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The use of cork in the thermoregulation of the hive: an innovation attempt to enhance non-wood products and beekeeping in Mediterranean forests

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ABSTRACT Hive thermoregulation is fundamental for the normal development of bee colonies and, consequently, hive productivity and honey bee health. External conditions mainly affect the walls of the hive. Therefore, hive construction materials and thermal conductivity features can influence its thermoregulation efficiency. The present trial made a comparison of experimental hives (modified Dadant-Blatt of 10 frames) made with cork as thermal insulator and conventional hives made entirely with firwood to evaluate their effects on thermoregulation of *Apis mellifera ligustica* colonies in Northwerstern Sardinia (Italy). The cork-modified beehives consisted of common conventional beehives modified by replacing the wooden walls with cork walls (pressed cork), whereas the control beehives (wooden hives) consisted of standard Dadant-Blatt beehives entirely made of firwood. Environmental (especially nest internal temperature) parameters were assessed periodically. The daily temperature pattern of cork-modified beehives was more regular than that of control beehives. In addition, bees had a more efficient winter thermoregulation in cork-modified beehives compared with control hives.

KEYWORDS: cork beehives, thermal insulation, thermoregulation, forest product.

Introduction

The microclimatic conditions of the hive play an important role in colony homeostasis, particularly in the maintenance of optimal nest temperature regardless of external conditions (Dyer and Seeley 1987, Ruttner 1988, Heinrich and Esch 1997). Stable conditions inside the hive have a positive effect on brood rearing, and the state of colonies at low temperatures (overwintering) and over summer in hot conditions (Winston 1991). Although honey bees (workers) are able to respond efficiently to environmental conditions using physiological and behavioural mechanisms for temperature control, this response involves an energy cost, such as consumption of honey stocks (Esch and Bastian 1968, Kronemberg and Heller 1982, Heinrich 1996). When the honeybee colony perceives the temperature inside the nest as too high, its foragers collect water, thus increasing ventilation and evaporative cooling by fanning their wings at the hive entrance (Lindauer 1955, Kiechle 1961, Lensky 1964, Kühnholz and Seeley 1997). When the elevated temperature is localized in a specific point of the nest, the workers respond with heat shielding (Starks and Gilley 1999). In contrast, when the temperature is perceived as too low, the worker bees respond by producing metabolic heat and forming a cluster (Heinrich 1981 and 1995, Kronenberg and Heller 1982, Harrison 1987). Although honeybees maintain the temperature of their nest elevated (Seeley 2014) mainly to accelerate brood development (Milum 1930), thermoregulation may also influence the sanitary status of bee colonies. In fact, the optimal temperature for the reproduction of the parasitic mite *Varroa destructor* in beehives is between 32.5 and 33.4 °C (Fremuth 1985, Le Conte and Arnold 1987 and 1988, Le Conte et al. 1990). Above 36.5 °C mite reproduction is significantly reduced and above 38 °C female mites die without reproducing (Le Conte et al. 1990). For this reason, the original natural host of *Varroa*, *Apis cerana* maintains the temperature of the brood higher than *A. mellifera* (Le Conte et al. 1990, Yang et al. 2010). Thermoregulation may play an important role in contrasting also other diseases, such as the fungus *Ascosphaera apis*, agent of the chalkbrood disease, which needs a temperature of approximately 30° C to germinate (Bailey 1966; 1981). In this case, it is necessary that the colony recognizes the infested larvae early and then increases the broodcomb temperature to limit the pathogen effects. This mechanism was defined as social fever by Starks et al. (2000). Finally, the elasticity in thermoregulation capacity is exploited by bees in defence against predators as well (Ono et al. 1995).

In the last decades, hive models made of polystyrene or plastic have been proposed, especially to meet the needs of cold climates. However, the use of these materials is not always satisfactory, due to their fragility or excessive impermeability, whereas conventional wooden hives do not have these disadvantages. On the other hand, a hive that is too isolated from the external environment could show problems related to internal overheating that, in this case, could not always be efficiently compensated by the regulatory function of bees (Büdel 1968). Another method that has been evaluated experimentally

