

The effect of temperature on the rearing of honey bee colonies, *Apis mellifera*, in northwestern Libya (a review)

Asmaa Dhow Abdullah Mkhebash^{1*}, Fathi Othman Omar Al-Hajj², Mariam Aboulqasim Alhunoud³

¹ Department of Environmental Science, Faculty of Science, Sabratha University, Libya

² Department of Biology, Faculty of Education, Tiji, University of Zintan, Libya

³ Department of Zoology, Faculty of Science, University of Zawiyah, Libya

*Email: asmaa.mkebash@sabu.edu.ly

أثر درجة الحرارة على تربية طوائف نحل العسل (*Apis mellifera*) في شمال غرب ليبيا (مراجعة)

أسماء ضو عبدالله مخيبش^{1*}، فتحي عثمان عمر الحاج²، مريم أبو القاسم الشطي الهنود³

¹ قسم علم البيئة، كلية العلوم، جامعة صبراتة، ليبيا

² قسم الاحياء، كلية التربية تبجي، جامعة الزنتان، ليبيا

³ قسم علم الحيوان، كلية العلوم، جامعة الزاوية، ليبيا

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Abstract

Climatic conditions are one of the most important factors affecting honey bees, and this impact may be negative or positive, and it may be direct or indirect, and this is reflected on their activity inside and outside the hive and affects their behavior in the entirety of their activity. It also leads to the death of many bee colonies as result to extreme heat and extreme cold, which leads to a lack or complete cessation its activity. Beekeeping in Libya developed and expanded, beekeepers follow modern methods, climate is suitable for beekeeping, strains reared are *Apis mellifera ligustica* in western region while *A.m. carnica* in eastern region, the forage of bees in Libya is consist of annual and perennial plants, shrubs and trees that produce different types of honey. In this review, we summarize and synthesize previous findings about the effects of temperature to feeding in bees and discuss the strategies bees use to cope with heat stress. Bee species mentioned here are mainly *Apis mellifera*.

Keywords: Temperatures, Bees (*Apis mellifera*), Libya, Mediterranean Sea.

الملخص

تُعد الظروف المناخية من أهم العوامل المؤثرة على نحل العسل، وقد يكون هذا التأثير سلبيًا أو إيجابيًا، ومباشرًا أو غير مباشر، وهو ما ينعكس على نشاط النحل داخل الخلية وخارجها ويؤثر على سلوكه في مجمل أنشطته. كما يؤدي المناخ إلى موت العديد من طوائف النحل نتيجة الحرارة الشديدة أو البرودة القارصة، مما يؤدي إلى نقص نشاطه أو توقفه تمامًا.

لقد تطورت تربية النحل في ليبيا وتوسعت، حيث يتبع النحالون الأساليب الحديثة، كما يُعد المناخ مناسبًا لتربية النحل. وتتم تربية سلالات "النحل الإيطالي" (*Apis mellifera ligustica*) "في المنطقة الغربية، بينما تُربي سلالة "النحل الكرنولي" (*A.m. carnica*) "في المنطقة الشرقية. ويتكون مرعى النحل في ليبيا من النباتات الحولية والمعمرة والشجيرات والأشجار التي تنتج أنواعًا مختلفة من العسل. نلخص ونركب في هذه المراجعة النتائج السابقة حول تأثيرات درجة الحرارة على تغذية النحل، ونناقش الاستراتيجيات التي يستخدمها النحل للتعامل مع الإجهاد الحراري. وأنواع النحل المذكورة هنا هي بشكل أساسي نحل العسل (*Apis mellifera*).

الكلمات المفتاحية: درجات الحرارة، النحل (*Apis mellifera*)، ليبيا، البحر الأبيض المتوسط.

1. Introduction:

In insects, environmental temperatures can affect biochemical and physiological processes. The thermal sensitivity of ectothermic performance is considered as a non-linear asymmetric curve exhibiting an optimal temperature and critical thermal minimum and maximum values (Dalmon et al, 2019), proteins in the honey bee cannot be synthesized above 40.5 °C, and mitochondria are altered above 41 °C causing irreversible damage to the host (Moltz, 1993). Bees are exposed to an increasing number of environmental pressures. The multiplicity and synergy between sources of stress can have an impact on the survival, physical integrity and physiological homeostasis of individuals. The bee is a pollinator with a major role in maintaining the biodiversity of ecosystems and the productivity of agro systems. It therefore appears essential to improve our knowledge on the responses of bees to these stresses, particularly at the level physiological (Even et al., 2012).

