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Using Sensing Technology Inside Beehive to Determine the Optimal Conditions Affecting the Demand for Bee (*Apis mellifera L.*) Venom Collector Device

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Abstract
This study aims to monitor changes inside the beehive in temperature (T_{in}) and relative humidity (RH_{in}) and their relationship to bee venom productivity (VP). Also, tested stimulation lights at a later time. This was done by setting up a bee monitoring system (BMS), which contains a bee venom collector device (BVCD). Therefore, the raw data of T_{in} and RH_{in} were collected 5 min before the device started and 20 after the device ran (25 min total) at three levels of colony strength (CS) (4, 6, and 8 frames covered with bees), twice collection and two periods of collection (day and night) during the autumn season. The results were revealed at BVCD off, and the T_{in} was returned to the natural T_{in} in about 5 min. But, the effect of RH_{in} was evident in the disturbance on the level of bee RH_{in} in 6 and 8 frames. While running BVCD, the T_{in} was rearranged and it was related to CS. The number of collection times and the CS were important factors effects on T_{in}, T_{max}, and VP. Regression models that could be used to express the relationship existing between Tin and Time, and between VP and T_{max}. Before running BVCD, the bees to get rid of the effect of opening the beehive to put the BVCD device need about 5 min to get T natural. As There is impairing the regulation of the RH_{in} the beehive. Run BVCD in the beehive led to an increased T_{in} of all treatments because the colony becomes stressed. In addition, the T_{in} was correlated with the CS. The venom productivity was correlated with T_{max}. The productivity at night was higher than during the day.

Keywords: *Beehive Environment, Bee Venom Collector, Sensors, Temperature, Relative Humidity, Arduino.*

Nomenclature and abbreviations		
BMS	:	Bees monitoring system
BVCD	:	Bee Venom Collector Device
CS	:	Colony Strength
PB	:	Precision beekeeping
Rh	:	Relative humidity
Rh_{max}, $Rh_{in,}$ and Rh_{out}	:	the maximum, inside, and outside relative humidity respectively
T	:	Temperature
T_{max}, $T_{in,}$ and T_{out}	:	the maximum, inside and outside temperature in a beehive respectively

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I. INTRODUCTION

Honey bees (*Apis mellifera L.*) are the most economically important managed insects **(Aizen and Harder 2009)** as significant pollinators, and the importance of honeybee products (venom, wax, royal jelly, propolis, honey, and pollen grains) **(Wang et al., 2014).** On the one hand, international venom consumption is growing **(García 2018),** but on the other hand, the numeral of bee colonies is declining **(Kviesis et al., 2020).** Beekeeping practices offer a source of economic products such as beeswax, honey, and bee venom **(Dolgov et al., 2017). Moritz and Erler (2016)** noted that mortality rates have reached 35% globally, and 44% in the U.S.A.

Multiple combinations of factors could explain the mass extinction of bees or CCD (Colony Collapse Disorder) phenomena observed internationally. To deal with these problems, ordinary beekeeping should be combined with modernizations and technologies. Under precision apiculture or precision beekeeping (PB), the high-tech solutions and their implementation for bee colony actual time monitoring are summarized. The PB is a

management strategy that relies on monitoring individual honey bee colonies using a group of devices to reduce resource consumption to a minimum and increase productivity **(Zacepins et al., 2012 & Zacepins, 2012)**. Similar to the precision agriculture concept, PB is based on a three-stage cycle: data collection, data analysis, and application. Data collection or the monitoring of beehives can supply significant and up-to-date information about the state of the beehive. Data acquired from monitoring requires complicated analysis and which would be a long time when carried out manually **(Zacepins et al., 2015 & Kviesis et al., 2020)**. So, PB systems should be improved by choosing appropriate combinations of different sensors, and conforming decision support systems that provide convenient, reliable, and cost-efficient solutions. The development of a PB system should consider commercial interests, probable risks, and other peculiarities **(Zacepins and Stalidzans 2013 & Rumman et al., 2021)**. PB aims to minimize the stress and needless activities of beehives as well as reduce resource waste. This is reached through the timely and beekeepers' adequate reaction at the individual colony level in necessity cases. Replace beekeepers is not the aim of the solution, but rather to support them, who will always remain the critical factor in the good management of beehives **(Zacepins et al., 2015).**

Since honey bees are one of the most important insects in the whole world, it is important to follow their life to preserve them from danger. That is possible to use new technologies as projects e.g., monitoring systems, data processing, and data analysis to recognize any anomaly inside the beehive at a premature stage **(Kviesis et al., 2020).** These projects will enable the application of PB in the future, but there are still many challenges to the productive operation of PB in beekeeping practices **(Zacepins et al., 2015).** From several research and commercial products regarding bee monitoring in PB. The beehive monitoring and actual-time data collection is the most developmental stage. Monitoring should be possible to detect the colony state in swarming and death, etc. Such information is decisive for colony management to reach the aims of PB **(Kviesis et al., 2020).**