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to mitigate the effects of cold climate, but with limited results, is the black colour of the hives (Madren 1995). Considering that the thermoregulatory capacity of the bees has its limitations and the influence of the external environment on the hive is exerted mainly through the walls of the hive, and only minimally through the entrance of the hive, the choice of the material used to make the beehive is important (Satta and Floris 2004). In various environments and civilizations, hive construction was influenced by the availability of suitable materials (earth materials, such as sun-dried mud and fired clay, or plant materials, such as hollowed log, cork bark, woven cylinder, Ferula stems and wooden boards) (Crane 1999). In Sardinia (Italy), North Africa and other Mediterranean regions, the cork bark cylinder (in horizontal or vertical position) was commonly used (Crane 1999). It is well known that cork is superior in insulating properties to wood, because it has a thermal conductivity of about 0.052 W/mK compared to a value of 0.10-0.12 W/mK of firwood or pine at 20 °C. In addition, cork is lighter and more resistant to mold. On the basis of these characteristics, the traditional use of cork in hive construction, and the economic interest in this non-wood forest product, we tested the insulating properties of cork as construction material of modern hives and its impact on thermoregulation of Italian bee colonies in comparison to traditional beehives made of firwood.

Materials and Methods

Hive models

The study was performed in an experimental apiary in Northwestern Sardinia from December 2016 to April 2017, at the experimental farm of the Department of Agriculture of the University of Sassari (latitude 40°46'23", longitude 8°29'34").

Based on the Dadant-Blatt model, modern cork-wooden hives (52.0 x 34.8 cm), with 3-cm-thick walls made mostly of cork (83%) and only a thin inner layer of wood (0.5 cm). These cork-modified beehives were handcrafted in the woodworking facility of the regional Forestry Agency (Forestas - Sardinia) (Fig. 1). Standard Dadant-Blatt wooden hives were used as control (Fig. 1). Differences in thermal insulation capability of the experimental hive and the control hive were preliminarily estimated by computing the *thermal power transmitted outside* (P) for each type of hive with the following formula:

$$P = \lambda S_{tot} [(Ti–Te)/D]$$

where:

λ = *Thermal conductivity* determined considering a wall thickness equal to 3.0 cm in the cork/wooden hive and 2.5 cm in the firwood hive
S_{tot} = external surface of the two hive models (1.11 m^2)
Ti = internal temperature
Te = external temperature
D = thickness of the hive walls

The *thermal power transmitted outside* was calculated for the months of December, January, February, March and April considering the temperature of the brood chamber (35 °C) as internal temperature and the monthly average of 9.86 °C for December, 7.29 °C for January, 9.73 °C for February, 10.37 °C for March and 11.49 °C for April as external temperature.

Figure 1 - Experimental beehive model (cork-wooden beehive, on the left), with walls made by cork, and standard Dadant-Blatt beehive (wooden beehive, on the right), with walls made by firwood, used as control hive.

Experimental hive group

Two experimental groups of four hives each were used in the experiment. Colonies of a local strain of *Apis mellifera ligustica*, containing about the same amount of adult bees, brood (eggs, larvae and sealed brood) and stocks of honey and pollen, preliminarily monitored using one-sixth of a Dadant–Blatt frame (188 cm^2) as a unit of measure (Marchetti 1985), were placed into each cork-modified or control beehive.

Data collection

Temperature inside and outside each experimental (cork-wooden) or control (wooden-only) beehive was monitored using ibutton mini-sensors (model DS 1923-F5#). Inside the hive, the sensors were placed in central position between two combs containing brood (central combs) or between two combs containing pollen or honey stores (side combs). Outside the hive, the sensors were placed at a short distance from the hive entrance and kept suspended with a small wooden support. Temperature data were recorded hourly throughout two periods of two weeks each, the first between the 15th and 28th of January 2017 and the second between the 18th and 31th of March 2017.

Data from each experiment were analysed separately by fitting linear models using Generalized Least Squares (GLS) in R software (R Development Core Team 2018) with nlme package (Pinheiro et al. 2017). A compound symmetry correlation structure was considered (Pinheiro and Bates 2000).

Another experiment was performed in April to assess the time necessary to restore the optimal temperature (~ 35 °C) in the brood chamber when the hive is opened to check the colonies. In this case, the brood-comb containing the sensor was extracted and kept out of the hive for five minutes. After this time, the brood-comb was put back into place and the beehive closed. The sensors had been programmed to record the temperature every minute.

Results

Theoretical isolation capacity of the experimental hives

Figure 2 clearly shows the greater thermal dispersion of wooden hives compared to cork-wooden hives, corresponding, on average, a difference of approximately 74,569 cal./h. It is also evident that the differences in the thermal dispersion between the two hive models increase when the outside temperature decreases, as it occurred in January.