Honey bees, *Apis mellifera* L., live in colonies that can contain thousands of individuals, ranging from 15,000 to 60,000 bees (Abou-Shaara et al, 2017). Honeybees are incredibly proficient at transferring pollen and provide essential pollination services for both cultivated and wild plants globally. However, their exposure to abiotic and biotic stressors has caused severe health issues in honeybees, which has received much attention in the context of global warming. Temperature is one of the abiotic factors influencing the growth and development of honeybees and other ectotherms (Xinjian et al, 2023). Earlier, 24 subspecies of *A. mellifera* were recognized based on morphometric analyses (Ruttner, 1988). According to him, each subspecies is a geographical race characterized with a set of distinctive characteristics that result from local adaptation to the various regions, abiotic factors such as temperature and rainfall and biotic factors such as food, natural enemies and diseases (Legesse and Getu, 2022). The honey bee (*Apis mellifera* L.) is distributed nearly world-wide, having evolved means of exploiting even those environments with cold winters. Individual honey bees do not overwinter in a dormant stage like many other insects (Salt 1969), nor are they tolerant to freezing. Their capacity to survive cold depends on maintenance of a steady-state temperature-about 35°C-in the colony's central brood area (Southwick and Heldmaier 1987). Honey bees have internal activities, i.e. within the colony, including brood rearing, food storing, and social

homeostasis adjusting internal colony temperature to a suitable range (Southwick and Heldmaier 1987). Honeybees' foraging behavior is affected by many environmental factors. Daytime, ambient temperature and food availability (nectar and pollen) are the most influencing factors on foraging behavior (Reem et al, 2021).

Libya extends over 1,759,540 km², making it the 17th largest nation in the world by size. The Libyan Desert which covers much of Libya (up to 90%) is one of the most arid places on earth. Libya's coastline (1,770 km²) is the longest of any African country bordering the Mediterranean. The climate is mostly dry and desert-like in nature. However, the northern regions enjoy a milder Mediterranean climate (Keshlaf, 2014). Beekeeping in Libya has been practiced traditionally since early times (Keshlaf, 2014). Over 25 subspecies of *A. mellifera* have been identified and biogeographic studies suggest a centre of distribution in the Middle East or Northeast Africa. Libya has been identified as a particular diversity hotspot for *Apis mellifera*, because it is here where the African biogeographic lineage "A" meets the Oriental lineage "O" (Shaibi and Moritz, 2010). The northern areas have a Mediterranean climate all most of the commercial beekeepers are ranged in an agricultural about thirty km from the coast. Has declared that Libya remains recognized via arid climatic situations, except the coastal strip belongs to the northern hills toward the east as well as the west (Shlibak and Ben Dalla, 2020). In Libya the local production of honey is about 500,000 kg per annum. This locally produced honeys brings a premium price, ranging from 17 to 30 US\$ per kg. They use local honey in preparing traditional food and a lot of sweet. In addition, Libyan people use local honey as a medicine to treat of different diseases and disorders as a popular home remedy (Shlibak and Ben Dalla, 2020).

In this review, we will work on summarize and synthesize previous findings about the effects of temperature to feeding in honeybees and discuss the strategies honeybees in Libya and studies of other countries use to cope with heat stress. Bee species mentioned here are mainly *Apis mellifera*.

1.1. The research aim:

This research study aimed to cover the following points which is presented below.

1. Literature review, honey bee (*Apis mellifera*) in Libya.
2. Literature review, effect temperature on honey bee (Research and Food storing) in Libya and other country.

2. Research Methodology

This study adopts a qualitative review methodology to analyze and synthesize existing scientific literature on the effect of temperature on feeding behavior and colony performance of honeybees (*Apis mellifera*), with a particular focus on Libya.

A systematic search of relevant studies was conducted using major scientific databases, including Google Scholar, ScienceDirect, and SpringerLink. Keywords used in the search process included: "honeybee temperature", "Apis mellifera feeding", "thermoregulation in bees", "climate impact on bees", and "beekeeping in Libya".