The method of using electric shocks to extract their venom from honey bees was first described by **(Marković and Mollnar 1954)**. There are different models. Typically, the voltage is between 24 and 30 V, the pulse lasts between 2 and 3 s, there is a 3 to 6 s gap, and the pulse frequency is between 50 and 1000 Hz. 150 mg of honeybee venom can be collected after three hours of harvesting. One gram of bee venom may be yielded over two hours from 20 colonies. Four grams of dried bee venom can be acquired if venom is collected three to four times each month between April and October. Accordingly, the price to pay is a 10 to 15% reduction in brood activity and honey production. Bee productivity is unaffected by less frequent harvesting (3 to 4 times a season) **(Sacchini et al., 2023)**. **De Graaf, et al., (2021)** noted that bee venom is collected in two ways (external and internal), based on where the device is put. When the collector is placed in the beehive, the whole colony becomes stressed, work is interrupted, and the temperature inside the beehive increases to dangerous levels. This could be very destructive through summer. The less harmful way is putting the collector of bee venom outside the beehive, by the entrance, which avoids unfavorable impacts.

The quality of bee venom is highly dependent on the production method, environmental factors (temperature, relative humidity), and harvest time **(Zidan et al., 2018 & Hussein et al., 2019)**. The use of temperature data is a prerequisite for each proposed model for honey bee colony state identification. **Zacepins and Karasha (2013)** reviewed some applications of temperature sensors for monitoring systems of beehives. That can provide a beekeeper with real-time data about the bee colony's behavior. Based on temperature data, beekeepers can detect such colony events as increased food consumption, the start of brood rearing, recognition of the pre-swarming state, or the bee colony death. Without enough data analysis, it is not possible to get added value from different bee colony monitoring systems **(Gratzer and Brodschneider 2018).**

This research focuses to study the honeybee colony to detect changes in temperature and relative humidity data and their relationship with bee venom productivity through using the bee venom collector device.

II. MATERIALS AND METHODS

The study was carried out at Agricultural Research Centre (ARC), Plant Protection Research Institute (PPRI), Bee Research Department, Giza (latitude 30.046356° N, longitude 31.207320° E and altitude 18 m above sea level), in September 2022.

Bees

This collection experiment was carried out on Craniolian hybrid (*Apis mellifera L.*) bees. The monitoring system was set up to continue on six beehives through the autumn of 2022. Colonies were placed in Langstroth-type hives made of wood with external sizes 510, 410, and 270 mm and internal sizes 485, 385, and 250 mm, with a wall thickness of 25 mm.

Bee Venom Collector Device (BVCD)

Bee venom was collected from colonies by Bee Venom Collector Device (BVCD). The specifications of the BVCD components (Electric shock device, VC-6F, Apitronic, Canada) were shown in Table 1.

Table 1: The specifications of BVCD

Input DC Voltage & Currant, V & A	Timer, s		Collector Frames, m	Operation Mode	Temp., ˚C	Humidity (max). % (at 40 ˚C)	Max operating time, h
	ON	OFF					
11.5-12.75 & 0.15	0.5 - 2	3 -5	0.5 × 0.4	Semi-automatic	-5: 40	95	8

The bee venom collection was conducted by the device. The collector frame was connected with wires to the collector device and the collection time is 20 minutes at every collection treatment. During this period, the device is working automatically and supplies preset impulses to the wire grids. The collector frame was removed from the bee colony. Then, the deposit of bee venom on the glass plate was scrapped using a scraping knife

Bees Monitoring System (BMS)

The monitoring unit was made from wood, which contains two (top and bottom) frames. The top frame is wooden. It has the stimuli holder to it from the top under a piece of wood. It is placed directly below the beehive cover and on top of the BVCD, as in Figure 1. While the bottom frame is wooden. It was placed directly above the beehive box to install the sensors.

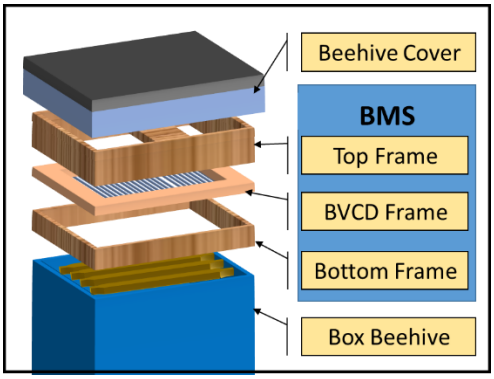

Figure 1: Installation method in the beehive of BMS

The two frames are assembled as shown in Figure. 1 and Figure. 2. They were placed under the cover of the beehive to avoid sunlight during the day or external influences at night.