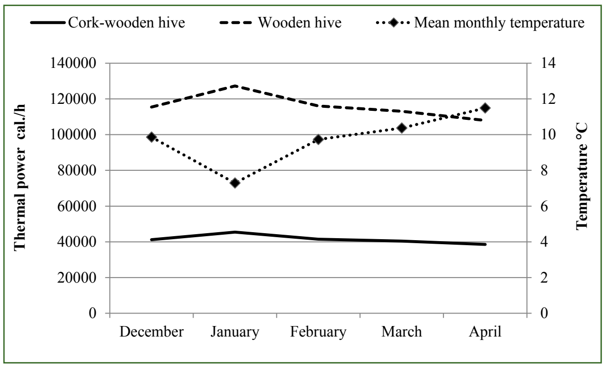


Figure 2 - Thermal power transmitted outside (main y axis) calculated for cork-wooden hives and wooden beehive (control hive). The mean monthly outside temperature is also represented in the figure (secondary y axis).

Temperature trend inside the hives

In January, the daily mean temperature in the brood chamber showed significantly higher values (F = 48.7, P<0.0001) and a more regular trend in the cork-wooden hives, with an oscillation of only 0.34 °C (T. min. = 34.53 °C and T. max = 34.87 °C), compared to control hives, which had lower values (T. min = 30.40 °C and T. max = 32.59 °C) and a more marked oscillation (2.18 °C) (Fig. 3). In the same month, the temperature of the side combs was also significantly higher in the cork-wooden hives (F = 117.3, P<0.0001), with a variation of 5.88°C (T. min. = 17.63 °C and T. max = 23.51 °C), compared to the control hives, which showed an average variation of 8.36 °C (T. min = 9.52 °C and T. max = 17.88 °C) (Fig. 4). A stronger relationship, with a significant positive linear regression between the side comb and the outside temperature, was found for wooden-only hives compared to cork-wooden ones (P = 0.0001 and R^2 = 73.68 *vs* P = 0.0487 and R^2 = 28.63).

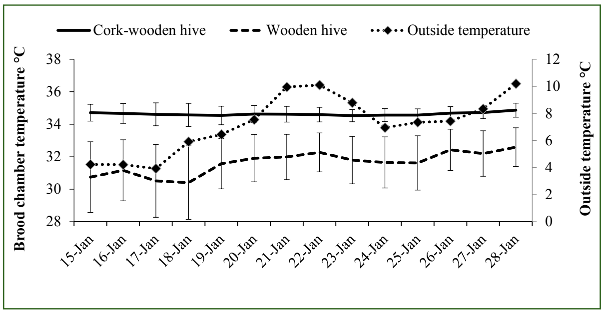


Figure 3 - Trend of the brood chamber temperature (mean ± SE) throughout a period of two weeks in January in cork-wooden and wooden beehives (main y axis). The outside temperature is also represented in the figure (secondary y axis).

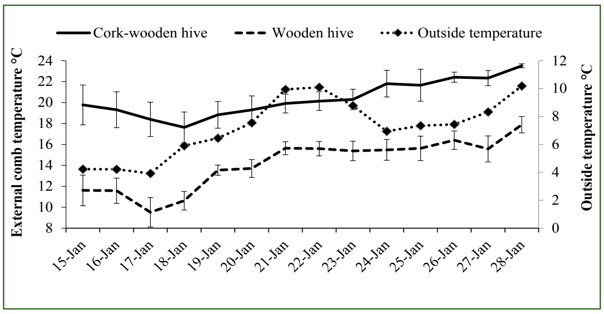


Figure 4 - Trend of the side comb temperature (mean ± SE) throughout a period of two weeks in January (winter) in cork-wooden and wooden beehives (main y axis). The outside temperature is also represented in the figure (secondary y axis).

As observed in January (Figs. 3 and 4), in March a greater oscillation of the brood chamber temperature occurred in the wooden-only hives (T. min. = 35.21 °C and T. max = 34.50 °C) compared to the cork-wooden ones (T. min. = 35.42 °C and T. max = 35.61 °C) (Fig. 5) but in this case the difference between the trend of temperature in the two type of hive was not significant (F = 1.2, P = 28.31). Moreover, the difference between T. max and T. min. was much less marked for both wooden-only hives and cork-wooden hives (0.29 *vs* 0.19) compared to that observed in January. Because brood was found also in the side combs in March, the temperature in this area of the hive was not recorded during that month.