The selection of studies followed specific inclusion and exclusion criteria. Studies were included if they:

- Addressed the relationship between temperature and honeybee behavior, feeding activity, or productivity

- Focused on *Apis mellifera* or closely related species
- Were published in peer-reviewed journals or recognized academic sources
- Provided empirical data or scientifically supported findings

Studies were excluded if they:

- Were not directly related to temperature effects
- Lacked scientific reliability or clear methodology
- Focused on unrelated species without relevance to honeybees

The collected literature was then analyzed using a comparative and descriptive approach. Key variables such as temperature ranges, foraging activity, food storage, and colony behavior were extracted and compared across different studies. Special attention was given to studies conducted in Libya and similar Mediterranean climates to ensure contextual relevance.

Finally, the findings were synthesized to identify common patterns, differences, and research gaps, allowing for a comprehensive understanding of how temperature influences feeding behavior and colony dynamics in honeybees.

3. Thermoregulation in honey bee:

Climatic conditions are one of the most important factors affecting honey bees, and this impact may be negative or positive, and it may be direct or indirect, and this is reflected on their activity inside and outside the hive and affects their behavior in the entirety of their activity. It also leads to the death of many bee colonies as result to extreme heat and extreme cold, which leads to a lack or complete cessation its activity (Mohamed and Faraj, 2022).

In general, the study Southwick and Heldmaier 1987, indicated this temperature control, known as social homeostasis, was first de- scribed more than 70 years ago and has been documented repeatedly in Several studies. It functions both to raise low environmental temperatures and to decrease high temperatures. Both physiological and behavioral characteristics contribute to the precise temperature control. Such intensive thermoregulation is extremely unique among the insects. On the individual level, when temperature rises to more than 36 C, honey bee brood is likely to be exposed to overheating. To better resist any passive effects, the induction of a heat shock protein is activated even during normal colony conditions in adults (Severson et al. 1990). Exposure to elevated temperatures and a wide variety of environmental stresses induces the production of a small number of highly conserved proteins in cultured cells and whole organisms: these proteins have been designated as the heat-shock proteins or hsps. The highly social structure of the honey bee (*Apis mellifera*) colony includes a unique adaptation among poikilotherms: although individual bees exhibit poor thermoregulatory capabilities, intact clusters of several thousand individuals exhibit excellent thermoregulation over a broad continuum of temperature extremes. The cluster center can be maintained at ca 33-34 ~ regardless of the ambient temperature. The honey bee cluster has, therefore, been viewed as a super organism and a functional homeotherm (Severson et al. 1990). There are strong relationships between ambient temperature and key bee colony behavior such as, for example, nest thermo-humidity regulation, annual population variability

and foraging. Additionally, dry conditions and heat waves have been empirically linked to declines in colony food stores and increased colony mortality rates (Van de et al, 2021).

The results study of Severson and Erickson 1990, indicate that the honey bee in winter cluster expands and contracts in a predictable manner relative to changes in the temperature. This suggests that individual clusters are able to efficiently regulate heat loss from the cluster surface. Observed decreases of about 55% in cluster volume and 40% in cluster surface area as the temperature decreased from 4 °C to - 23°C. Were observed in each colony following exposure to Ta of - 30 °C or less (during the period between 19 January and 4 February). Individual colonies comprised of at least 13 000 - 15 000 bees can, however, survive exposure to temperature of -80 °C for short periods.

4. The adaptations of honeybees:

The honeybee is a highly polytypic species distributed over very wide geographical regions with diversified morphological, behavioral, biological and genetic characters among the subspecies, and even among strains or ecotypes. The fact that, even though some of these characters are inherited, morphological characters of honeybees are shaped by the environmental factors and exhibit continuous geographical variations were noticed long ago. Moreover, the biological and behavioral variations observed among and within honeybee subspecies are driven by natural selection factors such as temperature, rainfall, availability and distribution of food, prevailing competition and predation. There are several major climatic distinctions between Africa and temperate affecting the seasonal cycles of honeybee colonies. Tropical honeybees do not experience severe cold seasons and may forage throughout much of the year. Africa has a more propitious climate that is perennially conducive to some flowering, honeybee flight and comb building. The extended foraging season and emphasis on pollen collection may be associated with the high swarming rates and migration of tropical honeybees. The phenology of the honeybees seriously follows the seasonal shift of the environmental factors like rainfall and phenology of the major honeybee plants and among African honeybee, these interconnected phenologies show shifts when colonies start issuing reproductive swarming in response to variations in climatic zones (Hepburn and Radloff, 1998: Legesse and Getu, 2022).