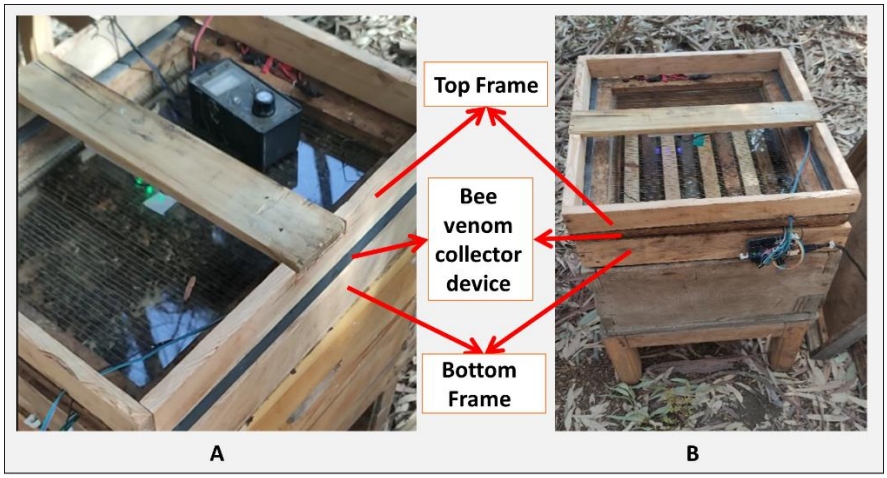

Figure 2: A and B photos of BMS components.

BMS was set up as a platform for monitoring temperature and relative humidity inside the beehive after putting it. Before that, it Record the temperature and relative humidity outside before putting on the beehive, to assess their influence on venom production (VP).

The electronic monitoring system was based on the approach proposed by **(Catania and Vallone 2020)**, as shown in Figure.3. The BMS consists of an Arduino Mega (ATMEGA2560, Arduino, Italy) microcontroller,

and a wired sensor network, that is divided into two groups. Each group is placed on a separate wooden frame, as shown in Figure 2, Figure 3. The first group is stimulating, it is installed in the middle of the stimuli holder on the top frame and placed facing the BVCD. It consists of an array of RGB LEDs (Red, green, and blue light-emitting diodes) five units. The second group is the sensing group, which was two sensors were installed on the edges of the bottom frame from the inside. The first was the HDT11 sensor to measure temperature and humidity, and the other sensor was the BMP180 to measure temperature. By installing them on the frame in opposite positions on the inside of the frame.

It is connected to a PC via a USB carrier cable. The BMS is set up as a measuring device to collect data and transfer it to MS Excel spreadsheet every 3 s. The data were acquired and tracked using a PC connected to the Arduino Mega as Figure 3.

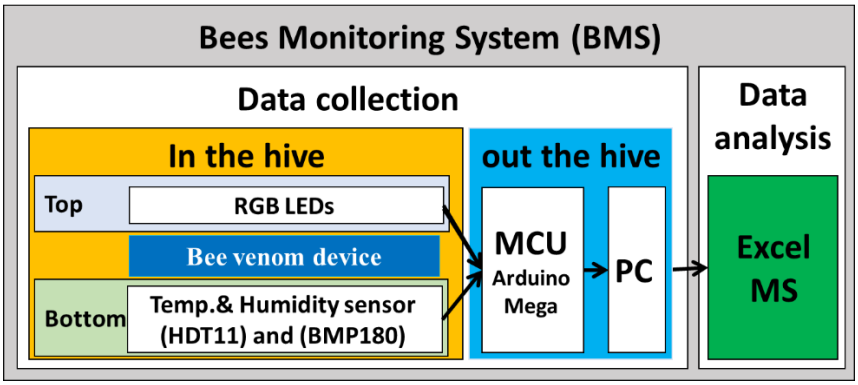

Figure 3: Stages of study and components of (BMS)

Data set

The data set or raw data set is used for further processing and analysis, it consists of temperature data (T1 of HDT11, and T2 of BMP180), and relative humidity (RH) inside the beehive during the BVCD OFF/ON that is taken every 3 s. The raw data set also included the date, time, and bee venom productivity. After that, the raw data set was divided into different groups-based beehive conditions and colony strength. Then, each measurement is isolated separately from the raw data file for analysis as a flowchart in Figure 4.

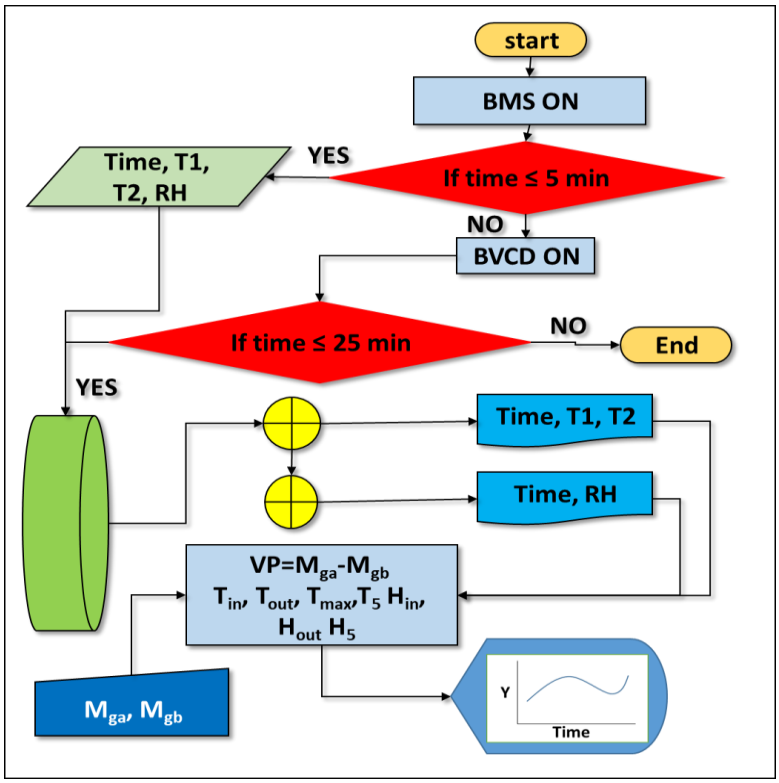

Figure 4: Flowchart of BMS.

