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ARTIFICIAL MICROCLIMATE USING IOT FOR OPTIMAL LARVAE PRODUCTION OF BLACK SOLDIER FLY EGGS

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Abstract. *Black Soldier Fly (BSF), Hermetia Illucens, is one of the insect family whose larvae have many benefits for nature. The production of BSF larvae, or usually called maggot in Indonesia is relatively inconsistent due to unstable weather condition. Thus, making the temperature and humidity levels fluctuate, that causes an inconsistent amount of BSF production. This study offers the solutions by controlling artificially the microclimate for BSF eggs to hatch successfully and produces optimal amounts of larvae. Artificial microclimate is made by using IoT devices constructed using Arduino UNO R3 and ESP8266 with DHT22 sensor to read the temperature and humidity of the BSF egg environment. Moreover, this study also uses heating lamp and mist maker (humidifier) to keep the temperature ideal which is about 30°C and 70% humidity. Result shows that BSF eggs with artificial microclimate produces more BSF maggot than the natural environment. Therefore, it shows that artificial microclimate using IoT is able to improve the production of BSF larvae.*
Keywords: Black Soldier Fly, BSF egg, BSF temperature and humidity, Internet of Things, Artificial microclimate

1. **Introduction.** BSF (Black Soldier Fly), Hermetia Illucens, is one of many fly species that has many uses and benefits. One of the benefits of BSF that is widely used is for waste management purposes [1]. The adult flies cannot spread diseases to humans because they cannot feed or bite; therefore, they are not considered as pathogens [2]. The larvae of this BSF, or usually called maggots which are shown in Figure 1, consume organic waste before they turned into pupae and become the adult Black Soldier Fly. Maggot of Black Soldier Fly deteriorates different kinds of natural waste and converts them into biodiesel and protein [3].

BSF also has a lot of value and use for livestock, and dairy manure and poultry manure can be converted into valuable products such as protein, oil, and sugar by the maggot [4]. BSF larvae could also be used as substitute of fish meal to provide nutrients for farm animals, e.g., poultry, cows, and farmed fish [5]. By milling the dried maggot, it is also possible to turn the maggot into texture protein that can be consumed by human [6]. The eggs of the BSF are very important for BSF breeder. If the amounts of hatched eggs are lower, automatically fewer larvae and adult flies will be produced. Hatching and incubation period of the eggs need approximately 4 days at 30°C [7].

The growth of the Internet also makes the big changes into the technology we can have right now. With the Internet of Things (IoT) we can remotely control devices or automate a device. The IoT will solve many problems because of the ability of IoT to give a transparency, control, and performance at the same time [8]. Farm monitoring can be done with cost and power efficient IoT devices [9]. Manpower can also be minimized to

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Figure 1. Black Soldier Fly larvae eating organic waste

manage an IoT device or more [10]. The aim of this IoT is to take the input and process it to produce the desired output, automatically adjusting the microclimate of the egg surrounding.

Example of already existing IoT devices that are used on the daily basis are smart home assistant, smart lightning system on the road, smart light bulb, and many others. Recent study shows that the uses of IoT technology help to provide higher productivity and higher resource efficiency for precision agriculture and livestock farming [11]. Research that associated IoT usage with Black Soldier Fly has been done by Putra in 2021, and the research shows that temperature of BSF maggot enclosure can be adjusted using light bulbs and Arduino [12]. However, the researcher only focused on the temperature of BSF maggot enclosure and did not consider humidity as one of the microclimate variables that need to be controlled.

