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Modification of a Beehive Warming System Based Upon Peltier Module

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ABSTRACT

The heat requirements for beehive are significant to preserve bee life, increase yield and obtain high honey quality. The increased electricity prices may diminish the honey production net profit. So, this study aims to modify a beehive warming system which operates using a PV panel to reduce bee mortality, improve honeybee colony activity, and enhance the strength and quality of honey. The warming system used based upon the Peltier module theory, operated with solar cells. The Peltier module works with DC power, requiring minimal maintenance and includes ceramic plates for both the hot and cold junctions. The study includes a warming system provided with 1, 2, 3, and 4 Peltier modules, respectively. The results indicate a gradual increase in PV panel output power, peaking at 250 Watts by 11 am and sharply declining to a minimum of 115 Watts by 3 pm. PV efficiency varies, reaching 13.9% at 9 am, dropping to 13.6% by 11 am, and peaking at 15.7% at 3 pm. The occupied frames increased by 4, 8, 11, and 13 frames using 1, 2, 3, and 4 Peltier modules, respectively. While, it decreased from 4 to 3 occupied frames under the traditional warming method. The honey production was 4.1, 5.1, 5.8, and 6.4 kg using 1, 2, 3, and 4 Peltier modules, respectively, opposite 2.8 kg for the non-warming system. The net profit of the modified warming system with 4 Peltier modules was 95.8% higher than that of the traditional warming system.

Keywords: Peltier, Solar system, warming, winter, Honeybee, improvement, bee colonies.

INTRODUCTION

The activity of beehives is affected by some factors that have harmful effects, while others do not harm their biological processes throughout their life. Among these factors, the temperature plays a critical role in influencing brood rearing. Since honey bees are cold-blooded insects, their ability to rear brood is directly influenced by the temperature of their surroundings. Optimal brood performance has been observed at the average optimum temperature of 35°C, as confirmed by Jarimi *et al.* (2020). This constant temperature range is crucial for the best growth and development of the brood (Abd-Elmawgood *et al*., 2015).

The temperature inside the beehive is closely related to the outside temperature, as pointed out by (Rice, 2013). When the surrounding air temperature fluctuates, it can lead to deviations from the ideal temperature range. The honeybees regulate the temperature inside their hives to cope with significant changes in the external environment (Jarimi *et al*., 2020). The failure of proper thermoregulation inside the hive has been linked to weak colonies (Abd-Elmawgood *et al*., 2015).

Preserving the optimal inside environment of beehives during the winter season is crucial for ensuring honeybee health. Traditionally, beekeepers have wintered their apiaries by placing colonies (hives) close together and covering the combs with a piece of sackcloth. However, using thermoelectric devices to provide a heated medium offers an important alternative to the traditional wintering method, enhancing the chances of maintaining suitable and optimum conditions for the bees.

Solar energy can be used as a solar thermoelectric generator. The Peltier effect can be converted into a potential green, eco-friendly, and silent cooler/heater for beehives by providing a DC voltage to both ends of the thermoelectric (Aranguren *et al*., 2019).

Various attempts have been made to address the issue of honeybee colony losses over the winter and to enhance the temperature conditions inside the beehives. Some researchers, like Braga *et al.* (2019) and El-Sheikh *et al.* (2021), developed systems that utilize electrically powered halogen lamps or beehives of various sizes to control the temperature inside the hive. These enhancements reflect continual efforts to enhance the health and productivity of bee colonies, promoting sustainable beekeeping practices and deepening our understanding of effective hive management.

Solar energy is non-polluting, abundant, and available in Egypt for a considerable portion of the year. It can offer solutions to various challenges, including the need for electricity in remote border areas. Egypt's solar resources, as indicated in the solar atlas, are substantial, presenting opportunities for numerous solar energy systems and industries (Moharram *et al*., 2022).

The objective of this research is to improve honeybee colonies' activity, maintain their strength and yield, and achieve effective beehive warming by implementing a new Peltier-based beehive warming system inside the hive.