MS Excel software was relied upon to analyze the data, as the data was transferred from the microcontroller to the worksheet on MS Excel (2021). Then, each reading was isolated with its time separately in a separate worksheet to perform the analysis for each colony separately. The reading was taken 5 min before the device started and 20 min after running the BVCD (25 min total). Then the values of temperature (T_{out}, T_{in}, and T_{max}) and relative humidity (Rh_{out}, Rh_{in}, and Rh_{max}) were gotten, and found the Regression models between T and RH with time, And between VP with T_{max} During the monitoring period, the date, approximate time, and colony ID were recorded to observe bee swarms and other bee activities. Therefore, researchers' observations were considered real field observations.

Experimental procedure

Only two steps in this study were followed **(Zacepins et al., 2015 & Kviesis et al., 2020)**. The first step is data collection and the second is interpretation of the data depending on measurements (temperature(T), and relative humidity (RH)). T and RH provide the necessary information about honeybee colonies using the BVCD, which is difficult to conduct manually as Figure 3. The temperature was measured by two sensors (HDT11 and BMP180) for each colony inside the hive above the bee's frames.

The bee venom collection was implemented in six honeybee colonies three of them during the day and another three at night and three CS (4 - 6 - 8 frames), all of them had venom collected twice with an interval of two weeks as shown in Table 2. Then, four types of stimulation lights of bees (red, blue, green, and white light) were carried out under all treatments as in flowchart Figure 4.

Table 2: Distribution of experimental treatments

Treatments, Code	Time of collecting	Colony strength (CS), frames.	1st time	2nd time
4f1d	Day	4	Yes	No
4f2d	Day	4	No	Yes
6f1d	Day	6	Yes	No
6f2d	Day	6	No	Yes
8f1d	Day	8	Yes	No
8f2d	Day	8	No	Yes
4f1n	Night	4	Yes	No
4f2n	Night	4	No	Yes
6f1n	Night	6	Yes	No
6f2n	Night	6	No	Yes
8f1n	Night	8	Yes	No
8f2n	Night	8	No	Yes

Measurements

For all experiments, measurements were obtained directly in real-time for each of relative humidity (%) and temperatures (°C), with inside and outside beehive under BVCD On/Off by using BMS. Then calculate bee venom productivity (VP), which was collected from each colony separately and weighted (mg) directly after finishing the experiments as follows equation.

$$\mathbf{VP = M_a - M_b}$$

Where VP: Bee venom productivity, M_a: Mass after collection, M_b: Mass before collection.

III. RESULTS AND DISCUSSION

The temperature at day:

Figure 5 and Figure 6 represent the temperature inside the beehive (T_{in}) BVCD on/off under three levels of CS (4, 6, and 8 frames) at 1st and 2nd time of collection.

BVCD-off mode, the results revealed that the T_{out} (30.5 °C: 35 °C) of beehives increases to the normal T_{in} (34,5 °C: 36 °C) during 5 min. Compatible with (**Jarimi et al., 2020**) results. Except for the beehive (8) frame was increased over the normal of T_{in} in 2nd collection, it was increased to 38.6 °C. This might be a result of the

bees clustering together on the device and an increase in ambient temperature. There were more obvious signs of the internal temperature rising than usual.

BVCD-on mode, the values of T_{in} were rearranged in a way that was related to colony strength (CS). The maximum temperature in the beehive (T_{max}) during a 20 min of device run was 37.3, 39, and 39.6 °C at the 1st time and 38.8, 39.5, and 40.8 °C at the 2nd time at 4, 6, and 8 frames of a beehive, respectively. The value of T_{max} increases with the increase of the CS. In addition, the T_{max} increased at 2nd collection time compared to the 1st collection. The results supported those of (**De Graaf et al., 2021**) and showed that the T_{in} of the beehive was influenced by the number of collections and CS critical factors.

At the multiple regressions, the relationship between each of T_{in} and CS to 1st & 2nd collect at the time (s) at BVCD-on mode. A description of the formula along with the coefficients for each factor is provided below as well:

$T_{in} = -6\times10^{-6}S^2 + 0.0126S + 36.32$ (R^2= 0.98) at 8f1d.
$T_{in} = -6\times10^{-6}S^2 + 0.0090S + 35.70$ (R^2 = 0.97) at 6f1d.
$T_{in} = -1\times10^{-6}S^2 + 0.0016S + 36.55$ (R^2 = 0.76) at 4f1d.
$T_{in} = -4\times10^{-6}S^2 + 0.0055S + 39.03$ (R^2= 0.82) at 8f2d.
$T_{in} = -8\times10^{-6}S^2 + 0.0105S + 36.30$ (R^2 = 0.78) at 6f2d.
$T_{in} = -7\times10^{-6}S^2 + 0.0089S + 36.17$ (R^2 = 0.82) at 4f2d.

