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# POTENTIAL EFFECT OF HIVE COLOR ON HONEY BEE COLONY PERFORMANCE

# Efecto potencial del color de la colmena en el rendimiento de la colonia de abejas melíferas

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## ABSTRACT

In this study, the objective was to determine the potential effect of hive color on honey bee colony performance. Among the three hive groups, the hives, and their covers in the first group were painted in white; the hives and covers in the second group were painted in blue, and finally, the hives in the third group were painted in blue while their covers were painted in white. Data recorders were placed inside all hives, and temperatures were recorded every 59 minutes between June 27 and July 26 in the hives kept in the open field. In the study, examining the effect of three combinations of two different colors on the hive's internal temperature, average temperature values were calculated for the first, second, and third groups as 22.36±7.23 °C, 24.26±8.27 °C, and 24.93±8.91 °C, respectively, for the entire day. The results of the one-way variance analysis showed that the difference among groups was statistically significant ($p<0.001$). Considering that ambient temperature might be more effective in-hive temperature at certain times of the day, the data recorded between 10:00 a.m. and 5:00 p.m. were discussed separately, and the analyses in question were repeated. As a result of the research, it was observed that the white color group had a lower average temperature for both the entire day and the hot hours of the day. Therefore, it was concluded that the white color of the hives significantly contributes to the honey bee colony's performance.

**Keywords:** Colony performance, hive color, honey bee, temperature

## RESUMEN

En este estudio, el objetivo fue determinar el efecto potencial del color de la colmena en el rendimiento de la colonia de abejas melíferas. Entre los tres grupos de colmenas, las colmenas y sus cubiertas en el primer grupo estaban pintadas de blanco; la colmena y las tapas del segundo grupo se pintaron de azul; y finalmente, las colmenas del tercer grupo se pintaron de azul mientras que sus cubiertas se pintaron de blanco. Se colocaron registradores de datos dentro de todas las colmenas. Las temperaturas se registraron cada 59 minutos entre el 27 de junio y el 26 de julio en las colmenas mantenidas en campo abierto. En el estudio, se calcularon los valores de temperatura promedio para el primer, segundo y tercer grupo como 22,36±7,23 °C, 24,26±8,27 °C , y 24,93±8,91 °C respectivamente, durante todo el día. Los resultados del análisis de varianza de una vía mostraron que la diferencia entre los grupos fue estadísticamente significativa ($p<0,001$). En el estudio, los datos registrados entre las 10.00 y las 17.00 horas. durante el día se discutió por separado y se repitieron los análisis en cuestión. Como resultado de la investigación se observó que el grupo de color blanco tenía una temperatura promedio más baja tanto durante todo el día como en las horas calurosas del día. Por lo tanto, se concluyó que el color blanco de las colmenas contribuye significativamente al desempeño de la colonia de abejas melíferas.

**Palabras clave:** Abeja melífera, color de la colmena, rendimiento de la colonia, temperatura

## INTRODUCTION

Honey bees are social insects known for their heat-balancing skills. Thanks to these features, bees are found worldwide, from temperate regions to cold climates (Southwick and Heldmaier, 1987; Kovac et al., 2009; Stabentheiner et al., 2021). For life to continue within the colony, the environment's temperature, humidity, and gas content must be balanced (Southwick and Moritz, 1987). Honeybees also have to operate in a colonial form to achieve these balances (Bonoan et al., 2014). With such structures, it is considered that the life of a colony is theoretically infinite. With their physiological and behavioral properties, honey bees are much more specific than other insects. The temperature stabilization capabilities of honey bees, called homeostasis, have been known for a long time. This feature occurs in the form of increased body temperatures at low ambient temperatures and reduced body temperatures at high temperatures (Southwick and Heldmaier, 1987).

The continuation of colonial life necessitates the continuous production of broods. Homeostasis, which ensures this production, involves responses to environmental changes to maintain the temperature required for brood production (Southwick and Heldmaier, 1987; Bonoan et al., 2014; Stabentheiner et al., 2021). Even small deviations (0.5 °C) in brood area temperature have significant effects on brood development and colony health. Honey bees that are not raised in favorable conditions are more susceptible to diseases, pests, and environmental conditions (Tautz, 2008).