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MATERIALS AND METHODS

Beehives

Five Langstroth beehives, each housing hybrid Carniolan bees of equal strength, were used all the study duration. The hives had exterior dimensions of 53×43×25 cm, with walls 2 cm thick and removable tops. These beehives had similar strength and contained four combs covered with bees on both sides. The queens were approximately three months old. Throughout the winter, Nosema apis and Varroa destructor infestations were monitored and treated separately as needed. Bees feds with syrup made from two parts granulated sugar and one part water during the study period. The traditional method to warm beehives involved placing them side by side in a sunny location with a narrow spacing, oriented towards the south. Additionally, the combs were covered with pieces of sackcloth for insulation.

Warming system

The warming system consists of three main parts: the warming source, the power source, and the temperature regulator. The warming source comprised a Peltier unit of type (TEC1-12706), a heatsink, and a heat distribution fan, as depicted in Figures 1, 2, and 3.

To heat the interior of the boxes (test beehives), a thermoelectric Peltier module (TEC1-12706) was utilized. This module is the most reliable and commonly used one. It operates with DC power, requiring minimal maintenance and featuring ceramic plates in hot and cold junction surface. The Peltier module is compact, lightweight, vibration-free, and operates silently, making it an ideal fit for bee colonies.

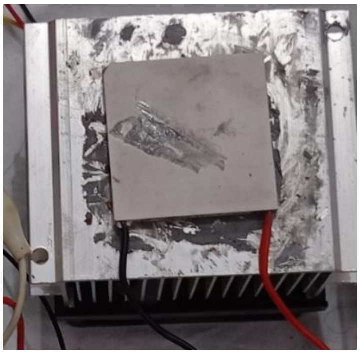

Figure 1. Thermoelectric Peltier module

The specifications for the thermoelectric Peltier module are in Table 1.

Table 1. Thermoelectric Peltier Module specifications.

Peltier model (TEC1-12706)	Description
I max	6A
V max	15.4V
Q max	63W
ΔT max	67°C
Thermocouples (n)	127
Material	Aluminum Oxide
Thickness	0.0038m
Length	0.04m
Width	0.04m
Setback coefficient (α)	$\alpha p = \alpha n = 2.2\times10^{-4}$ V/K
Electrical resistivity (p)	$Pp = \rho n = 1.2\times10^{-2}$ Ωcm
Thermal conductivity (k)	$Kp = Kn = 1.62\times10^{-2}$ W/cmK
Geometric factor, Ge	0.12cm
Length of element, Le	0.20cm

As cited by Totala *et al*., 2014, Figure 2 shows the construction of the Peltier module (P-type and N-type). Semiconductor materials used to manufacture Peltier modules. Each Peltier module consists of a thermocouple, having a pair of P-type and N-type elements. These thermocouples are arranged in series and connected in parallel on the two plates of the Peltier module. To ensure distinct electron densities, two separate semiconductors—one of the N-type and one of the P-type—are employed (Nesarajah and Frey, 2016).

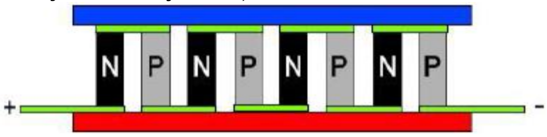

Figure 2. Peltier module structure (Totala *et al*., 2014)

The hot junction of the thermoelectric plate is connected to an aluminum heat sink using thermal paste. The thermal paste prevents the heat transfer losses between heat sink and the thermoelectric module (Khoukhi and Jassim, 2012). The heat from the aluminum heat sink's fins is dissipated through the radiator fan. Heat sinks are highly valued for their superior heat transfer capacity and efficiency per unit volume. The extruded fin heat sink is particularly popular due to its affordability and ease of production (Lian-Tuu Yeh, 2012).

1- Peltier module **2- Aluminum heat sink's fins** **3- The radiator fan**

Figure 3. The warming source

As depicted in Figure 4, the power source comprises the solar panel, the battery, the electric current regulator for charging the battery, and the DC-to-AC converter.