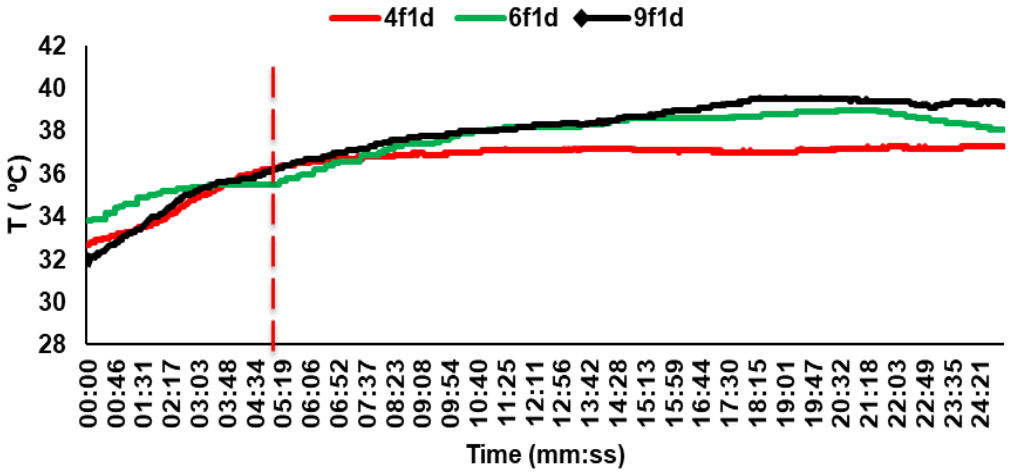

Figure 5: Temperature under using BVCD on/off in beehive 1st collect at day.

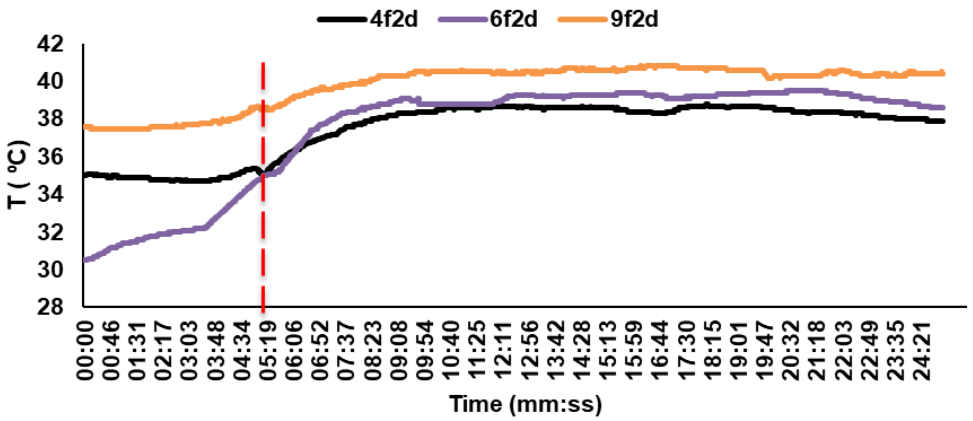

Figure 6: Temperature under using BVCD on/off in beehive 2nd collect at day.

The temperature at night:

Figure and Figure 8 show the T_{in} of beehive before and after BVCD-on under three CS (4, 6, and 8 frames) at the 1st and 2nd collections.

BVCD-off mode, the results revealed that the T_{in} of beehive increased by increasing CS from an average T_{out} of 28.13 °C to T_{in} 30.3, 30.5, 31.4, 32.3, 35.1, and 35.3 °C after 5 min of BVCD-off mode under 4f1n, 4f2n, 6f1n, 6f2n, 8f1n and 8f2n, respectively. The bees might be better able to get rid of the effect of opening the beehive to

install the BVCD and changing the internal temperature if CS is increased. As well as, the T_{in} was returned to the normal temperature inside the beehive in a short time, and the results were compatible with (**Jarimi et al., 2020)**.

BVCD-on mode, the T_{max} were 34.1, 35.6, and 39.4 °C at the 1st collection time and 36.1, 36.8, 39.6 °C at the 2nd collection time for 4, 6, and 8 frames of the beehive, respectively. During 20 min of running the device, the T_{in} values were related to the CS, where it increased with the CS increases. The T_{max} increased at the 2nd collection time compared with the 1st collection. The results showed that the number of collection times and CS were important factors affecting on T_{in}. The values of T_{in} were increased in all treatments. This may be because the BVCD is located internally in the beehive that has become a stressed colony, and that was according to (**De Graaf, et al. 2021)**.

At the multiple regressions, the relationship between the time of running the device in BVCD-on mode and each of T_{in} and CS at the 1st & 2nd collection time(s). Also, the formula with the coefficient of each factor can be described as:

$T_{in} = -9\times10^{-6}S^2 + 0.0119S + 35.37$ (R^2= 0.85) at 8f1n.
$T_{in} = -8\times10^{-6}S^2 + 0.0105S + 32.03$ (R^2 = 0.79) at 6f1n.
$T_{in} = -9\times10^{-6}S^2 + 0.0101S + 31.15$ (R^2 = 0.81) at 4f1n.
$T_{in} = -7\times10^{-6}S^2 + 0.0082S + 36.88$ (R^2 = 0.75) at 8f2n.
$T_{in} = -7\times10^{-6}S^2 + 0.0108S + 32.90$ (R^2 = 0.91) at 6f2n.
$T_{in} = -5\times10^{-6}S^2 + 0.0097S + 31.30$ (R^2 = 0.95) at 4f2n.