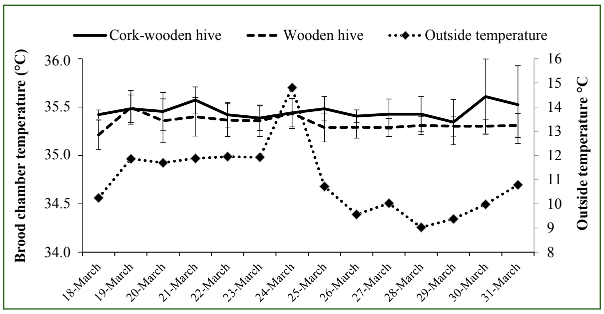


Figure 5 - Trend of the brood chamber temperature (mean ± SE) throughout a period of two weeks in March (spring) in cork-wooden and wooden beehives (main y axis). The outside temperature is also represented in the figure (secondary y axis).

Figure 6 - Trend of the brood chamber temperature (mean ± SE) over 24 hours (20th of January) in cork-wooden and wooden beehives (main y axis). The outside temperature is also represented in the figure (secondary y axis).

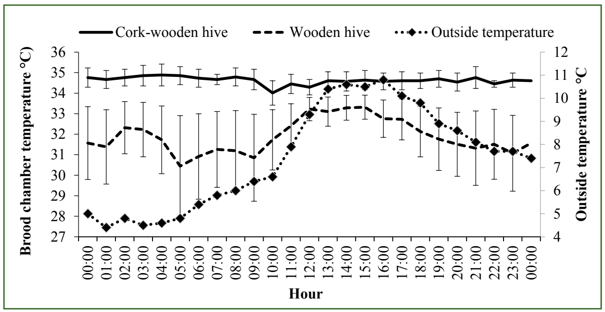


Figure 7 - Trend of the external comb temperature (mean ± SE) over 24 hours (20th of January) in cork-wooden and wooden beehives (main y axis). The outside temperature is also represented in the figure (secondary y axis).

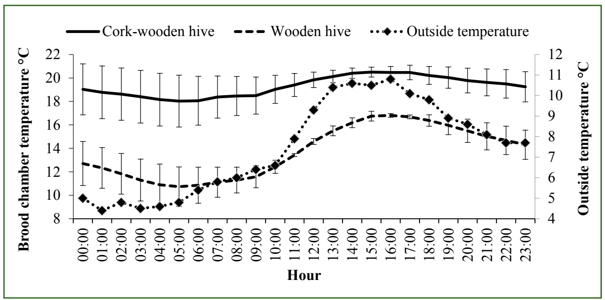
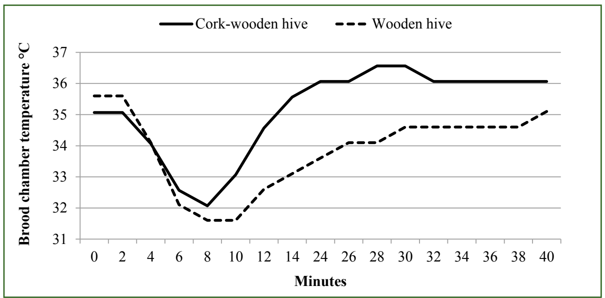


Figure 8 - Rhythm of restoration of the optimal temperature in the brood chamber in cork-wooden and wooden beehives. The brood-comb containing the sensor for measuring the temperature was left outside the hive for 5 minutes and then repositioned in its place (April, spring).



In a winter day (20th of January), the temperature recorded in the brood chamber over a 24-hour period showed more constant values in the cork-wooden hives than in the control ones (Fig. 6). In general, temperature was kept significantly higher ($F = 24.99$, $P<0.0001$) in cork-wooden hives (T. min = 34.01 °C and T. max = 34.88 °C), with an oscillation of 0.87 °C, compared to wooden-only hives (T. min = 30.44 °C and T. max = 33.31 °C), which had a higher oscillation (2.87 °C). A similar significant trend was observed in the same day for the temperature recorded in the side comb (Fig. 7) ($F = 177.2$, $P < 0.0001$).

In March, the temperature trend monitored in the brood chamber over a 24-hour period did not evidence significant differences between hive groups, with minimal fluctuations (0.16-0.17 °C) of temperature in both model of hives ($F = 2.5$, $P=0.119$).

