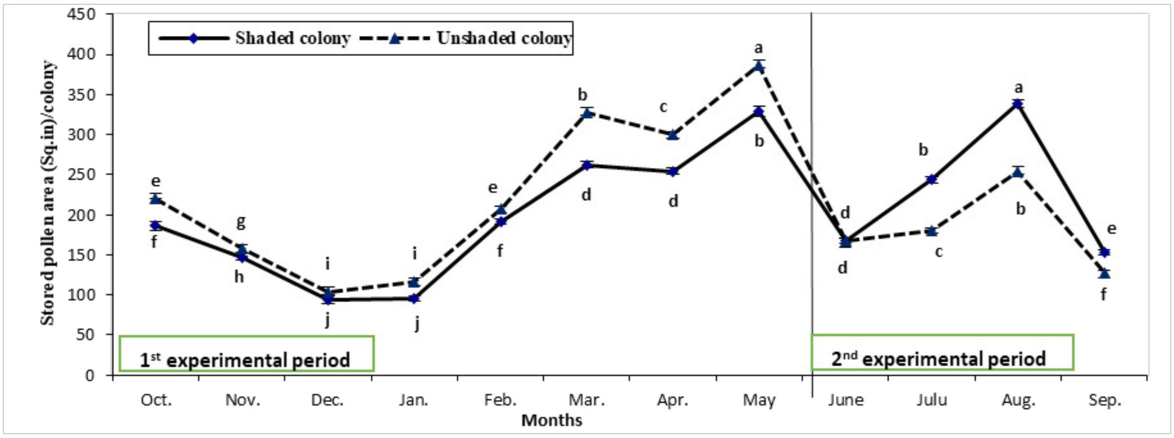

Fig 3. Monthly fluctuation of stored pollen in shaded and unshaded Carniolan hybrid bee colonies in Kafrelsheikh province during 2022/2023. Different letters above the bars within each experimental period indicate a significant (p<0.05) difference.

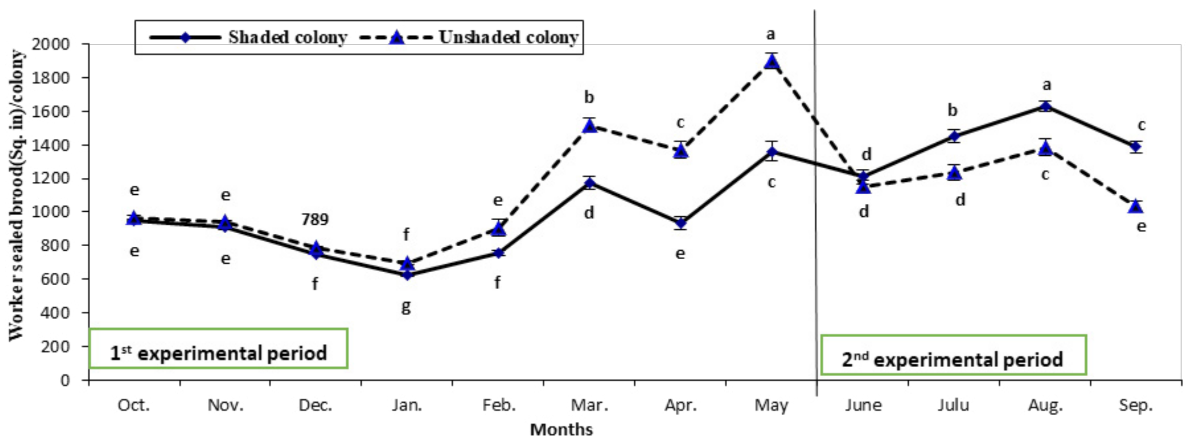

Fig 4. Monthly fluctuation of worker sealed brood area in shaded and unshaded Carniolan hybrid bee colonies in Kafrelsheikh province during 2022/2023. Different letters above the bars within each experimental period indicate a significant (p<0.05) difference.