The power source includes a solar panel with the following specifications: rated maximum power: 250 W, voltage at Pmax: 30.5 V, current at Pmax: 8.2 A, open-circuit voltage: 37.8V, short-circuit current: 8.85 A, weight: 18 kg, and dimensions: of 1640×992×40 mm. The solar panel is fixed at a 30° slope relative to the horizontal plane. A solar charger controller is placed between the solar panel and the battery to regulate the voltage from the solar panel.

The temperature regulator comprises an Arduino electronic circuit that can be controlled using setting buttons and includes a temperature sensor to regulate the unit's internal temperature, as illustrated in Figure 5.

1- **Solar panel** **2- The battery** **3- Solar charger controller** **4- Converter.**

Figure 4. The power source

Figure 5. The temperature regulator

To achieve the temperature regulation and controlling the temperature flow in the Peltier heating system, specific controller circuits are employed. Temperature sensors (W1209) are used to maintain a fixed temperature inside the beehive at 22±1°C and turn off the system when it is needed. The controller utilizes temperature information from the sensor to regulate the power supply to the Peltier module. The controller circuit usually operates on a 12 V DC supply.

The electric circuit diagram of the entire warming system is illustrated in Figure 6.

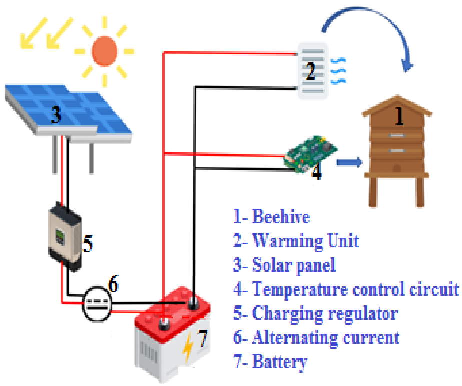

Figure 6. Circuit diagram

Solar irradiation variation throughout the day significantly impacts system efficiency. The influence of solar irradiation variation on system efficiency can be elucidated by examining the correlation between solar irradiance (intensity of sunlight) and the power output of photovoltaic (PV) panels. Solar irradiance directly dictates the amount of energy that can be converted into electricity by the PV system The details of Solar irradiation during the experiments are shown in Figure 7.

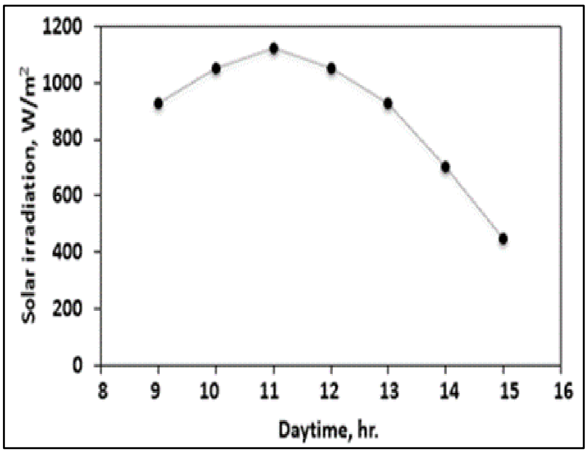

Figure 7. Mean solar irradiation during the daytime.

Figure 8 shows the average maximum and minimum ambient temperatures around beehives from December 2022 to February 2023.

Figure 9 shows data on average temperatures inside a control beehive during a three-month period from December 2022 to February 2023.

