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Impact of Temperature Variations on *Apis mellifera* (Honey Bee) Productivity: A Systematic Review

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Abstract
Aim: This systematic review explores the impact of temperature variations on the productivity of *Apis mellifera* (honeybees), focusing on how environmental changes influence nectar production and honey collection. By analyzing studies published between 2020 and 2024, the review examines honeybee responses to temperature fluctuations, particularly those beyond their optimal range. Research articles were systematically gathered from PubMed, ResearchGate, SemanticScholar, and SpringerLink to identify the key temperature and humidity conditions affecting honeybee productivity.
Methodology: Using PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines, 10 studies were selected based on criteria such as temperature variation, relative humidity, colony size, and honey collection duration.
Results: Findings indicate that *Apis mellifera* adapts to environmental changes and optimizes honey production under favorable conditions.
Conclusion: The highest productivity occurs within a temperature range of 20°C to 30°C and a relative humidity of 80–90%, which supports active foraging, colony growth, and increased honey yields.

Keywords: colony, efficiency, honey yields, relative humidity

INTRODUCTION

Honey is a well-known substance with colors from amber to dark amber brown (usually found in nature) that people typically take because of its sweetness. Aside from its scrumptious taste, honey also provides several health benefits because of its composition. According to an overview of the nutrient contents of honey, it indicates that honey is composed of carbohydrates, proteins, vitamins, minerals (like Potassium), and polyphenols (Talha et al., 2023). These components may also vary on the origin of the honey, which then ramifies the divergence of characteristics of honey in terms of its appearance, texture, aroma, flavor, etc. (Zhu et al., 2020). In a 2017 study by El-Haskoury et al., Moroccan Honey is mainly composed of potassium with 644.02mg/kg of honey. On the other hand, a Novel Chinese Honey from *Amorpha fructicosa L.* is composed of 250.024 mg/kg of honey, according to (Zhu et al. 2020). These two studies vary in honey's geographical origin, resulting in the difference in their potassium levels. Referring to the previous studies, different kinds of nutrients in honey may also vary depending on the flower, specific honey bee species, and the working area of bees.

Apis mellifera, also known by its common name "Honeybee", is the producer of this sweet, viscous substance, honey. They produce honey by sucking through their hollow straw-like tongue called a proboscis and storing it in the first chamber of their stomach called proventriculus (Villazon, 2023). The density of honey bees in different continents of the world (including Asia, Europe, Africa, Oceana, North America, and South America) is determined by Visick and

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Ratnieks (2023), wherein there are 102 million managed colonies of honeybees worldwide while the wild honeybee colonies are more than doubled with 280 million colonies around the world. Roughly half of all the managed colonies are found in Asia, with 45.3 million colonies of managed honeybees. This is due to the fact that the top producer of natural honey in the world is an Asian country, China; the latest statistics in 2025 by M. Shahbandeh showed that China has produced over 463,500 metric tons of honey. Other countries in the top five of the top producers of natural honey are Turkey, Ethiopia, Iran, and India; four out of five countries in the top five natural honey producers are all from Asia. These vast numbers of managed honeybee colonies considered a lot of factors for them to produce tons of honey per harvesting season. According to a beekeeper named Joseph Davis, 7 days to 2 months is the average time frame for bees to produce a honeycomb, while an established colony may take only 3 days to fill up at least 10 full frames of honeycombs (time may vary in size of honeycombs). With a 10-frame box of honeycomb, you can produce 80 to 100 lbs of honey, which means that China harvested a minimum of 11 million, 10 full-frame boxes of honeycombs in a year. Davis also mentioned that climate and weather conditions are some of the factors to consider when beekeeping. Sunny or warm weather enhances the productivity of bees to produce honeycombs. Correlating with climate and weather, honeybees can be affected by both biotic and abiotic stressors (Neov et al. 2019). One of these abiotic factors is the temperature, wherein the maximum amount of produced honey is accumulated at a temperature of 30°C based on the first monitoring of bee productivity in a study (Olate-Olave et al. 2021). In contrast, an extreme temperature of 45°C is monitored to show changes in colony organization in attempts of bees to stabilize their beehive temperature (Jhawar et al. 2023).