Honey bee larvae and pupae, which are highly stenothermic (Tautz et al., 2003; Becher et al., 2009), require a brood area at 32-36 °C for normal development (Seeley and Heinrich, 1981; Kronenberg and Heller, 1982; Kleinhenz et al., 2003; Petz et al., 2004). Thermal homeostasis of the colony is therefore especially important for the broods. Open brood cells (eggs and larvae) can tolerate low temperatures for a short period, while sealed brood cells (pupae) are more sensitive to these temperatures (Wang et al., 2016). Since the brood cannot regulate temperature (Petz et al., 2004), thermal constancy within the colony must be maintained by worker bees (Stabentheiner et al., 2010). Therefore, thermoregulation is more pronounced when there is a high level of brood presence in the colony (Southwick 1985; Kleinhenz et al., 2003; Stabentheiner et al., 2010). For adult honey bees, on the other hand, low or high temperatures can cause behavioral and neural abnormalities (Stabentheiner et al., 2021).

In a cold environment, honey bees try to transfer their body heat, which they raise to warm the brood area, to the brood. For this purpose, worker bees press their heat on their pupa fields and transfer heat into their cells. Honeybees can increase their chest temperature to 43°C and maintain this level for 30 minutes (Tautz, 2008). To prevent heat loss, other worker bees tightly cover the brood area. Given that a bee will die when its body temperature reaches 45°C, it will be revealed how sensitive and vital this stage is (Abou-Shaara et al., 2012; Stabentheiner et al., 2021; Millers Homestead, n. d.).

The thermal conditions that are a source of stress for honey bee colonies are not only related to cold weather.

Honey bees respond to temperature changes with behavioral or metabolic adaptations (Heinrich and Esch, 1994; Zhao et al., 2021; Jhawar et al., 2023). At high temperatures that are likely to disrupt colony life, honey bees activate different cooling mechanisms. If the internal temperature of the hive rises above normal levels, bees ventilate using their wings. For ventilation, one group of worker bees circulates the air by sending fresh air in, while another group circulates hot air out of the hive. In this way, they try to reduce the temperature inside the hive to 35 °C (Southwick and Heldmaier, 1987).

If the temperature in the brood area approaches a critical level, there is an increase in the number of foragers collecting water to lower the hive temperature, and they start collecting water (Kovac et al., 2018; Zhao et al., 2021). They sprinkle water droplets all over the hive, including the egg and larval areas (Southwick and Heldmaier, 1987; Jarimi et al., 2020; Zhao et al., 2021). By evaporating the water, they try to lower the internal temperature while preventing the open brood from drying out. In addition to the clean water carried into the hive, some water produced by the worker bees during the processing of nectar can also be used for this purpose.

Another method used by honey bees to protect their brood in a hive with increasing temperatures is for young worker bees to absorb heat by pressing the ventral side of their body against the heated surface. The heat-absorbing bees then distribute this heat to cooler areas of the hive (Bonoan et al., 2014). However, if cooling measures are insufficient, many honey bees will leave the hive and form clusters outside the hive, and a new division of labor in the colony will take place (Zhao et al., 2021).

In global warming scenarios, the effects of which are beginning to be seen and which pose different dangers for the future, high environmental temperatures are expected to put honey bee colonies in difficulty (Stabentheiner et al., 2021). Overheating of the hive, which limits the activity of the bees, must therefore be considered.

Honey bees are directly affected by temperature changes in their life in conventional hives. Even if breeding is carefully planned, some factors, such as temperature, cannot allow honey bees to reach a completely comfortable state (Souza et al., 2015).