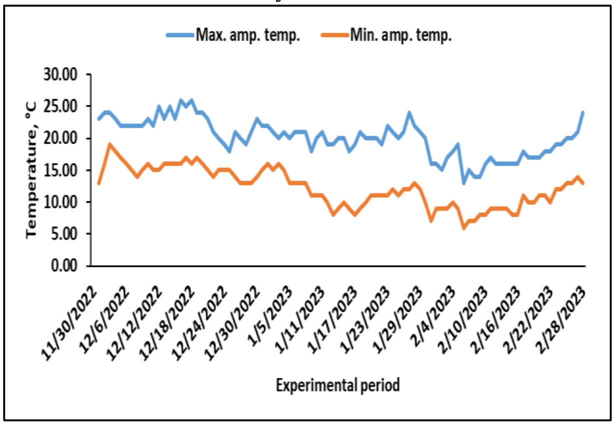

Figure 8. The average maximum and minimum ambient temperature around beehives

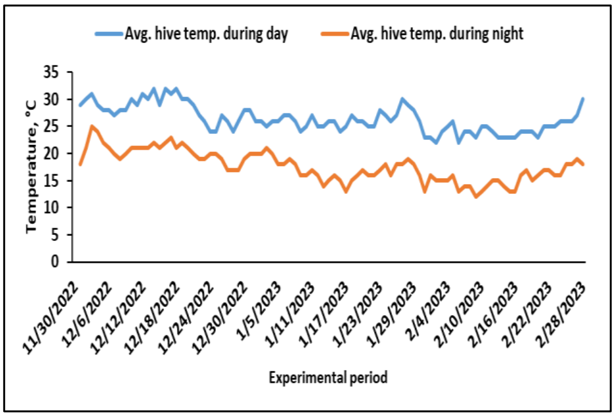

Figure 9. The average inside control hive temperature during day and night

Experimental procedure

The experiments were conducted in a private apiary located in El-Salihia village, El-Sharqia Governorate, Egypt, at geographic coordinates 30.782178, 32.010380, during the winter season of 2022-2023. The warming system consisted of four setups: the first contained one Peltier module, the second had two Peltier modules, the third had three Peltier modules, and the fourth had four Peltier modules. When the internal temperature drops below 21 ºC, worker bees tend to cluster around the brood, as reported by Altun (2012), who found optimal performance between +21 and +35 ºC. Maintaining this temperature range is crucial for creating an ideal environment for hive activities. Consequently, a thermoelectric warming system has been implemented. The experiments were conducted with this fixed set temperature, and the performance of the Peltier-based beehive warming system was evaluated.

Measurements included recording the electrical power consumed by the Peltier module and the fan. The power is calculated using a voltage/ampere meter to obtain voltage and current values and apply the formula

W = VI × t. (Afshari, 2020).

The effectiveness of the solar module η was calculated using the formula (Hussain, *et al.*, 2015):

$$\eta = P\_max / (E \times A) \ ... \ (1)$$

where:

- P_max: represents the maximum power output in watts (W).
- E: stands for the available global irradiance in watts per square meter (W/m²).
- A: denotes the surface area of the solar PV module in square meters (m²).

The total operating time for Peltier modules throughout the day over a three-month period, from December 2022 to February 2023, was calculated by summing their durations over the specified period.

The total power consumption (P, kWh/day) was calculated by using the following formula

$$P = \frac{N \times Q_{max} \times t}{60}$$

where:

- N: is the number of Peltier modules.
- Q_{max} : is the energy consumption per Peltier module in kW.
- t : is the total operating time in minutes per day.

Each colony was monitored every 10 days throughout the testing period, and empty new combs were added when necessary. The number of new occupied frames was also recorded, and the amount of honey produced from each hive was measured. The experiment was conducted on the following dates throughout the winter season: 10th, 20th and 30th December, 9th, 19th and 29th January and 8th February, 8th, 18th and 28th February.

The cost analysis in this study was conducted by considering both the initial cost and annual depreciation of the warming system, as well as input and output costs for honeybee products based on the Egyptian market prices.

The data were edited and graphs were created using MS Excel program 2016 (Microsoft Corporation, Redmond, WA, USA).

RESULTS AND DISCUSSION

PV output power

The PV panel's output power increases gradually from 9 Am to a peak of 11 Am (250 Watt) due to higher solar radiation (Figure 10). However, in the afternoon, the power decreases sharply to a minimum of 115 Watts by 3 pm as solar radiation declines.