Although it is evident that the focus of this systematic review is the influence of temperature on the productivity of honeybees, there are several abiotic factors aside from temperature that may affect the bees' productivity. These factors include wind, pesticide exposure, light, humidity, nutrients, population and its growth, and climate change (Amiri et al. 2024; Neov et al. 2019; Olate-Olave et al. 2021). However, other abiotic factors mentioned may not be considered in this review as we only specified the effect of temperature on honey bee productivity as the sole purpose of this systematic review. Reviewed results from various published studies are chosen to determine how temperature influences honeybee productivity in making honey

Objectives

This systematic review aimed to examine ten different studies regarding the influence of temperature on the productivity of *Apis mellifera*, seeking to address the following questions:

1. How does temperature affect the productivity of *Apis mellifera*? Does it impact the quantity of honey produced? Does it influence the composition of honey? Does it affect honey quality?
2. Which countries produce the most honey, and is their productivity related to temperature? Is humidity also a significant factor?
3. Does colony size or population influence the honey productivity of *Apis mellifera*?

METHODS

The study applied a systematic review approach, adhering to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines (see Fig. 1), to establish a structured method for identifying, selecting, and assessing relevant studies published between 2020 and 2024 that on the impact of temperature on honey bee productivity.

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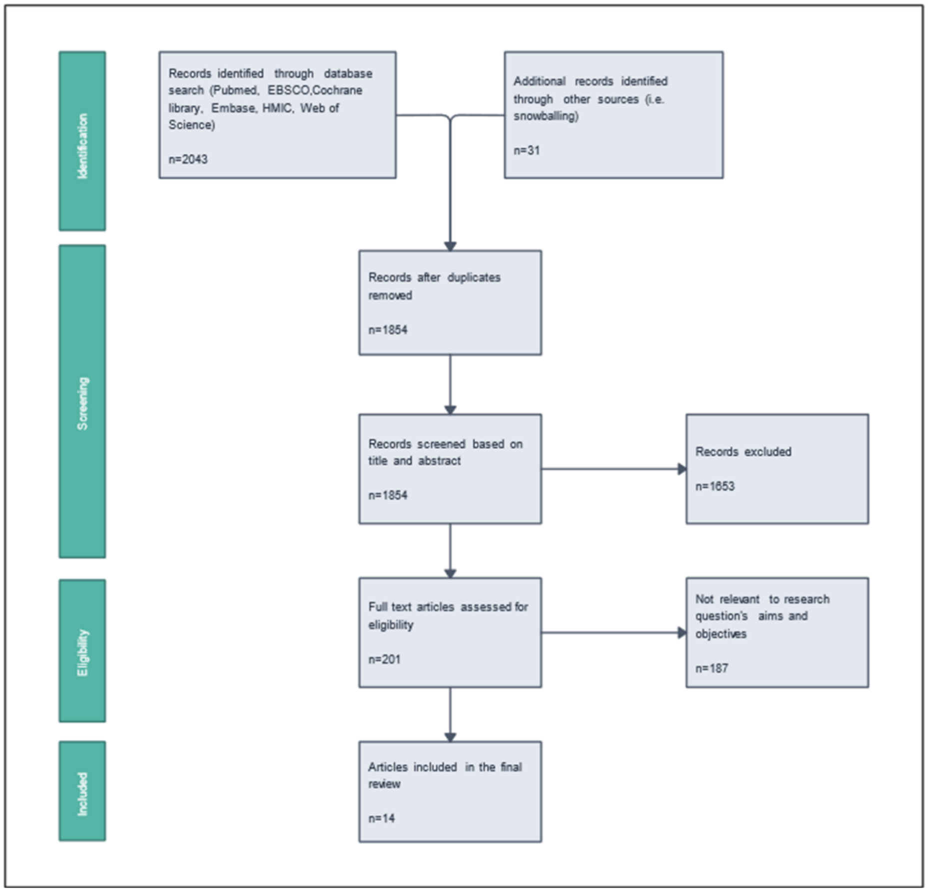

Figure 1. PRISMA Flow Diagram

Systematic Search Strategy

The PRISMA guidelines were rigorously followed throughout the search process. All the relevant published materials were carefully selected from reputable and trusted resource platforms, including PubMed, ResearchGate, SemanticScholar, and SpringerLink, to ensure the inclusion of high-quality evidence.