The time necessary to restore the temperature of the brood chamber after opening the hive in April differed between the two hive types (Fig. 8): after closing the hive (time 0), the cork-wooden hives took 14 minutes to reach the temperature of 35.56 °C, whereas the wooden hives took 40 minutes to reach 35.10 °C.

Discussion

The efficiency of cork in the isolation of the hive, expected from a theoretical point of view due to its lower thermal conductivity compared to wood, was confirmed by the experimental observations. In fact, in comparison to the conventional firwood beehives, during January the experimental cork-wooden hives showed a more regular temperature pattern in the nest (brood chamber and side combs) and the ability to restore the optimal thermal conditions more quickly after the opening and closing of the hive, which simulated its management in apiary. Moreover, the temperature variations recorded inside the hives were more dependent on the external temperature variation in the conventional wooden hives than in the experimental cork-wooden hives, where the temperature trend was more constant and in line with the optimal temperatures for brood growth (Winston 1991). The greater thermal insulation capacity of the cork-wooden hives observed in January was less evident in March, when differences in temperature trends between the cork-wooden hives and the conventional firwood hives were not significant. Considering this scenario, it can be hypothesized that bees had to consume greater quantities of honey in the firwood beehives, in order to maintain comparable thermal conditions with those of the experimental cork-wooden hives. Indeed, another interesting effect of hives modified with the use of cork, reported in a previous study (Satta and Floris 2004), concerns a lower consumption of honey during winter by the colonies reared in cork-modified hives compared to those in the firwood hives, probably due to lower heating needs for winter thermoregulation in the cork-wooden hives. In that study, an average amount of approximately 3.5 kg per hive of stored honey was saved in the winter season. Considering the fairly mild environmental conditions in which that amount of honey was saved in the study of Satta and Floris (2004) and the more efficient thermoregulation found in the cork-modified beehives in the present study, there are interesting prospective applications of cork-wooden beehives in more severe climatic conditions. Historical findings on traditional apiculture indicate a widespread use of cork for the rustic hive construction in the Mediterranean area (Floris and Prota 1989, Crane 1999), with some attempts of adoption of this material in initial forms of semi-rational or rational beekeeping (Floris and Satta 2009).

Based on our preliminary results, the combination of cork and wood in the construction of modern hives represents a kind of product innovation since exploiting in synergy the properties of the two materials, consents the enhancement of both in a new application (Wolfslehner et. al. 2019) and could result in an interesting synergy between apiculture and woodland management or forestry. In the Mediterranean areas, the agro-silvo-pastoral system covered by cork oak forests is not only the most widespread but also a very important hotspot of biodiversity (Myers et al. 2000). Currently, this type of ecosystem is threatened, and adequate management and active use by human are required to maintain its existence. The main product of the agro-silvo-pastoral system is cork, but a decline in cork oaks has been observed in sub-western Europe, due to the substitution of this natural material with other types of materials (Bugalho et al. 2011). For this reason, a greater use of cork in the green building sector could have a positive economic and environmental impact.

For example, the production of panels for the construction of cork hives does not require a raw material of particular quality or a different type of management of cork forests. In fact, but the cork used in bee hives, called "granulated", is obtained from secondary products of the cork industry. The exploitation of this "waste resource" is a considerable advantage of this model of beehive, which ecofriendly. In addition, the use of this hive model promotes the sustainable use of Mediterranean agroforestry systems, thus contributing to their conservation, with a positive effect on sensitive species such as the eagle (Mannu et al. 2018). Another added value of this type of agro-forest ecosystem is the maintenance of beekeeping thanks to the availability of resources throughout the year that positively affect the development and health of the colonies (Floris et al. 2016). Moreover, in this context, honey is another resource in balance with the agro-pastoral activities and the forest system to be preserved (Croitoru and Merlo 2005). In conclusion, this new beehive model provides a new possibility for enhancing a non-wood product as cork and improving the performance of hives not only in the forest context. This is in line with the European Union's bio-economy strategies, which support and promote new opportunities for the forestry sector that may arise from the combination of sustainable bio-based materials such as cork and wood (European Commission 2012). Finally, although further studies on a larger number of hives and during a longer time are required, our study demonstrates the effectiveness of cork in the thermal insulation of hives and, consequently, in their thermoregulation.

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