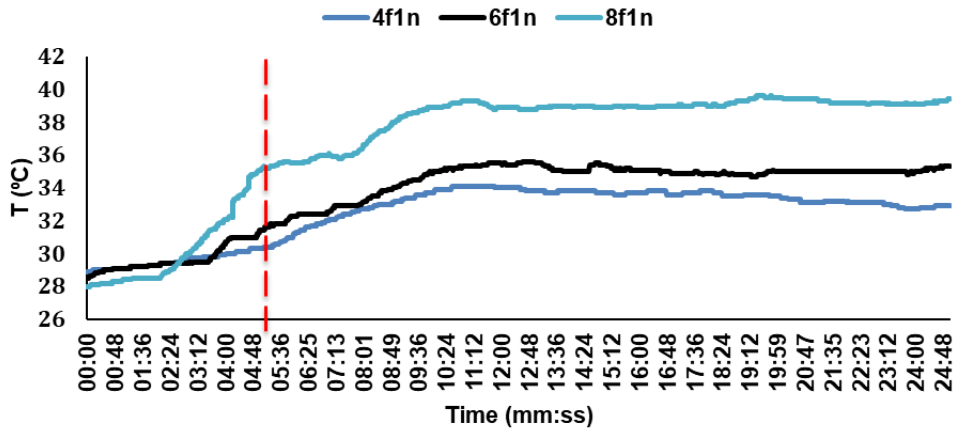

Figure 7: Temperature under using BVCD on/off in beehive of 1st collect at night.

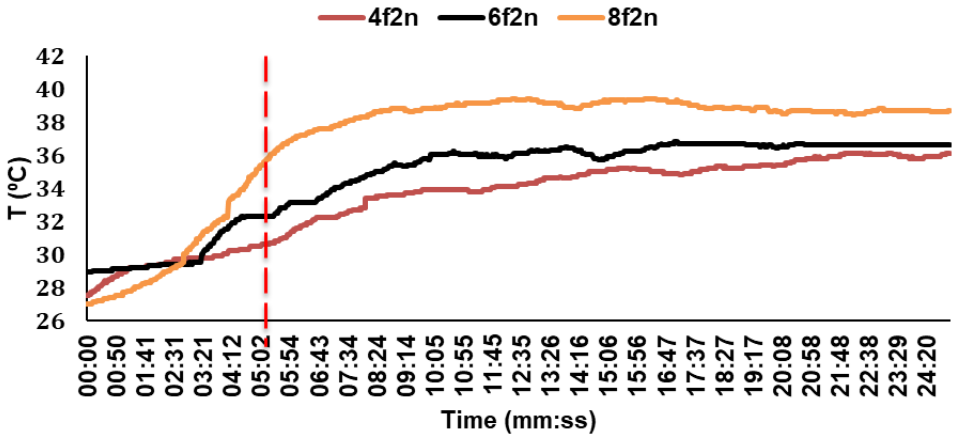

Figure 8: Temperature under using BVCD on/off in beehive of 2nd collect at night.

Relative humidity (RH) at day:

Figure 9 and Figure 10 represent the relative humidity (RH) in beehive (RH_{in}) when BVCD is on/off under three CS (4, 6, and 8 frames) at 1st and 2nd collection time.

BVCD-off mode, the results revealed that RH, that was rearranged from the average relative humidity of out of beehive (RH_{out}) of 43.17 % to RH_{in} 58, 50, 43, 43, 45 and 45% after 5 min under 4f1d, 4f2d, 6f1d, 6f2d, 8f1d and 8f2d, respectively. The RH_{in} level of the beehive after 5 min was greater than the RH during the day. It was evident that the disturbance in the level of RH_{in} in the 6f1d, 8f1d, 6f2d, and 8f2d. Also, the RH_{in} was dependent

on variable external factors, such as beehive opening and the putting of the MBS unit, which further impair the regulation. Moreover, there are trade-offs with the regulation of temperature and respiratory gas exchanges that can disrupt the establishment of optimal RH levels according to (**Human et al., 2006**).

BVCD-on mode, the results revealed that RH at 1st and 2nd collection time in of beehive (RH_{in}) was 54, 50, 41, 45, 39 and 39 % after 20 min of BVCD-on mode under 4f1d, 4f2d, 6f1d, 6f2d, 8f1d and 8f2d, respectively. So, the RH_{in} values were in an inverse relationship with the CS which is logical within the framework of the inverse relationship between temperature and humidity at stable conditions. But the relationship between T and RH was almost stable after 10 min of device ON only. While the relationship between T and RH was unstable through the first 10 min of device ON. This is maybe a return to take the time aspect of nest homeostasis **(Human et al., 2006)**. This means the atmosphere of the colony was stable after 15 min of putting the MBS unit.