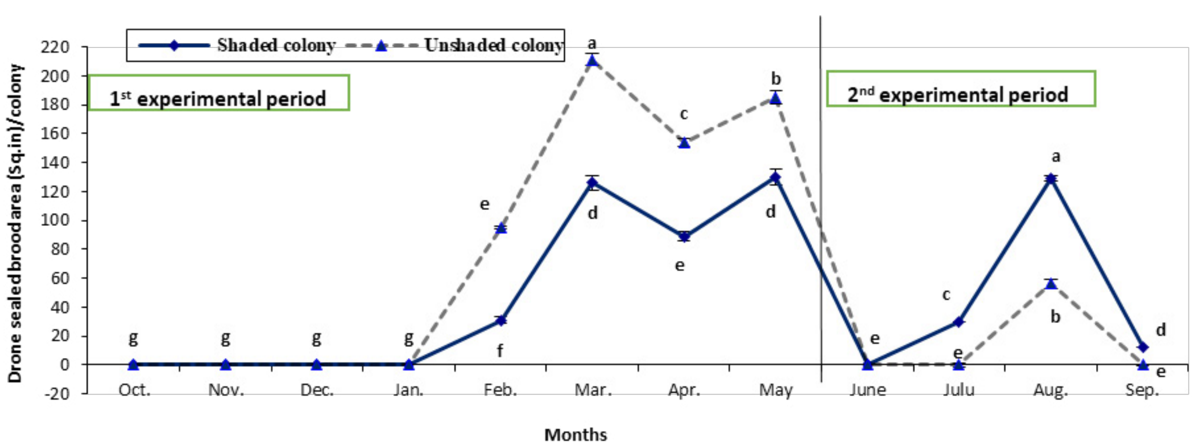

Fig 5. Monthly fluctuation of drone sealed brood area in shaded and unshaded Carniolan hybrid bee colonies in Kafrelsheikh province during 2022/2023. Different letters above the bars within each experimental period indicate a significant (p<0.05) difference.

Generally, the highest significant (P<0.01) values of forager bees, pollen foragers, stored pollen area, and worker sealed brood area were recorded during May, followed by August and March. Meanwhile, the largest area of drone-sealed brood was recorded in March, followed by May and April, and the largest colony population was recorded in August, followed by May and April.

Data in Figure 7 show that Egyptian colover honey yield in unshaded colonies was significantly (P<0.01) higher than that in shaded colonies (5.20 vs 4.12 kg/colony) in the 1st experimental period (October-May), and the inverse trend was observed with cotton honey yield (4.10 vs 4.89 kg/colony) during the 2nd experimental period (June-September).