The trend indicates a peak in power output around midday, with decreasing output in the morning and late afternoon. This pattern aligns with expectations based on solar irradiance variations throughout the day. Understanding such trends is crucial for optimizing energy utilization and system design. Further analysis could focus on factors influencing variability, such as weather conditions, to enhance the reliability and efficiency of solar energy systems.

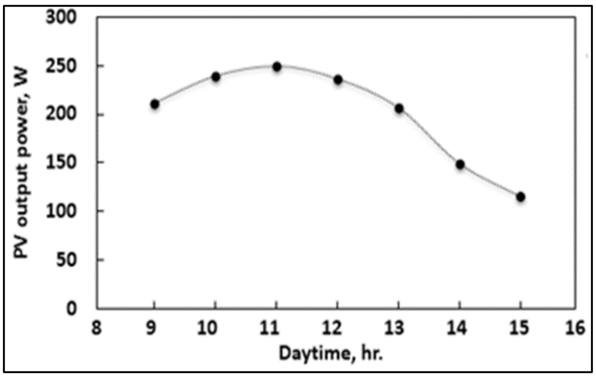

Figure 10. Mean PV output power during the daytime.

PV efficiency.

Figure 11 shows the hourly efficiency varies, with a morning efficiency of 13.9% at 9 am, a slight decrease to 13.6% at 11 am, and a significant afternoon surge to 15.7% at 3 pm.

The trend indicates fluctuations, albeit within a relatively narrow range. The highest efficiency is observed around midday, with a slight decrease in efficiency during the morning and late afternoon. This pattern is intuitive, as solar panels typically exhibit higher efficiency when exposed to direct sunlight, which peaks around noon.

Analyzing the efficiency trends can provide valuable insights into the performance of the PV system throughout the day. Understanding when the system operates most efficiently can help optimize energy generation and utilization strategies. For example, energy-intensive tasks could be scheduled during peak efficiency hours to maximize utilization of solar-generated power.

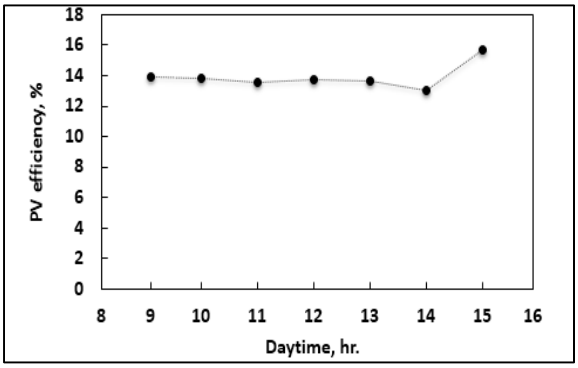

Figure 11. Mean PV efficiency during the daytime.

The Peltier modules number via total operating time

Data in Figure 12 reveal a noticeable trend where the total operating time changes in response to the number of Peltier modules used. In December, as the number of Peltier modules increases from 1 to 4, there is a consistent decrease in the average total operating time. The values were 878.02±123.29 min/day, 656.73±143.8 min/day, 477.63±104.57 min/day, and 404.09±88.47 min/day when using 1, 2, 3, and 4 Peltier modules, respectively. This decrease in total operating time indicates that using multiple Peltier modules results in more efficient temperature regulation during this month.

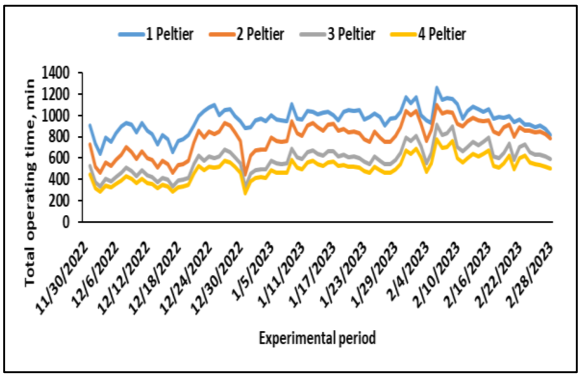

Figure 12. Effect of Peltier module numbers on the total operating time

A similar trend is observed in January, with the average total operating times being 998.13±57.24 min/day, 819.15±90.62 min/day, 594.97±69.75 min/day, and 504.23±59.11 min/day when using 1, 2, 3, and 4 Peltier modules, respectively. Once again, the data suggests that utilizing a higher number of Peltier modules leads to reduced total operating time during this month.