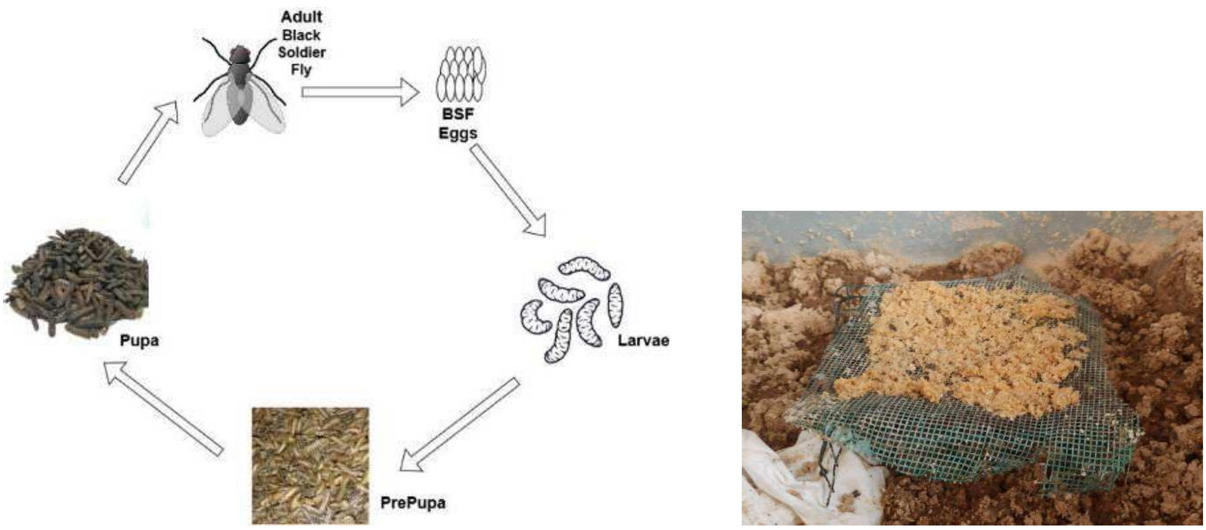
This study aims to artificially create optimal microclimate to support the hatching process of the eggs by utilizing IoT device to take the microclimate data from the environment to monitor and automatically control the microclimate such as temperature and humidity by using heating lamp and humidifier or mist maker device as the actuators to obtain the desired temperature and humidity state. With the implementation of this technology on BSF egg incubation, it is expected that hatched egg success rate will increase; thus, larvae production is also increased considering that the ideal microclimate conditions are achieved.

The remainder of this paper is organized as follows. Section 2 gives a brief introduction to problem identification and BSF life cycle. Section 3 provides a detailed description of the proposed method, while experiment result of the performance comparison is presented in Section 4. Finally, conclusions are offered in Section 5.

2. **Literature Review.**

2.1. **Problem identification.** BSF production is dependent on larvae amount hatched from the egg produced by adult BSF. The amounts of eggs hatched are inconsistent by reason of temperature and humidity uncertainty. In global warming situation the weather is uncertain on the equator, the rain and drought cannot be predicted, and the weather will impact the BSF eggs temperature and humidity. In odd moments the eggs are too dry and make the eggs dry and cannot be hatched. More eggs are dried which will lower the production of BSF larvae. Besides the temperature, humidity is also important because the eggs will get wet and die if the humidity level is too high. Therefore, to help the eggs not dry and wet when BSF eggs are waiting to hatch, we need to keep the temperature and humidity stable. To monitor the temperature and humidity of BSF eggs environment, artificial microclimate will help the temperature and humidity balanced. In this study we will compare the environment without using microclimate and using microclimate.

2.2. **Literature study.** In recent studies, eggs are able to hatch in 30°C with 65%-70% of humidity in the experiment that was tried by previous researchers [13]. BSF eggs really depend on the humidity and temperature to hatch. Lighting is also one of the important aspects for maximizing BSF egg production [14]. The life cycle of this BSF is very short and can be used to reduce organic waste and nourishment for poultry and agriculture [15]. BSF can only live for about 45 days, and for each life stage that depicted in Figure 2(a) below is only less than 3 weeks.



(a) (b)

Figure 2. (a) Black Soldier Fly life cycle; (b) Black Soldier Fly eggs

The adult BSF only has 5 to 8 days to intimate and lay eggs. BSF eggs are collected every day from the cage of adult Black Soldier Fly. The eggs need to be separated from adult BSF into their own cages so the egg can have its own microclimate [16]. The hatching phase of BSF egg is one of the keys to keep the BSF lifecycle going. Before the egg turns into larvae state, it needs to pass the hatching phase in 3.5 days in 30°C or in 4.3 days in 24°C [17]. Not all of the eggs will hatch at the same time, hatching time varies depending on individual egg itself. Some of the eggs need a little bit more time to hatch than the others, but usually it takes roughly 3-4 days for the eggs to be hatched. Figure 2(b) shows BSF eggs in its enclosure inside one of the cage boxes.