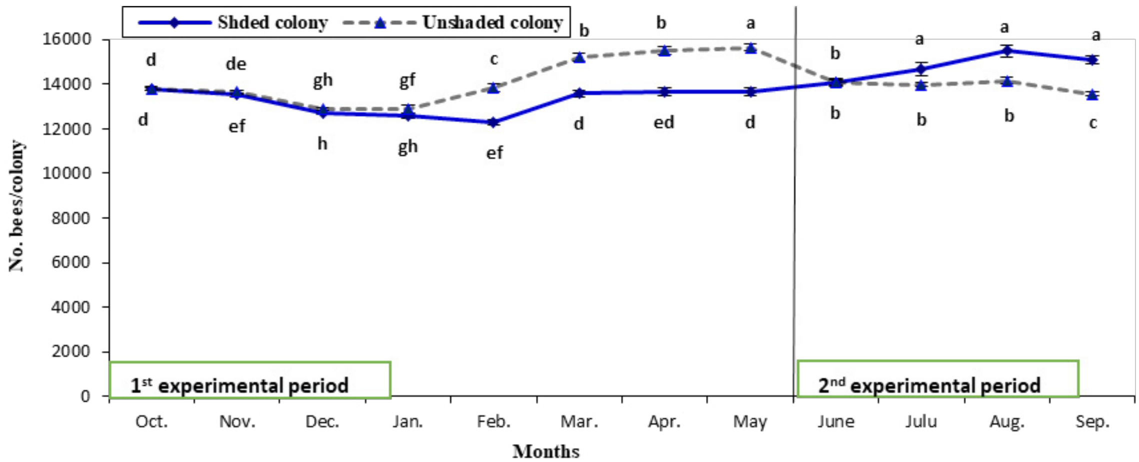

Fig 6. Monthly fluctuation of population size of shaded and unshaded Carniolan hybrid bee colonies in Kafrelsheikh province during 2022/2023. Different letters above the bars within each experimental period indicate a significant (p<0.05) difference.

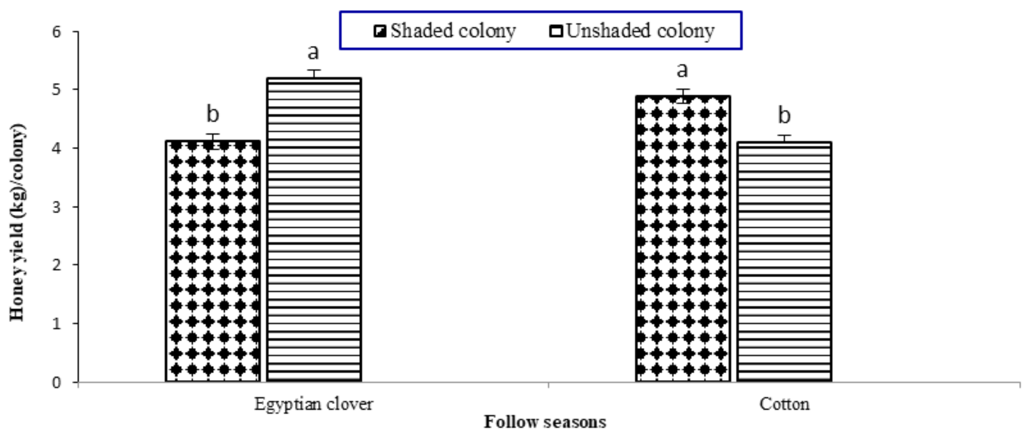

Fig 7. Honey yield (kg)/colony of shaded and unshaded Carniolan hybrid bee colonies in Kafrelsheikh province during 2022/2023. Different letters above the bars within each flow season indicate a significant (p<0.05) difference. Egyptian clover season flow was during the 1st experimental period, and cotton season flow was during the 2nd experimental period.

Discussion

The unshaded honey bee colonies maintained higher brood nest and outside brood nest temperatures compared to shaded colonies from October to May. On the contrary, during the 2nd experimental period, starting in June and continuing through September with rising temperatures, the brood nest and outside brood nest temperatures of unshaded colonies were consistently higher than those of shaded colonies. This observation aligns with the findings of Stabentheiner et al. (2010), who have demonstrated that shading reduces thermal stress and helps maintain more stable temperatures within the hive. While honey bees actively regulate the temperature of their brood nest to ensure optimal brood development, exposure to direct sunlight can elevate hive temperatures, requiring the bees to increase cooling efforts, such as fanning and water evaporation (Duffy et al., 2015; Sanz et al., 2024). Shading the hives helps mitigate these temperature increases, thereby reducing the energy expenditure required for thermo-regulation (Jones & Oldroyd, 2006). Sanz et al. (2024) have noted that external environmental conditions significantly influence the thermoregulation of hives. With rising ambient temperatures, maintaining optimal brood nest temperatures becomes more challenging, especially for unshaded colonies, where solar exposure adds to the thermal load (Stabentheiner et al., 2010).