In February, the trend persists, with average total operating times of 1014.20±106.77 min/day, 913.40±86.30 min/day, 705.80±93.58 min/day, and 599.90±79.78 min/day recorded when using 1, 2, 3, and 4 Peltier modules, respectively. This indicates that the relationship between the number of Peltier modules and the total operating time is consistent even as environmental conditions may change over the course of the three months.

The Peltier modules number via power consumption

Data presented in Figure 13 indicate a clear positive relationship between the number of Peltier modules and the power consumption throughout the winter months. In December, the average total power consumption exhibited an ascending trend as the number of Peltier modules increased. The power consumption increased from 0.92±0.13 to 1.7±0.4 kWh/day as Peltier modules increased from one to four. This trend highlights the increasing power demands with higher Peltier module counts during the coldest period of the year.

Moving into January, the power consumption continued to rise with an increase in the number of Peltier modules. The average daily power consumption ranged from 1.05±0.06 kWh/day for a single Peltier module to 2.12±0.25 kWh/day when utilizing four Peltier modules. This escalation in power consumption can be attributed to the need for greater heating capacity to combat the lower temperatures in January.

The trend observed in February followed a similar pattern. As the winter persisted, the heating systems' power consumption surged in response to the prevailing cold weather conditions. The average daily power consumption ranged from 1.06±0.11 kWh/day when using one Peltier module to 2.52±0.34 kWh/day with four Peltier modules. The consistent increase in power consumption signifies the importance of additional Peltier modules in maintaining an adequate heating level during the coldest period of the winter.

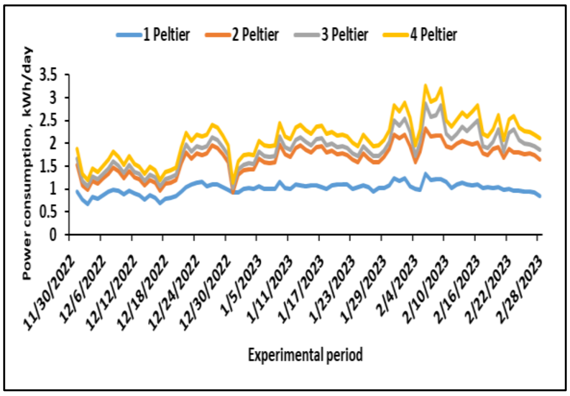

Figure 13. Effect of Peltier module numbers on power consumption, kWh/day

The Peltier modules number via the number of occupied frames

One key observation is that as the test period increased, the number of occupied frames consistently increased for all hives equipped with Peltier modules. In contrast, the control hive experienced a decrease in the number of occupied frames, dropping from 4 to 3 occupied frames by the end of the test period (Figure 14). This decline in hive occupancy in the control hive may be attributed to factors such as temperature fluctuations or inadequate thermoregulation mechanisms.

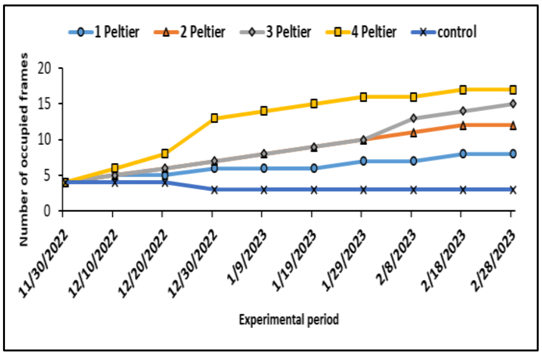

Figure 14. Effect of Peltier module numbers on occupied frame numbers

The number of occupied frames in hives employing the Peltier modules warming system demonstrated a clear proportional relationship with the test period's duration. With each passing day, the number of occupied frames gradually rose, reaching 5, 12, 15, and 17 frames at the end of the test period for hives using 1, 2, 3, and 4 Peltier modules, respectively. This trend suggests that the Peltier modules' consistent heating maintained favorable conditions within the hives, attracting and encouraging more bee workers to occupy and inhabit the frames.