Keywords

To conduct an effective search for this review, the authors performed a comprehensive literature search in the aforementioned databases search engine used. The search terms were organized into two key categories. The first category focused on productivity terms, incorporating phrases such as "effects of temperature on honey bee productivity" and "temperature and honey bee production". This allowed for the identification of studies that specifically explored how temperature influences the output of honey bees. The second category targeted species identification, targeting the scientific name of the honey bee, *"Apis mellifera,"* ensuring the search focused on relevant species.

To maintain relevance and focus, the search was limited to the English language and review articles published between 2020 and 2024. Databases such as PubMed, ResearchGate, and Springer were utilized for this purpose, providing access to a wide array of recent studies on the topic. Initially, studies were selected based on their titles, authors, publication dates, and journals to eliminate duplicates and streamline the process. Following the initial selection, the remaining papers underwent a rigorous screening process. Abstracts were reviewed to assess the relevance of each study to the topic, and studies that passed the abstract screening underwent full-text evaluation for qualifying criteria.

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Inclusion and Exclusion Criteria

To ensure the selection of all relevant studies included in this review, the studies were classified: (1) studies addressing the effects of different temperatures on honey bee productivity. (2) field of the study and study nationality. (3) studies reporting data on *Apis mellifera* population per colony distribution.

Studies are excluded based on the following criteria: (1) studies evaluating the nectar distribution of *Apis mellifera* in relation to different temperatures; (2) studies focusing on different *Apis mellifera* subspecies. (3) studies deemed outdated; or (3) articles not available in full text.

Search Results

The relevant studies on the impact of temperature on honey bee productivity involved a comprehensive online database search. This effort targeted research and review articles published in English between 2020 and 2024, utilizing databases such as PubMed, ResearchGate, and SpringerLink. The search process yielded a total of 20 studies initially.

Upon reviewing the titles and abstracts of these studies, ten were excluded due to not meeting the inclusion criteria, leaving 10 full-text papers for further evaluation. These selected studies provided both qualitative and quantitative data that aligned with the predefined criteria, ensuring a strong dataset for the final review.

Data Extraction

In these studies, ten studies from twelve studies were extracted for detailed analysis based on the established eligibility criteria. The systematic review encompassed various studies conducted around different countries such as the USA, Egypt, Australia, India, Turkey, Greece, and Russia. Relevant data and information were gathered from these studies throughout the review process. The information and data extracted from 20 studies include how temperature affects honey bee activities and productivity.

Data Analysis

Following the data extraction, the ten selected studies were assessed for their suitability for both quantitative and qualitative analysis. The studies consistently demonstrated that temperature plays a pivotal role in honey bee productivity. Optimal temperature ranges are essential for various activities, including thermoregulation, brood rearing, foraging, and mating. Deviations from these optimal ranges can lead to adverse effects, such as diminished productivity and heightened susceptibility to diseases.

RESULTS and DISCUSSION

Numerous published articles were carefully inspected for this systematic review, wherein the authors finalized choosing only 10 out of 20 papers investigated. The following studies were chosen due to their high relevance to the scope of the researcher's systematic review, which is the influence of temperature on the productivity of *Apis mellifera* (Western Honeybee). Selected studies were divided into two tables wherein Table 1 indicates the population of *Apis mellifera* given in the conducted study in a specific area distribution to differentiate various honeybee populations in each study.

According to Shahbandeh (2025), Asian countries like China, Turkey, Iran, and India topped the rankings for the highest production of honey worldwide. Given the data below, 7 out of 11 countries are Asian. Although not all of them are in the world rankings of highest honey production, it is still pertinent to include countries like the Philippines, which is a country unknown for honey production, to observe the temperature influence in this country in the production of honey by *Apis mellifera.* World Population Review published a statistical report from 2022 wherein 6 countries from the data below are included in the top 50: Turkey at rank 2, India at rank 4, Russia (Euroasian) at rank 6, Vietnam at rank 15, Thailand at rank 26, and Nepal at rank 41. In these Asian countries, temperature varies from 14.58°C (cool) average temperature in Turkey in 2023 to 30°C (hot) average temperature in India by the year 2024. This temperature variation in Asian countries offers them high productivity results since working bees will focus on the shivering thermoregulation technique if the temperature is lower than 15°C and the cooling thermoregulation technique if the temperature reaches 35°C and above (Kamboj, et al., 2024).