The foraging activity is influenced by pollen and nectar floral resources (Helal et al., 2003), honey bee race (Taha & Al-Kahtani, 2019), colony strength (Taha & Al-Kahtani, 2013; Sihag & Rawal, 2025), presence of bee-eater (*Merops* spp.) birds (Ali & Taha, 2012), and air temperature and relative humidity (Taha, 2014). In the current investigation, all factors, regardless of shading, were similar across the two groups. Therefore, the differences should have been related to shading. The rates of foraging activity, including the numbers of forager and pollen forager bees, were significantly higher in unshaded colonies than in shaded colonies during the cold and middle-temperature months (October to May), and the inverse trend was observed during the hot period (June-September). Generally, three peaks of foraging activity were recorded during May, March, and August. Relatively similar results were recorded in Egypt (Taha et al., 2019; Shawer et al., 2021), and in Saudi Arabia (Taha, 2014; Taha & Al-Kahtani, 2019). The peaks of forager and pollen forager bees coincided with the flowering season of Egyptian clover (*Trifolium alexandrinum* L.) in May, faba bean (*Vicia faba* L.) in March, and cotton (*Gossypium herbaceum* L.), sunflower (*Helianthus annuus* L.), and maize (*Zea mays* L.) in August (Taha et al., 2019).

The area of stored pollen depends on the amount of collected pollen, the rate of pollen consumption, and colony population size (Taha & Al-Kahtani, 2013; Sihag & Rawal, 2025). Three peaks of collected and stored pollen area were recorded; the most prominent peak was recorded during May, the 2nd during August, and the 3rd during March. Similar results were reported in Egypt (Taha, 2005; Taha et al., 2019) and Saudi Arabia (Taha & Al-Kahtani, 2019). The peaks coincided with those of forager and pollen-forager bees, which occurred during the flowering periods of Egyptian clover, maize, and faba bean, respectively. These results were confirmed by the data published by Taha et al. (2019).

The area of the sealed brood and the population of adult bees can assess the strength of a honey bee colony. Brood rearing was significantly influenced by foraging activity, pollen collection, and colony population size (Taha & Al-Kahtani, 2019; Elwakeil et al., 2025). The peaks in brood rearing were closely linked to the peaks in stored pollen, indicating positive correlations between worker sealed brood area and the number of foragers, pollen foragers, and stored pollen area. This is consistent with the findings of Shawer et al. (2003), Russell et al. (2017), and Taha & Al-Kahtani (2019), who have demonstrated that brood rearing activity is dependent on the amount of nectar and pollen collected, which, in turn, depends on the availability of young and foraging workers (Shawer et al., 2021). The unshaded colonies reared worker sealed brood areas significantly more than the shaded colonies during the months from October to May, and the opposite trend was observed during the months from June to September. Also, drone-sealed brood areas in shaded colonies showed a marked decrease compared with the unshaded colonies during the months from February to May. Lower brood production in shaded colonies during cold periods can be explained by the increased energy expenditure required for thermoregulation. Workers devote more effort to maintaining hive temperatures than to brood-related activities, such as feeding larvae or constructing brood cells (Nürnberger et al., 2018; Ulgezen et al., 2024). Meanwhile, during the 2nd experimental period, conducted during the summer (June to September), shaded colonies exhibited significantly larger sealed brood areas for both workers and drones compared to unshaded colonies. The increase in brood nest temperatures in unshaded colonies, caused by direct sunlight, exceeded the permissible limits, prompting workers to increase their ventilation efforts to reduce internal hive temperatures. This, in turn, negatively impacted colony productivity. These results align with those found by Taha (2014).