Some suggestions have been developed to increase colony productivity by reducing temperature stress in breeding, such as ventilated and insulated hives and providing shade. In addition to these, hive color is also an important issue to be considered. Although it is general knowledge that light colors reflect sunlight and dark colors absorb it, it will be useful for colony management to evaluate the influence of color in the hive. In the study prepared for this purpose, the effect of three combinations of white and blue colors on hive internal temperature was tried to be revealed. Thus, suggestions were proposed for breeding and honey bee welfare.

## MATERIALS AND METHODS

### Materials

The research was conducted in the province of Van, situated between longitudes 42° 40' and 44° 30' E, and latitudes 37° 43' and 39° 26' N. Van, with a central altitude of 1725 m, is located in the closed basin of Lake Van and in the Eastern Anatolia Region of Türkiye. Summers are characterized by high temperatures and dry conditions, with approximately 20 days experiencing temperatures above 30°C. Annual rainfall varies between 370 mm and 570 mm (Erkan et al., 2024).

The average temperature for July, where the research was conducted, over the last 30 years (1991-2020), is 22.3 °C, and the average sunshine duration is 12.1 hours. Van experiences an average of 120.1 sunny days annually, with 19 days in July (Meteorology, 2024). The research was conducted in an area without shade.

For the study, hives of the standard Langstroth type, measuring 50.5 x 43.5 cm and with a height of 29.5 cm, were used to examine the effect of color on the inner temperature of hives. The hives had a wood thickness of 2.5 cm and were made of pine wood. The first group of hives used in the study was painted white, including the cover, while the third group was painted light blue. The second group, designed as a combination of two colors, was painted white as the body color and light blue as the cover color.

The hives were painted with water-based wood paints that are UV-resistant and contain zero VOC (Volatile Organic Compounds). The study utilized Trotec BL30 data recorders to retrieve the hive's internal temperature data.

### Methods

In the study conducted between June 27 and July 26, 2020, at the Central Directorate of Beekeeping Application and Research of Van Yüzüncü Yıl University, nine honeybee hives (three for each group) were utilized. The devices, installed inside beehives left unaltered in the field, recorded temperatures once every 59 minutes.

The study examined the impact of three combinations of two different colors on hive internal temperature, and the necessary statistical analysis was performed using the SAS (SAS, 2020) Statistics Software Program. One-way analysis of variance was applied to the data to compare temperature averages across the three different color combinations. The variance analysis utilized the Duncan Multi-Compare Test to determine significant color values.

## RESULTS

The introductory statistics for each group resulting from the study are presented in (Table 1).

**Table 1.** Introductory statistics

| Color | N | Average (°C) | Std. Deviation | Std. Error | the lowest value (°C) | the maximum value (°C) |
|---|---|---|---|---|---|---|
| White | 2232 | 22.36 | 7.23 | 0.15 | 10.30 | 37.90 |
| White/ Blue | 2232 | 24.26 | 8.27 | 0.17 | 10.70 | 41.10 |
| Blue | 2232 | 24.93 | 8.91 | 0.19 | 10.90 | 44.30 |

According to the results of one-way analysis of variance regarding the hive colors and their impact on these data, the difference among the three-color ranges in terms of average temperature was found to be statistically significant ($p<0.001$). Subsequently, Duncan Multiple Range Test results were applied to the data to identify the specific color levels that differed, as shown in (Table 2).

**Table 2.** Duncan Multiple Range Test Results

| Color | N | Average (°C) | Group |
|---|---|---|---|
| Blue | 2232 | 24.93 | A |
| White/Blue | 2232 | 24.26 | B |
| White | 2232 | 22.36 | C |

According to Duncan's Multiple Range Test results, each color group exhibited a significant difference in average temperature. Specifically, the highest average temperature was recorded in the blue group at 24.93 °C, followed by the white/blue group at 24.26 °C, and lastly, the white group at 22.36 °C.

In the study, considering that ambient temperature could be more impactful on in-hive temperature during certain times of the day, the data between 10:00 a.m. and 5:00 p.m. were separately analyzed, and the relevant statistical tests were repeated.