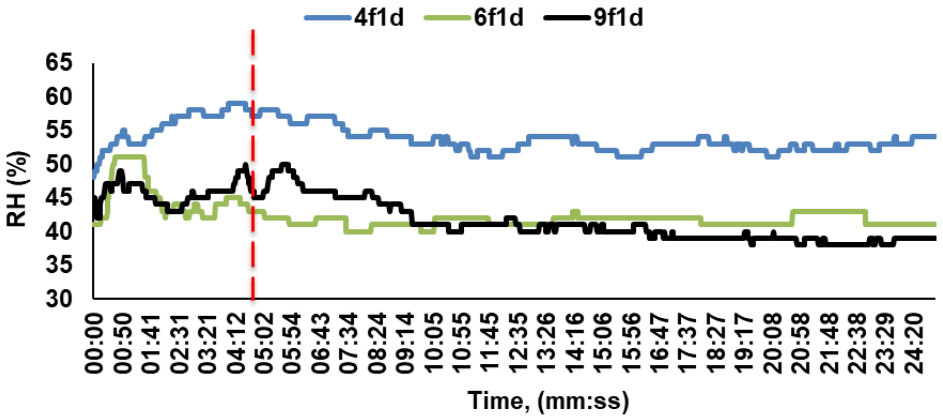

Figure 9: RH under using BVCD on/off in the beehive of 1st collect at day.

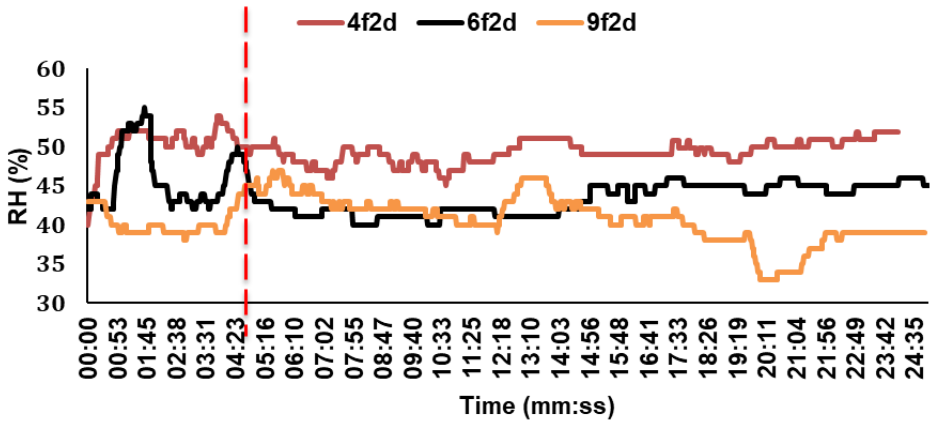

Figure 10: RH under using BVCD on/off in the beehive of 2nd collect ae day.

Relative humidity (RH) at night:

Figure 11 and Figure 12 show RH_{in} when BVCD is on/off under three CS (4,6,8 frames) at 1st and 2nd collection time.

BVCD-off mode, the values of RH_{in} were evident that the disturbance in the level of RH_{in}, which could to further impair the humidity regulation. Maybe there are trade-offs with the regulation of temperature and respiratory gas exchanges that can disrupt the establishment of optimal humidity levels (**Human et al. 2006**). The RH_{in} level of the beehive after 5 min was lower than the RH during the night, that logically within the framework of the inverse relationship between T and RH in stable conditions of the colony.

BVCD-on mode, the RH_{in} at the 1st and 2nd collection time was 52, 46, 37, 38, 40, and 38 % after 20 min of the device running under 4f1d, 4f2n, 6f1n, 6f2n, 8f1n and 8f2n, respectively. The relationship between T and RH was almost unstable under the 1st collection. It may be to take time to nest homeostasis after 20 min from device ON that according to (**Human et al. 2006**). While the relationship between RH_{in} and time of the device ON through 20 min was stable under the 2nd collection. It was in an inverse relationship with the CS, and this is understood within the framework of the inverse relationship between T and RH in stable conditions. It is meaning, the atmosphere of the colony was stable in 2nd collection, and it's higher than in the 1st collection.

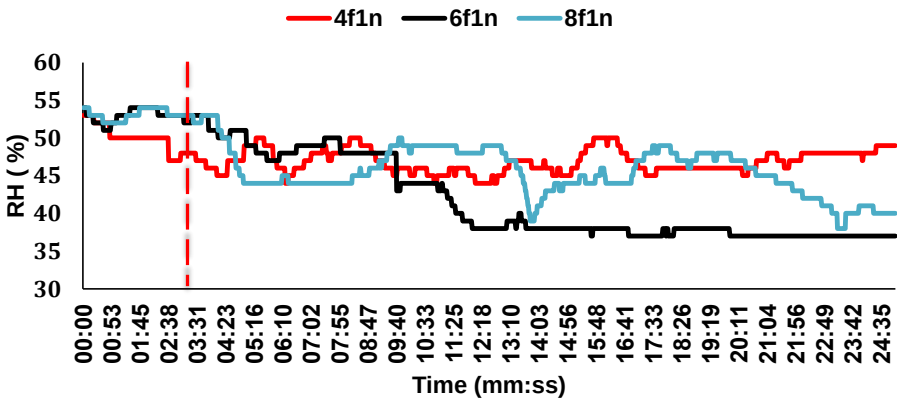

Figure 11: RH under using BVCD on/off in the beehive of 1st collect at night.