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Table 1. *Apis (Honey Bee) population per colony distribution and its relative temperature and humidity.*

Area (Distribution)	Temperature(°C)	Humidity	Average Population	Average Colony	Reference
Philippines	27.6°C to 27.8°C	N/A	N/A	6,160	Cervancia et al., 2023
Vietnam	24°C to 25.46°C			7,176,600	
Thailand	26°C to 26.3°C			845,000	
Turkey	11°C to 18°C	N/A	10,000 to 65,000	70,000	Demirel 2024
Egypt	8°C to 33.72°C	N/A	N/A	12	M et al., 2021
Greece, Rhodes Island	17.4°C to 22.5°C	40% to 80%	N/A	2	Gounari et al., 2022
Australia	16.21°C to 41.05°C	N/A	231	N/A	Jaboor et al., 2022
India	25°C to 35°C	70%	N/A	N/A	Kamboj et al., 2024
Western Nepal	14.24°C	N/A	N/A	6,844	Kortsch et al., 2024
Turkey	10.81°C to 18.36°C	66.03%	334	N/A	Şengül et al., 2023
Russia	18°C to 24°C	N/A	N/A	42	Solovev 2020
Hungary	20°C to 30°C	80-90%	15,000 to 60,000	N/A	Vincze et al., 2024

The Food and Agriculture Organization of the United Nations in Rome, Italy, collaborated with three Southeast Asian countries, the Philippines, Thailand, and Vietnam, in 2023 to conduct a survey on the bee diversity in these three Asian countries. The survey covered managed bees and wild bees, their colony population, and the produced honey per colony. In their study, the Philippines has an average colony size of 6,160 at temperatures of 27.6°C to 27.8 °C. It is quite small compared to all the other variables on the honeybee population from other countries from the same research. On the other hand, Vietnam possesses a temperature of 24°C to 25.46°C and a population of 7,176,600 honeybee colonies, which is the highest among all the other countries. And lastly, Thailand has 845,000 honeybee colonies at the temperature of 26°C to 26.3°C. In this case, the population of honeybees depends on the number of beekeepers around the country (Cervancia, et al., 2023). Turkey, the top 2 on the world's ranking of honey production, facilitates 10,000 to 65,000 bees per colony, wherein they have 70,000 colonies (Demirel, 2024). Turkey also possesses a cool temperature of 11°C to 18 °C, which is typically cooler than most countries above.

Moving on from the four Asian countries discussed above, a country from Africa, Egypt, has cool to hot temperature variations of 8 °C to 33.72 °C. They only observed 12 Langstroth hives of honeybees, which they divided into three groups with different warming systems in each hive for monitoring their response to temperature (M et al., 2021). On the other side of the world, Rhodes Island in Greece has a 17.4 °C to 22.5 °C temperature and humidity of

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40% to 80%, containing a significant amount of water vapor. Their study focuses on the effect of temperature on the productivity of honeybees. However, only two hives were used in their study to compare relative changes in their honey production with variance in temperature (Gounari et al., 2022).

Based on the given data in Table 1, *Apis mellifera* exhibited the highest overall abundance and the broadest activity temperature range (16.21 - 41.05°C), suggesting that some species are more adaptable to temperature fluctuations. The average population of honeybees in this region was recorded at 231 per colony, indicating a strong correlation between temperature variation and colony distribution in the country of Australia (Jaboor et al., 2022). Similarly, in India, honeybees thrive within an optimum temperature range of 25–35°C, where they exhibit natural thermoregulatory behaviors such as wing fanning and water collection for convective cooling at high temperatures or clustering together for heat production in colder conditions (Kamboj et al., 2024).

Relative humidity plays a crucial role in honeybee colony stability. In India, the optimal brood comb temperature was maintained between 30°C and 35°C, with an approximate relative humidity of 70%, significantly influencing colony productivity and survivability (Kamboj et al., 2024). In Turkey, findings indicated that an annual average temperature of 18.36°C was associated with higher honey yields, particularly when relative humidity remained at 66.03% or lower. Conversely, at an average maximum temperature of 10.81°C, honey production was negatively affected (Şengül et al., 2023).