**Table 3. Introductory Statistics for hours between 10.00 a.m. -5.00 p.m.**

| Color | N | Average(°C) | St. Deviation | St. Error | tthe lowest value (°C) | the maximum value (°C) |
|---|---|---|---|---|---|---|
| White | 732 | 30.47 | 3.90 | 0.14 | 14.50 | 37.90 |

| Color | N | Avera-ge(°C) | St. Devia-tion | St. Error | tthe lowest value (°C) | the maxi-mum value (°C) |
|---|---|---|---|---|---|---|
| White/ Blue | 732 | 33.28 | 4.34 | 0.16 | 15.80 | 41.10 |
| Blue | 732 | 34.90 | 4.92 | 0.18 | 15.30 | 44.30 |

According to the one-way analysis of variance results for the data recorded between 10:00 a.m. and 5:00 p.m., the difference among the three-color levels in average temperature was also found to be statistically significant ($p<0.001$). Detailed temperature values and Duncan Multiple Range Test results are presented in (Table 4).

**Table 4.** Duncan Multiple Range Test Results for hours between 10.00 a.m -5.00 p.mm

| Color | N | Average (°C) | Group |
|---|---|---|---|
| Blue | 732 | 34.90 | A |
| White/Blue | 732 | 33.28 | B |
| White | 732 | 30.47 | C |

Overall, in terms of average temperature, all three-color groups exhibited differences, consistent with the findings from the entire day's data. The Duncan Lettering Boxplot (Fig. 1) chart below provides an alternative visualization of the study's results.

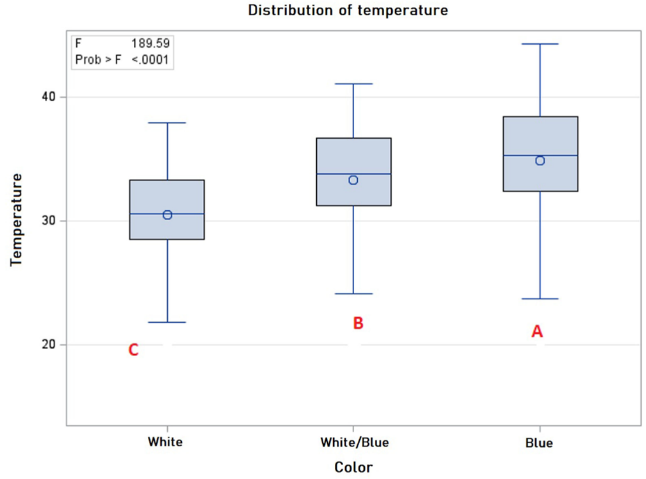


**Figure 1.** Box-Plot Chart for hours between 10.00 a.m. -5.00 p.m.

## DISCUSSION

In this study, which aimed to examine the potential effects of hive color on honey bee colony performance, the temperature averages recorded every 59 minutes from white, white/blue, and blue hives were calculated as 22.36±7.23 °C, 24.26±8.27 °C, and 24.93±8.91 °C, respectively, for the entire day; and as 30.47±3.90 °C, 33.28±3.34 °C, and 34.90±4.92 °C, respectively, for the hours between 10:00 a.m. - 5:00 p.m. Consequently, the white color group showed a lower temperature average when considering data for the entire day and the hot hours. If these values obtained in empty hives are recorded in colonized hives, they will likely increase due to various activities.

A hive internal temperature exceeding 36 °C is harmful to honey bees. Even an increase of 1-2 °C in this value can lead to the death of offspring in the comb cells (Winston, 1991). The maximum values obtained for all three groups in the experiment exceeded this limit.

The thermal homeostasis in the colony is achieved through the collaboration of thousands of bees (Stabentheiner et al., 2010; Cook et al., 2016). Worker bees, aiming to maintain the internal temperature of the hive between 32-35°C to prevent overheating (Heinrich, 1980; Seeley, 1985; Tautz, 2008; Kovac et al., 2018), attempt to cool the hive by ventilating and evaporating the water they bring into the hive (Southwick and Heldmaier, 1987; Kovac et al., 2018; Zhao et al., 2021). If all efforts prove insufficient, the colony may leave the hive (Santos et al., 2017).