5. Effects temperature on feeding of honeybees in Libya:

beekeeping in Libya developed and expanded, beekeepers follow modern methods, climate is suitable for beekeeping, strains reared are *Apis mellifera ligustica* in western region while *A.m. carnica* in eastern region, the forage of bees in Libya is consist of annual and perennial plants, shrubs and trees that produce different types of honey Such as spring honey (annual flowers) i.e. *Didesmus aegyptius*, honey from; *Citrus* sp., *Eucalyptus* sp, *Thymus* sp, Seder *Ziziphus lotus*, carob *Ceratonia siliqua*, bitter honey (pia) is produced from a Chammari shrub *Arbutus pavarii*, and tamarisk honey *Tamarix articulata* , Libya featuring with a major flow season almost runs from mid-February to April, after that transfer the colonies to blooming of Seder shrubs from May to the beginning of June, followed by transferring to thyme pasture from end

of May to the end of June. The secondary season is during the months of July and August, blooms where trees tamarisk and *Eucalyptus gomphocephala*, the seasons vary in time between the western and eastern region, the latter also characterized with blooming of carob trees between September and October while Chammari shrubs through December approximately (Alfallah, 2015). A few studies examine the relationship between food in honey bees and temperature in Libya, including:

Moreover, in Libya, study of Mohamed and Faraj 2022, to investigate the effect of rainfall and temperature on honey production, modeling is employed by using annual data over the period of 1990-2013. Results showed Bounds test results reveal that there is co-integration between study variables under investigation. Also, the study results indicate a positive effect and significantly of temperature and a negative and non-significant of rainfall effect on honey production in long-run. As indicated by a study Alfallah 2015, the environmental factors affecting the secretion of nectar cannot be separated one from the other, but the effects would be complicated and intertwined and it is difficult to predict what will be happen. In poor seasons, we find good flowering rate and the foragers spend long time and effort to collect a small load of nectar as a result of low nectar excretion because of the environmental factors, plenty flowers is not an indication of higher production of honey but nectar secretion which is a limiting factor. Season 1995 has been remarkable in terms of the secretion of nectar in the flowers and appropriate for foragers to the extent we harvest the honey every week. With high rates of rainfall before and during the season, maximum temperatures ranged from 20° to 33° during the months of bee activity, and relative humidity ranged from average monthly of 55 to 67%, this season distinguished with ideal environmental factors as an environmental phenomenon.

6. Impact temperature on metabolism:

Enzymatic activity being thermodynamic, metabolism and temperature are correlated positively, therefore an increase in temperature will necessarily induce an acceleration of metabolism. Thus in bees, which are partially ectotherms, the basal metabolic rate, at rest, is positively correlated with temperature ambient (Bordier, 2017). Research, relative to low ambient temperature survival, has generally concentrated on the role of metabolism (i.e., honey consumption for heat production) in colony-level thermoregulation. Evidence suggests that increased levels of metabolism are indeed associated with exposure to cold temperatures. Also, reported that cluster CO₂ production is minimal at about 10 °C and increases above or below this temperature (Severson and Erickson, 1990).

7. Food storing:

In a study Abou-Shaara et al 2017, confirmed are complex relationships between season, brood rearing activity, availability of bee plants, foraging activity, and food storing activity. A honey bee colony requires a big amount of food, about 10–26 kg pollen per year. During winter, a honey bee colony consumes a large amount of honey, about 20 kg. Nectar foragers showed no significant variations in their activity with the level of stored honey, whereas pollen foraging

behavior was found to be extremely sensitive to colony state in a study by Fewell and Winston (1996). Neupane and Thapa (2005) found a significant impact of season on stored pollen amount, number of pollen foragers, and brood rearing activity. The highest values were in spring, while the lowest values were in the rainy season. Moreover, through the table (1), a study showed Woyke et al 2003, showed that during the first 3 weekly observations, the temperature at 8:00 h was above 20°C, and at these temperatures the workers had already foraged. On the 8 November the temperature at 8:00h was 19°C, and the foragers were inactive. However, half an hour later, the first workers started foraging although the temperature did not change. On the 15 November the temperature at 8:00 h was 18°C, and the foragers were inactive.