Temperature fluctuations have a direct impact on honey yield. Studies revealed that maximum honeybee gains occurred when daily temperatures exceeded 24°C. When temperatures dropped below this threshold, the average daily gain declined by 51.4%, with further decreases leading to an almost complete absence of honey flow below 18°C (Solovev, 2020). Additionally, research on black locust (*Robinia pseudoacacia L.*), a significant nectar-producing plant, indicated that the optimal conditions for nectar production were calm daytime temperatures of 16–25°C with a relative humidity of 80–90%. These conditions supported colony sizes ranging from 15,000 to 60,000 individuals (Pătruică et al., 2017).

Numerous studies confirm a strong positive relationship between air temperature and honey yield. Weather conditions accounted for approximately 50–80% of the variability in daily honey production, highlighting the substantial influence of climatic factors on apiculture productivity (Vincze et al., 2024). These findings emphasize the critical role of maintaining optimal temperature and humidity conditions for maximizing honeybee productivity and ensuring stable honey yields.

Table 2. *Productivity of Apis mellifera (Honeybee) in a specific temperature within a specific duration in various countries.*

Country	Temperature Variations (°C)	Productivity	Duration (days)	Reference
Philippines	25°C to 32°C	25kg per hive	N/A	Cervancia et al., 2023
Thailand	22°C to 35°C	35kg per hive		
Vietnam	20°C to 34°C	66kg per hive		
Turkey	11°C to 18°C	18kg per hive	365	Demirel 2024
Egypt	Halogen Warming System: Avg. Outside: 21.6°C, Inside: 36.65 °C (Minimum 21°C)	19.51%	90	M et al., 2021

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Greece, Rhodes Island	14°C to 18°C (Spring)	High relative change	N/A	Gounari et al., 2022
	21°C to 27°C (Summer)			
Australia	16.21°C to 41.05°C	Most Abundant	N/A	Jaboor et al., 2022
India	15°C	Cluster bee's	N/A	Kamboj et al., 2024
	20°C	Collect water, nectar, pollen, or resin		
	25°C to 35°C to 60°C	Decreased productivity because of heat stress		
Western Nepal	14.24 °C	50 to 100 kg	365	Kortsch et al., 2024
Turkey	Min Temp above 10.81°C	26.29 kg	Per year	Şengül et al., 2023
Russia	Summer 2018: 8.8°C to 28.0°C	50.4 kg	40	Solovev 2020
	Summer 2019: 7°C to 26.9°C	40.8 kg		
	24°C to 26°C	2.8 kg	1	
Hungary	Below 10°C or above 40°C	Reduce productivity	N/A	Vincze et al., 2024
	20°C to 30°C	Highest productivity level		

The climatic conditions can significantly influence the yield of honey from the productivity of honey bees both positively and negatively (Şengül et al., 2023). Table 2, along with the insights from 10 related studies, shows the correlation of *Apis mellifera* productivity to a specific temperature within a particular duration across various countries. The study by Vincze et al., 2024, shows that it reduces honey production if the temperature is below 10°C or above 40 °C, which is an extreme temperature for honey bees, so this suggests that the too-hot or too-cold temperature can negatively affect the activity of bee production and activity such as foraging. This is evident in regions like Russia, where summer ambient temperature tends to be higher, affecting honey yields. For instance, with temperatures ranging from 8.8°C to 28.0°C and 7°C to 26.9°C over the 2018 and 2019 summers, 50.4 and 40.8 kg of honey were produced over 40 days, respectively. Comparing the results, 2018 had more favorable conditions mainly because of abiotic factors such as higher nectar gain (Solovev, 2020). In addition to the abovementioned study, honey production depends on the availability of flowers wherein the bee's activity is to find a nectar attainability such as sunflower and

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black locust. Generally, temperatures between 20 °C and 30 °C are associated with the highest productivity levels of honey. This optimal productivity occurs an active foraging and colony growth that leads to increased honey yield. For instance, in Thailand, bees produce 35 kg of honey between the temperatures of 22°C and 35°C, based on the study of the diversity of bees in the Philippines, Thailand, and Vietnam. Similarly, in Vietnam, the yield of honey reaches 66 kg within a temperature range of 24°C to 25.46 °C (Cervancia, et al., 2023). The examples demonstrate how optimal temperatures increase honey bee activity and production.