All activities to reduce the inside temperature of the hive result in significant energy and time losses. Honey bees assigned to brood care focus on hive ventilation, while those collecting nectar and pollen concentrate on water transport (Kühnholz and Seeley, 1997). The unreduced internal temperature of the hive can render individuals in the brood stage more susceptible to diseases and pests, reduce their lifespan, and damage the wax material.

So far, studies have shown that even when the environmental temperature reaches 60°C, honey bees can maintain a balance at 35-36°C (Millers Homestead, n. d.). This super community can provide air changes, reaching 60 l/min when need (Southwick and Heldmaier, 1987), and can continue ventilation for hours.

Another method to reduce the high temperature inside the hive is to vaporize the water brought into the hive. Under normal conditions, the colony's water needs are around 0.12 liters per day (Hegić and Bubalo, 2006), but this rate can increase further during activities and high environmental temperatures. The energy consumed to evaporate every gram of water used to reduce ambient temperature and provide the required humidity is approximately 580 cal (Al-Rajhi, 2017).

The activities carried out by worker bees to ensure thermoregulation result in a waste of energy and time. Additionally, uncontrolled temperature increases cause damage to the brood.

The main recommendations to protect colonies from high temperatures include providing ventilation to hives and shade (Lopes et al., 2011). Al-Rajhi (2017), who evaluated shading and ventilation together, found that it is more advantageous to produce with colonies with good ventilation and shade in summer. Additionally, in one of the rare studies on hive color, Mitchener (1940) stated that the white color of hives has a positive effect on internal temperature. Similarly, Souza et al. (2015) recorded lower internal temperatures in white-colored hives compared to blue-colored hives.

When considering the hot hours of the day (10:00 a.m.-5:00 p.m.) in the study, a difference of 4.43 °C was observed between the blue and white color groups. This difference was calculated as 6.40 °C at maximum values. The temperature difference caused by painting the covers white in blue hives is 1.62 °C. The same difference was 3.20 °C at maximum values. These temperature changes mean that the bees in the blue hives will spend more effort on thermoregulation than the others.

Honey bees are highly dependent on nature, and many environmental factors affect their lives. High temperatures are among these factors, and global climate changes are increasingly affecting colonies every day.

## CONCLUSIONS

As a result of the study, only the internal temperature differences caused by the different colors of the hives were revealed. With the obtained data, it was found that, in addition to insulation, shading, and ventilation arrangements to enhance the performance of honey bee colonies on hot summer days, the white color of the hive significantly contributes to colony performance. Additionally, placing geometric shapes in different colors at hive entrances will be sufficient to eliminate errors that bees may encounter in finding the right hive when all hives are painted white, especially in crowded apiaries with dense colonies.

## AUTHORS PARTICIPATION

All authors contributed to every stage of the study.


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## CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest.

## REFERENCES


Abou-Shaara, H. F., Al-Ghamdi, A. A., and Mohamed, A. A. (2012). Tolerance of two honey bee races to various temperature and relative humidity gradients. *Environmental and Experimental Biology*, *10*(4):133–138.

Al-Rajhi M. A. (2017). Effect of shading and ventilation on the amount of water consumed for cooling beehive during summer season. *Misr Journal of Agricultural Engineering, 34*(4-1):1857-1868. https://doi.org/10.21608/mjae.2017.96196

Becher, M. A., Scharpenberg, H., and Moritz, R. F. A. (2009.) Pupal developmental temperature and behavioral specialization of honeybee workers (*Apis mellifera* L). *Journal of Comparative Physiology A*, *195*:673–679. https://doi.org/10.1007/s00359-009-0442-7

Bonoan, R. E., Goldman, R. R., Wong, P. Y., and Starks, P. T. (2014). Vasculature of the hive: Heat dissipation in the honey bee (*Apis mellifera*) hive. *Naturwissenschaften*, *101*:459–465. https://doi.org/10.1007/s00114-014-1174-2