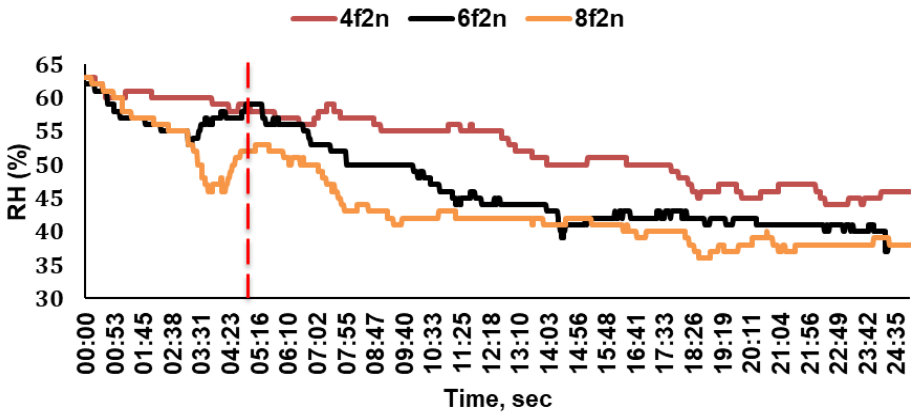

Figure 12: RH under using BVCD on/off in the beehive of 2nd collect at night.

Bee venom productivity:

Figure 13, represents the relationship between the maximum temperature (T_{max}) and bee venom productivity (VP) in beehives through day and night. The results revealed that the VP was increased with increasing the T_{max}. Perhaps the increase in T_{max} was associated with the number of bees on the device, in addition, to the electrocution for bees and, consequently, the rate of bee venom production. The VP at night was higher than during the day. This is because the number of bees inside is more at night than during the day, and therefore a larger amount of bee venom can be collected. At the multiple regressions, the relationship between VP and T_{max} was described as:

$VP = 6{,}294\ T_{max} - 194.24$ ($R^2 = 0.94$) at night.

$VP = 7.277T_{max} - 257.36$ ($R^2 = 0.82$) a day.

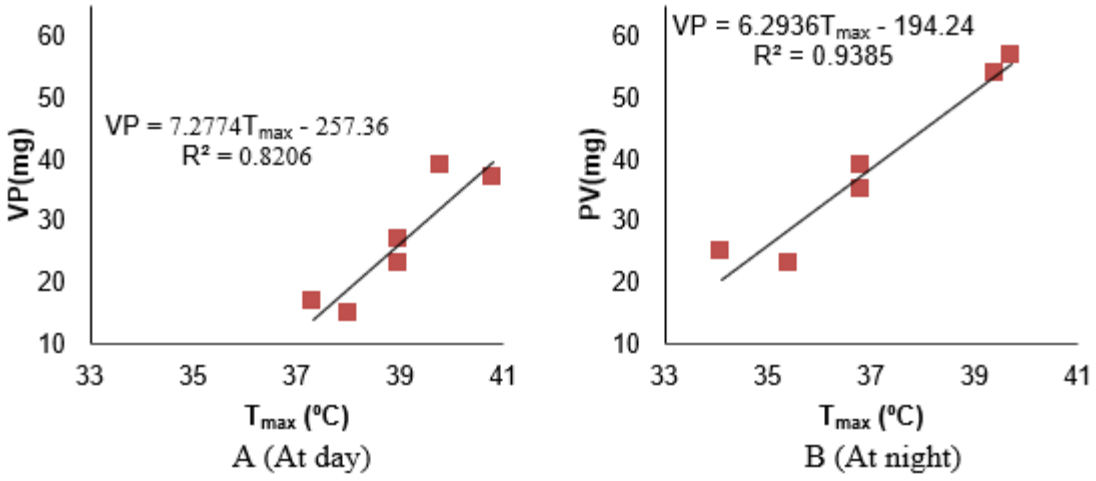

Figure 13: (A and B) The relationship between T_{max} and PV at day and night.

IV. CONCLUSIONS

BMS was used to monitor and operate the device and Stimuli at the same time. The bees to get rid of the effect of opening the beehive to put the BVCD device need about 5 min to get T natural of the beehive. The T_{in} was increased with increases in the CS. There was a disturbance in the level of RH_{in}, that can disrupt the creation of optimal humidity levels. There is impairing the regulation of the RH inside the beehive. Run BVCD in the beehive led to an increased T_{in} of all treatments, which turns into a stressed colony. In addition, the T_{in} was correlated with the CS. The venom productivity was correlated with T_{max}. The productivity at night was higher than during the day. It is recommended to begin using the BVCD 10 min at least after closing the colony to ensure that the beehive's internal environmental conditions are stable, particularly relative humidity.

Conflict of Interest

The authors have no conflicting financial or other interests.

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