However, some countries have specific climate conditions that the honey bees need to adapt to proceed with their activity. In cold countries such as Nepal, Turkey, and Greece. Honey bees in Nepal maintain productivity when conditions are stable over extended periods. At an average temperature of 14.24 °C, the honey yields 50 to 100 kg annually (Kortsch, 2024). While, in Turkey, two studies were gathered in the same country wherein according to Demirel (2024), 18 kg per hive of honey is produced at a temperature of 11°C to 18 °C and (Şengül et al., 2023) show that honey production can reach 26.29 kg per year when minimum temperatures remain above 10.81°C. Then, in Greece, which has a seasonal temperature, during its spring season, 14 °C to 18 °C has a high relative change in hive weight. Likewise, in the different season of Greece, which is summer, the temperature between 21 °C and 27 °C further enhances productivity, creating optimal conditions for honey production (Gounari et al., 2022). In summer countries such as the Philippines and Thailand, warmer temperatures support higher productivity levels. The Philippines reports a yield of 25 kg between 25 °C and 32 °C, while Thailand produces 35 kg between 22 °C and 35 °C (Cervancia et al., 2023). These countries in Southeast Asia show a favorable temperature with a benefit for bee activity.

On the contrary, *Apis mellifera* either struggle to forage efficiently, face heat or cold stress, and tend to reduce their activities during hot, dry, and windy weather, which can lead to colony decline and reduced foraging activity (Kamboj et al., 2024). Just like in Australia, which is characterized by diverse climate zones since the temperatures range from 16.21°C to 41.06 °C (Jaboor et al., 2022). As a result, some regions employ innovations to enhance productivity despite the extreme conditions. For example, in Egypt, the researchers use a modified halogen warming system to maintain the optimal temperature, even in colder conditions. This system increases productivity by ensuring the internal hive temperatures remain conducive to producing honey, even though the external temperatures are less favorable (M et al., 2021). The average temperature outside and inside the nest is 21.6 °C and 36.65 °C, respectively. The monitored temperature is a minimum of 21 °C through the heat sensor, and the productivity level is 19.51% for honey in 90 days (M et al., 2021).

After all, rising temperatures and extreme weather events disrupt habitats and food sources, leading to reduced productivity. A study in India (Kamboj et al., 2024) emphasizes the impact of heat stress on honeybee populations, noting that temperatures between 25 °C to 35 °C can lead to decreased productivity due to heat stress, and honey bees pose unique challenges to 15 °C because bees tend to cluster. However, at 20 °C, they collect water, nectar, pollen, or resin. (Kamboj et al., 2024). This observation highlights the importance of temperature regulation and cooling strategies for maintaining honey bee health and productivity in warmer climates. Overall, these varying productivity conditions of honey bees show how they adapt and thrive based on external factors. By understanding and adapting to the specific climate conditions in each region, beekeepers can manage to produce honey while sustaining the Apis mellifera population.

Conclusion

Temperature fluctuations play a crucial role in the productivity of *Apis mellifera* (honeybees), directly influencing honey production, nectar foraging, and water collection. As environmental temperatures shift, honeybee colonies must adapt to maintain their survival and efficiency. Warmer temperatures generally promote greater hive activity, leading to increased honey production, while extreme temperatures pose significant challenges to colony sustainability. Based on the analyzed data, the highest honey yield, ranging from 50 kg to 100 kg per year, was recorded at an average daily temperature of 14.24°C. However, productivity declines significantly at higher temperatures, with the lowest gain of 2.8 kg per day observed at 24°C to 26°C, depending on the geographical distribution of the colony. The optimal temperature range for honeybee productivity is 20°C to 30°C, with a relative humidity of 80-90%, as these conditions support active foraging and colony growth.

In contrast, honey production decreases at temperatures below 10°C and above 40°C, as extreme cold limits foraging activity and extreme heat stresses the colony, affecting nectar processing and hive maintenance. Aside from temperature, the availability of flowers plays a significant role in honey production. Honeybees rely heavily on nectar-rich plants, such as sunflowers and black locusts, which provide essential resources for honey synthesis. When floral availability declines due to seasonal changes or environmental disruptions, colony productivity is further impacted, regardless of temperature conditions. Overall, maintaining an optimal temperature range and ensuring a stable supply

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of nectar sources are key factors in sustaining high honey yields and supporting the long-term survival of *Apis mellifera* colonies.

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