Cook, C. N., Durzi, S., Scheckel, K. J., and Breed, M. D. (2016). Larvae influence thermoregulatory fanning behavior in honeybees (*Apis mellifera* L.). *Insectes sociaux*, *63*(2):271-278. https://doi.org/10.1007/s00040-016-0463-5

Erkan, C., Günbey, V. S., Günbey, B., and Cengiz, F. (2024). Comparison of pure caucasian, carniolan and native anatolian ecotype honey bee (Apis mellifera L.) colonies in the eastern anatolia region with reciprocal F1 hybrids. *Bioscience Journal*, *40*:e40008. https://doi.org/10.14393/BJ-v40n0a2024-68555

Heinrich, B. (1980). Mechanisms of body-temperature regulation in honeybees, *Apis mellifera*: I. Regulation of Head Temperature. *Journal of Experimental Biology*, *85*(1):61–72. https://doi.org/10.1242/jeb.85.1.61

Hegić, G., and Bubalo, D. (2006). Hygienic water supply for the bees. *Journal of Central European Agriculture, 7*(4):743-752. https://doi.org/10.5513/jcea.v7i4.420

Heinrich, B., and Esch, H. (1994). Thermorregulation in bees. *American Scientist*, *82*:164-170.

Jarimi, H., Tapia-Brito, E., and Riffat, S. (2020). A review on thermoregulation techniques in honey bees' (Apis mellifera) beehive microclimate and its similarities to the heating and cooling management in buildings. *Future Cities and Environment, 6*(1):1–8. https://doi.org/10.5334/fce.81

Jhawar, J, Davidson, J. D., Weidenmüller, A., Wild, B., Dormagen, D. M., Landgraf, T., Couzin, I. D., and Smith, M. L. (2023). How honeybees respond to heat stress from the individual to colony level. *Journal of The Royal Society*, *20*(207):20230290. https://doi.org/10.1098/rsif.2023.0290

Kleinhenz, M., Bujok, B., Fuchs, S., and Tautz, J. (2003). Hot bees in empty broodnest cells: heating from within. *Journal of Experimental Biology*, *206*(23):4217–4231. https://doi.org/10.1242/jeb.00680

Kovac, H., Stabentheiner, A., and Brodschneider, R. (2009). Contribution of honeybee drones of different age to colonial thermoregulation. *Apidologie*, *40*:82-95. https://doi.org/10.1051/apido/2008069

Kovac, H., Käfer, H., and Stabentheiner, A. (2018). The energetics and thermoregulation of water collecting honeybees. *Journal of comparative physiology. A, Neuroethology, sensory, neural, and behavioral physiology, 204*(9):783–790. https://doi.org/10.1007/s00359-018-1278-9

Kronenberg, F., and Heller. H. C. (1982). Colonial Thermoregulation in Honey Bees (*Apis mellifera*). *Journal of* *comparative physiology B*, 1982; *148*(1):65–76. https://doi.org/10.1007/BF00688889

Kühnholz, S., and Seeley, T. (1997). The control of water collection in honey bee colonies. *Behavioral Ecology and Sociobiology*, *41*:407–422. https://doi.org/10.1007/s002650050402

Lopes, M. T. R., Barbosa, A. L., Pereıra, F. M., Camargo, R. C. R De, Rıbeiro, V. Q., and Souza, B. A. (2011). Alternative apiaries shading. *Pesquisa Agropecuária Tropical*, *41*(3):299-305. https://doi.org/10.5216/pat.v41i3.8919

Meteoroloji. (Turkish State Meteorological Service), (2024). *Seasonal norms for the provinces*. https://www.mgm.gov.tr/veridegerlendirme/il-ve-ilceler-istatistik.aspx?m=VAN (Access date: January 24, 2024).