Table 1. Beginning of flight activity of *Apis dorsata* worker bees in Rampur, 1999
(Observations started at 8:00 h)

Date	Temp. °C at 8:00 h	Beginning of flight		No. colonies
		Temp. °C	Time	
Water Tank Tower				
18.10	25	already active		9
25.10	23	already active		11
1.11	21	already active		23
8.11	19	19	8:30	23
15.11	18	18	8;10	27
22.11	18	16	8:30	29
7.12	15	17	10:00	65
14.12	14	18	11:00	65
Dormitory Building				
20.12	13	18	11:30	18

The results show that a lower temperature at 8:00 h results in a later beginning of foraging, never-the less the flights start at lower temperatures. But when the temperature drops below 16°C, the workers require more time to heat the outside layer of workers of the nest curtain, and as a result, they start foraging later at higher temperatures. Worker bees in the field were not found at temperatures lower than 17°C - 18°C. At this time many *A. cerana* and *A. mellifera* were already foraging.

In study Reem et al 2021, honeybees' foraging activities, as well as their seasonal and monthly abundance were studied and evaluated. The study was run during the period of 12/2017-11/2018. The obtained results revealed that honeybees have a bimodal daily foraging activity pattern with morning and afternoon peaks. The daily activity pattern of honeybees showed a significant correlation with the measured temperature. Meanwhile, the seasonal abundance of forager bees changed significantly among different seasons with the highest abundance peak during spring. Results also suggest that the honeybees' activity had a microclimatic window of opportunity for ambient temperatures within which foraging flight can be continued, where their forage temperature was fallen within the range of 20°C to 28°C. Moreover, in the study Xinjian et al 2023, Impacts of high temperature during early capped brood on pupal development and the size of appendages in adult workers *Apis cerana*, its sensitivity to high

temperature was investigated in *Apis cerana* worker bees. Mature larvae (ML), the first and second days of prepupa (PP1 and PP2), and the first day of pupa (P1) were exposed to 40°C for varied durations of time. The mortality, development duration, birth weight, size of the body, and appendages of eclosed *Apis cerana* worker bees were measured. Results showed that PP1 had the highest mortality, the lowest birth weight, and the longest development duration among the pupation stages. When exposed to 40°C for 12 h and 16 h, more than 28 and 84% of PP1 failed to complete development, respectively. Additionally, high-temperature treatment had a significant effect on the length of the proboscis, the size of the forewing, and the size of the hind leg.

Also, in study of van de et al 2021, That to assessment of the direct impacts of climate change, specifically related to temperature and precipitation variability, on honey bee colonies in the Aegean, food resource changes, especially regarding nectar and pollen availability. The results confirmed the increase in heat extremes will likely lead to increased colony losses. Meanwhile, the availability of water and nectar (used for evaporative cooling) will decrease during warmer and drier spring-summer periods. Temperatures within the range for optimal foraging activity are also less likely to occur during the flowering period. Finally, years with spring seasons characterized by low rainfall and extreme temperatures simultaneously, implying lower food availability (pollen and nectar) and decreasing colony food stores. Combined, these factors likely result in increased colony mortality rates and reduced food storage (honey production). Moreover, Tautz et al. (2003) studied the effects of brood incubation temperature on the foraging performance of adult honey bees. They examined two important aspects of foraging behavior: the ability to perform communication dances, and the ability to associate a floral odour with a reward. For their first experiments Tautz et al. (2003) trained forager bees to visit a feeder and analysed three characteristics of the dance communication used by the trained foragers to recruit nest-mates to a profitable food source. Despite low sample sizes, their data strongly indicate that adult workers that pupate at 36°C are normal with respect to their performance of communication dances. However adult workers that pupated at 32°C are less likely to perform dances and perform shorter ones than bees that pupated at 36°C.