The observed differences in sealed brood areas between shaded and unshaded colonies can be attributed to environmental conditions, particularly temperature, on colony activity and brood production. During the cooler months (October to May), unshaded colonies had significantly higher sealed brood areas for both workers and drones than shaded colonies. This finding aligns with previous research indicating that increased exposure to sunlight enhances internal hive temperatures, thereby reducing the energy required for thermoregulation (Stabentheiner et al., 2010). Consequently, more energy is available for brood care, cell construction, and larval feeding, thereby increasing brood production. Conversely, in shaded colonies, lower ambient and brood-nest temperatures during colder months resulted in a significant decline in sealed brood areas. Workers in these colonies likely redirected more energy and effort toward maintaining optimal hive temperatures, which could detract from brood-related activities (Ulgezen et al., 2024). This shift in energy allocation has been well-documented as a key factor influencing colony productivity during colder seasons. Drone brood production followed a similar seasonal trend, decreasing markedly in shaded colonies. The colony's prioritization of resources may explain this phenomenon. Drone production is often reduced during periods of resource scarcity or adverse environmental conditions (Taha & Al-Kahtani, 2019), as it does not directly contribute to immediate colony survival (Metz & Tarpy, 2022). However, during the warmer months (June to September), shaded colonies had higher sealed brood areas than unshaded colonies. In unshaded colonies, exposure to direct sunlight raised brood nest temperatures above optimal levels, prompting workers to engage in intensive ventilation to cool the hive. This thermoregulatory effort likely detracted from brood care activities, leading to a reduction in sealed brood areas (Stabentheiner et al., 2010; Taha, 2014).

Lower temperatures in shaded colonies led to increased consumption of stored honey, reduced brood areas, and a subsequent decline in the bee population. Compared with the unshaded colonies, the population size in shaded colonies decreased by 0.27%, 0.91%, 1.14%, 2.57%, 12.72%, 11.82%, 13.55%, and 14.58% during the months from October to May, respectively. Meanwhile, the population size in the shaded colonies increased by 0.07%, 5.01%, 9.37%, and 11.12% from June to September, respectively. The size of the bee population plays a critical role in determining colony growth, behavior, and survivorship (Taha & Al-Kahtani, 2019). Larger colony populations have been shown to enhance the colony's ability to survive winter (Loftus et al., 2016) and to resist environmental challenges, such as unfavorable seasonal conditions (Calovi et al., 2021), as well as biological threats, like disease and parasite pressure (Gibson, 2021). Large brood areas in colonies were associated with larger bee populations (Elwakeil et al., 2025), which generated additional heat to thermoregulate and optimize brood nest conditions. Moreover, larger populations enhance the colony's ability to store honey and pollen (Taha & Al-Kahtani, 2019; Balvino-Olvera, 2024), which is essential for survival during the winter months. Similar results were also reported by Taha & Al-Kahtani (2013) and Calovi et al. (2021).

Honey production has been influenced by many factors, including bee race (Al-Ghamdi et al., 2017; Taha & Al-Kahtani, 2019), colony strength (Taha & Al-Kahtani, 2013; Sihag & Rawal, 2025), comb age (Taha & Al-Kahtani, 2020; Al-Kahtani & Taha, 2021; Taha et al., 2021b), and flow season (Taha & Al-Kahtani, 2019; Shawer et al., 2021). Compared with the unshaded colonies, honey yield in shaded colonies decreased by 26.83% during the Egyptian clover flow season (May). Meanwhile, the honey yield in shaded colonies increased by 19.27% during the cotton flow season (July and August). The amount of honey produced in shaded and unshaded colonies differed due to the different numbers of workers collecting nectar as well as the amount of nectar consumed in thermoregulation, including raising the temperature of the brood nest in cold months or lowering it in hot months. The correlation between honey yield and colony population size has been confirmed by Taha & Al-Kahtani (2019, 2020) and Elwakeil et al. (2025).

Conclusion

Based on the research outputs, environmental factors, particularly shading and temperature fluctuations, play a crucial role in shaping the activity and productivity of honey bee colonies. This highlights the importance of implementing effective colony management strategies to optimize microclimatic conditions, thereby enhancing colony performance and productivity. It is recommended to shade the beehives in summer and remove the shading in autumn, winter, and spring.

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Authors' Contribution

E.K.A.T.: conceptualization, methodology, investigation, analysis, writing, supervision.
S.N.A.: conceptualization, funding acquisition, analysis, writing.
M.B.S.: conceptualization, methodology, visualization, supervision.
R.T.: visualization, analysis, writing.
S.G.: investigation, analysis, writing.
N.M.E.: conceptualization, funding acquisition, writing.
K.M.: conceptualization, writing, visualization.

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