Millers Homestead. (n.d.). *Internal Temperatures in a Honey Bee Hive*. http://www.millershomestead.com/NCBroodHeatingCooling.pdf

Mitchener, A. V. (1940). The effect of color of hive covers upon the temperature within the hive. *Journal of Economic Entomology, 33*(4):649-650. https://doi.org/10.1093/jee/33.4.649

Petz, M., Stabentheiner, A., and Crailsheim, K. (2004). Respiration of individual honeybee larvae in relation to age and ambient temperature. *Journal of Comparative Physiology B*, *174*(7):511–518 https://doi.org/10.1007/s00360-004-0439-z

Santos, R. G., Domingos, H. G. T., Gramacho, K. P., and Gonçalves, L. S. (2017). Sombreamento de colmeias de abelhas africanizadas no Semiárido Brasileiro. *Revista Verde de Agroecologia e Desenvolvimento Sustentável*, *12*(5):828-836. https://doi.org/10.18378/rvads.v12i5.5407

SAS, (2020). *SAS Institute Inc 2013*. SAS/ACCESS® 9.4 Interface to ADABAS: Reference. Cary, NC: SAS Institute Inc.

Seeley, T., and Heinrich, B. (1981). *Insect Thermoregulation (Regulation of temperature in the nests of social insects)*. Heinrich, B, Editor, Wiley Press.

Seeley, T. D. (1985). *Honeybee Ecology: A Study of Adaptation in Social Life*. Princeton University Press. https://doi.org/10.1515/9781400857876

Southwick, E. E. (1985). Allometric relations, metabolism and heat conductance in clusters of honey bees at cool temperatures. *Journal of Comparative Physiology B*, *156*:143–149. https://doi.org/10.1007/BF00692937

Southwick, E. E., and Heldmaier, G. (1987). Temperature control in honey-bee colonies. *Bioscience, 37*(6):395–399. https://doi.org/10.2307/1310562

Southwick, E. E., and Moritz, R. F. A. (1987). Social control of air ventilation in colonies of honey bees, *Apis mellifera*. *Journal of Insect Physiology*, *338*(9):623–626. https://doi.org/10.1016/0022-1910(87)90130-2

Souza, M. F. P., Turco, S. H. N., Silva, E., Costa, D. S., and Freire, M. S. (2015). Internal ambience of beehives *Apis mellifera* with different colors and roofing materials in the sub middle of the São Francisco Valley. *Engenharia Agrícola*, *35*:625–634. https://doi.org/10.1590/1809-4430

Stabentheiner, A., Kovac. H., and Brodschneider, R. (2010). Honeybee colony thermoregulation-regulatory mechanisms and contribution of individuals in dependence on age, location and thermal stress. *PLoS ONE, 5*(1):e8967. https://doi.org/10.1371/journal.pone.0008967

Stabentheiner, A., Kovac, H., Mandl, M., and Käfer, H. (2021). Coping with the cold and fighting the heat: thermal homeostasis of a superorganism, the honeybee colony. *Journal of Comparative Physiology A*, *207*:337-351. https://doi.org/10.1007/s00359-021-01464-8

Tautz, J., Maier, S., Groh, C., Roessler, W., and Brockmann, A. (2003). Behavioral performance in adult honey bees is infuenced by the temperature experienced during their pupal development. *PNAS*, *100*(12): 7343–7347. https://doi.org/10.1073/pnas.1232346100

Tautz, J. (2008). *The Buzz about Bees.* (1st ed.). Springer. https://doi.org/10.1007/978-3-540-78729-7

Wang, Q., Xu, X., Zhu, X., Chen, L., Zhou, S., Huang, Z. Y., and Zhou, B. (2016). Low-temperature stress during capped brood stage increases pupal mortality, misorientation and adult mortality in honey bees, *PLOS ONE, 11*(5):e0154547. https://doi.org/10.1371/journal.pone.0154547

Winston, M. L. (1991). *The Biology of the Honey Bee*. (1st ed.). Harvard University Press.

Zhao, H., Li, G., Guo, D., Li, H., Liu, Q., Xu, B., and Guo, X. (2021). Response mechanisms to heat stress in bees. *Apidologie, 52*:388–399. https://doi.org/10.1007/s13592-020-00830-