Foraging behavior includes bees gathering nectar, pollen, propolis, or water to fulfill colony needs. Foraging takes place within a wide range of temperatures from 10 to 40 °C. Below 10 °C, honey bees reduce foraging trips (Joshi and Joshi 2010). The beginning of foraging activity has been recorded to be at a mean of 6.57 °C, whereas the highest activity was at 20 °C. In another study, Woyke et al 2003, found that 10 °C is the temperature at which foraging is initiated. These authors also noticed that the number of foragers increased tenfold when temperature increased to 12 °C. adversely, at a temperature of 43 °C, the lowest foraging activity was observed (Abou-Shaara et al 2017). A study Free and Spencer 1958, also indicated an increase the amount of food (sugar syrup) consumed per bee increased with decrease in the environmental temperature. Very little water was drunk at environmental temperatures of 25° C. or lower but, at 35° C. and above, relatively enormous quantities were taken. Free & Spencer-Booth (1959). They investigated the behavior and the sugar usage of bees kept in cages in the laboratory at different environmental temperatures. It was shown that at 10°C 99% of the bees clustered together, at 15°C 80% did so, and at 20°C less than 50% clustered. The energy use was lower at 10°C than at 15°C. According to literature bees start clustering around 13,9 °C.

8. Conclusion:

The study aimed to examine the effect of temperature on feeding behavior in honeybees. The highly social structure of the honeybee (*Apis mellifera*) colony represents a unique adaptation among poikilothermic organisms. Although individual bees exhibit limited thermoregulatory capabilities, intact clusters consisting of several thousand individuals demonstrate remarkable thermoregulation across a wide range of temperature conditions. The cluster center can be maintained at approximately 33–34°C, regardless of the ambient temperature. Therefore, the honeybee colony can be considered a superorganism and a functional homeotherm.

The findings of this review indicate that temperature has a significant and positive effect on feeding activity in honeybees. In Libya, the optimal temperature range for honeybee activity varies between 20°C and 33°C during active seasons, while relative humidity ranges between 55% and 67%. These environmental conditions are considered ideal and contribute positively to bee activity and feeding behavior.

In their experiments, Jürgen Tautz et al. (2003) trained forager bees to visit a feeder and analyzed three characteristics of the dance communication described by Karl von Frisch (1993), which is used by foragers to recruit nest-mates to profitable food sources. Despite relatively small sample sizes, their results strongly suggest that adult worker bees that pupated at 36°C exhibit normal performance in communication dances. In contrast, bees that pupated at 32°C are less likely to perform dances and tend to perform shorter dances compared to those developed at optimal temperatures.

9. Recommendations

Based on the findings of this review regarding the effect of temperature on feeding behavior and colony performance of honeybees (*Apis mellifera*), the following recommendations are proposed:

Recommendations for Beekeepers:

- Beekeepers in Libya should carefully monitor environmental temperature, particularly during extreme heat periods, to minimize stress on bee colonies.
- Providing adequate water sources near hives is essential, especially during high-temperature seasons, to support thermoregulation and prevent dehydration.
- The use of shading techniques and proper hive placement (e.g., under trees or artificial shelters) is recommended to reduce direct exposure to high temperatures.
- Seasonal migration of colonies should be optimized according to flowering periods and temperature variations to maximize feeding efficiency and honey production.

Recommendations for Researchers:

- Further experimental studies are needed in Libya to quantify the direct relationship between temperature and feeding behavior under controlled conditions.
- Future research should focus on identifying the optimal temperature thresholds for different subspecies of honeybees reared in Libya.
- More studies are required to investigate the combined effects of temperature and other climatic factors such as humidity and rainfall on honey production.
- The impact of climate change and increasing temperature extremes on long-term colony survival should be explored in greater depth.

Recommendations for Policy Makers and Agricultural Authorities:

- Agricultural authorities should support beekeepers through training programs focused on climate adaptation strategies.
- Development of national monitoring systems for climate variables affecting beekeeping is recommended.
- Policies should encourage sustainable beekeeping practices and conservation of bee forage plants to ensure food availability under changing climatic conditions.

General Recommendations:

- Raising awareness about the ecological and economic importance of honeybees is essential for biodiversity conservation.
- Integrating modern technologies, such as environmental sensors and smart hive systems, can improve monitoring of temperature and colony health.

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Compliance with ethical standards*Disclosure of conflict of interest*

The authors declare that they have no conflict of interest.

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