A notable finding is the net gain in the number of occupied frames observed in hives using the Peltier modules. Compared to the control hive, which experienced a net loss of 1 occupied frame, the hives employing Peltier modules gained 1, 8, 11, and 13 occupied frames with 1, 2, 3, and 4 Peltier modules, respectively. This indicates that the warming system positively impacted hive population growth, leading to higher levels of hive occupation and likely contributing to increased overall colony health and productivity.

The observed increase in hive occupancy in the treated hives can be attributed to the Peltier modules' ability to maintain optimal nest temperatures. As the Peltier modules provided consistent and controlled warming, the need for worker bees to engage in thermoregulation activities decreased. Consequently, more worker bees were available to focus on essential tasks, such as nurturing brood cells, resulting in a more significant brood area growth in the hives using Peltier modules warming system.

The observed similarities between these findings and the results reported by Gene et al. (1999) support the validity of the current study's outcomes and suggest that the use of Peltier modules as a warming system can indeed positively influence brood area growth and hive occupancy in bee colonies.

The Peltier modules number via citrus honey yield

The results presented in Figure 15 indicate the positive relation between the citrus honey yield and number of Peltier modules. Data showed that utilization of Peltier modules warming system achieve higher honey yield than that of the control hive. Data presented in Figure 15 demonstrate that the control hive produced a total yield of 2.8 kg of honey at the beginning of spring. In contrast, hives equipped with Peltier modules showed significantly higher honey yields. Using 1, 2, 3, and 4 Peltier modules, achieved honey yield of 4.1, 5.1, 5.8 and 6.4 kg/hive, respectively. This notable increment in honey production indicates the substantial positive impact of Peltier modules warming systems on the overall yield of the bee colonies.

The fluctuations in ambient temperature during the study likely played a crucial role in influencing honey production in the colonies. Peltier modules provide a controlled warming effect, which helps stabilize the temperature around the brood area. This stable and warmer climate is beneficial for the bees, as it enhances their activity and overall yield.

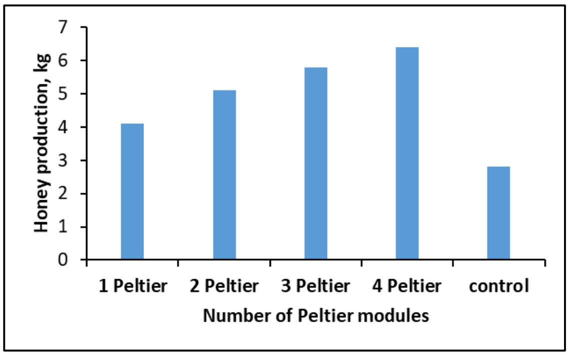

Figure 15. Effect of Peltier module numbers on citrus honey yield

Cost analysis

The warming system total costs in 2022 was about US 371.2 $. The cost analysis considered the annual depreciation of the heating unit and overall input and output costs. The study determined the solar energy unit's average lifespan as 25 years, resulting in an annual depreciation of US 14.8 $ based on the initial heating unit cost of US 371.2 $. Net profits for the warming system were calculated by considering expenses such as maintenance, sugar syrup, foundation sheets, treatments, labor, and antiseptics, and comparing them to earnings from honeybee product sales (Table 2).

Table 2. The input and output costs for honeybee products based on market prices.

Number of Peltier modules	Costs			Total costs	Earnings			Total earnings, USA $	Net Profit, USA $
	Sugar cost, USA $	Other costs, USA $	Cost of solar heating system USA $/year		Honey earn, USA $	brood comb price, USA $	Other products cost, USA $		
1	2.94	2.26	1.48	6.68	17.2	3.55	2.74	23.5	16.82
2	2.45	2.58	2.97	8	21.4	28.4	3.13	52.9	44.9
3	2.16	3.07	4.45	9.68	24.34	39.06	4.07	67.46	57.78
4	2.03	3.71	5.94	11.68	26.86	46.16	5.46	78.47	66.79
Control	3.8	1.9	0	5.7	11.7	0	2.3	14	8.3

***Price of citrus honey of 2023 season is US 4.2 $/kg**
***Price of brood comb covered with bees from two sides of 2023 season is US 3.55 $/kg**
***Other products include Royal jelly, propolis, pollen, wax… etc.**
***Other costs include foundation sheets, treatments, labors, antiseptics …etc.**

The results showed that the warming system generated net profits ranging from US 16.8 $ to US 65.8 $, primarily due to increased colony yield and performance. The warming system positively impacted colony health, brood area growth, and honey yield, leading to higher revenue from honeybee product sales. Net earnings from the warming system outperformed those of the control colony by a substantial margin, ranging from 101.9% to 609.3%.

CONCLUSION AND RECOMMENDATION

From the results it can concluded that the number of occupied frames increased by 4, 8, 11, and 13 frames using 1, 2, 3, and 4 Peltier modules, respectively. While, it decreased from 4 to 3 occupied frames under the traditional warming method. The honey production was 4.1, 5.1, 5.8, and 6.4 kg using 1, 2, 3, and 4 Peltier modules, respectively. While, it was 2.8 kg without a warming system. The warming system net earning was 609.3% more than the control colony.

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تعديل نظام تدفئة لخلية النحل اعتماداً على وحدة بلتيير

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الملخص

تعتبر الاحتياجات الحرارية لتربية النحل عنصرا هاما للحفاظ على حياة النحل، وزيادة الإنتاج، والحصول على نوعية عسل جيدة. لذلك، يهدف هذا البحث إلى دراسة نظام تدفئة خلايا النحل باستخدام الطاقة الشمسية كبديل عن الطاقة الكهربية. يستند نظام التدفئة المستخدم على استخدام وحدة بلتيير، تعمل بالخلايا الشمسية. تستمد الطاقة من التيار المستمر. يتضمن البحث نظام تدفئة مزود بـ ١، ٢، ٣، و٤ وحدات بلتيير. أظهرت النتائج زيادة تدريجية في القدرة الخارجة من لوح الطاقة الشمسية، حيث تصل إلى ذروتها عند ٢٥٠ وات في الساعة الحادية عشر صباحًا وتنخفض بشكل حاد إلى الحد الأدنى عند ١١٥ وات بحلول الساعة الثالثة بعد الظهر. كذلك كفاءة لوح الطاقة الشمسية تتغير، حيث تصل إلى ١٣,٩% في الساعة التاسعة صباحًا، وتنخفض إلى ١٣,٦% بحلول الساعة الحادية عشر صباحًا، وتصل إلى ذروتها عند ١٥,٧% في الساعة الثالثة بعد الظهر. كما كان عدد البراويز المغطاة بالنحل زادت بمقدار ٤، ٨، ١١، و١٣ إطارًا باستخدام ١، ٢، ٣، و٤ وحدات بلتيير على التوالي. في حين أنها انخفضت من ٤ إلى ٣ إطارات مشغولة باستخدام الطريقة التقليدية للتدفئة. وكان إنتاج العسل ٤,١، ٥,١، ٥,٨، و٦,٤ كجم/خلية باستخدام ١، ٢، ٣، و٤ وحدات بلتيير على الترتيب ، بينما كان ٢,٨ كجم/خلية باستخدام الطريقة التقليدية للتدفئة. كانت الأرباح الصافية لنظام التدفئة المعدل بـ ٤ وحدات بلتيرية أعلى بنسبة ٩٥,٨٪ من الخلايا المدفأة بالطريقة التقليدية.