After egg phase, the egg will turn into larvae which are able to consume almost all kinds of organic waste with a soft texture. The larvae then will enter prepupa phase. To become prepupa, the larvae will crawl into the edge of the wall to avoid other larvae, and then it will harden it skin. At this phase, prepupa can be used for poultry and agricultural feed and it will have a lot protein until it starts to pupa phase [15]. After the pupa phase it will turn into BSF in 5-7 days and the cycle goes on and on.

The lifecycle of BSF is dependent on the temperature and humidity level, it needs to be monitored and controlled as those 2 elements are climate conditions that influence the BSF lifecycle and development of the BSF [18]. Temperature is also the most effective factor for BSF development stated by many studies [19]. It is necessary to maintain humidity and temperature for optimal Black Soldier Fly development [20]. BSF eggs hatching, adult fly survival, and larvae mortality are affected by the environment relative humidity [15].

3. Proposed Method.

3.1. **IoT infrastructure.** The infrastructure of the IoT system is using a microcontroller board as the brain to process logics for the control system, a built-in Wi-Fi module for transfering the data wirelessly so the data can be seen online via android app or website-based application. Sensors that are used to obtain the data from surrounding area will constantly check the microclimate condition of the BSF eggs environment. Output devices or the actuators that are used on the controller to control the microclimate in the surrounding environment. A relay module is also used to distribute certain amount of power for the output devices such as the lamp and humidifier to work. The power from the Arduino only supports for 5 volt and 3.3 volt so the usage of the relay module is necessary. Diagram of the IoT infrastructure is shown in Figure 3 below.

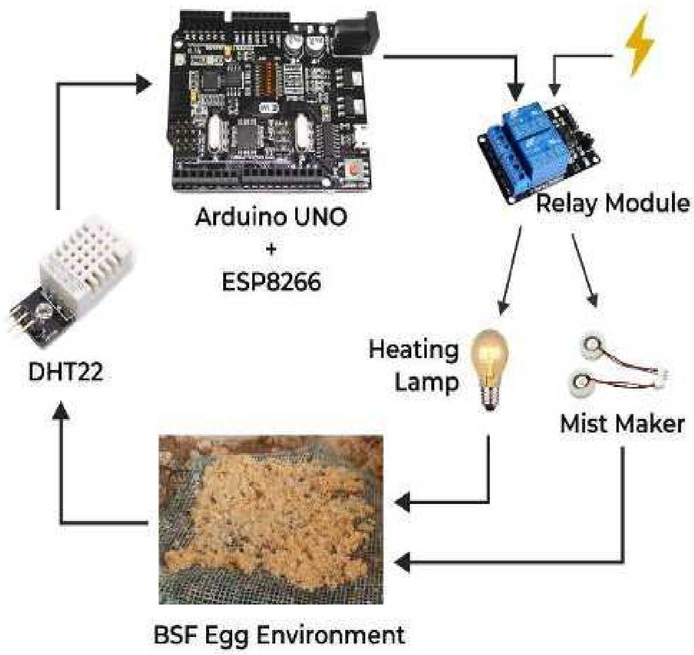


FIGURE 3. IoT infrastructure diagram

This infrastructure, as shown in Figure 3 above used Arduino UNO R3 Wi-Fi ESP8266 CH340G, a microcontroller board based on the ATmega328P as the brain to receive data inputs and compute them to the desired outputs. In this case, the outputs are temperature and humidity level, which are obtained from DHT22 sensors which are used to check the humidity and temperature in the cage. DHT22 is a popular temperature and humidity sensor for Arduino and has better accuracy than its predecessor, DHT11 [22]. If the temperature or humidity is lower or higher than a certain threshold, input will be calculated and the control system to alter the microclimate will be executed.

The humidifier is used to make a mist from the water and increase the humidity into 70%-80%. Temperature also will be monitored using the DHT22 sensor which also can read the temperature in the cage. If the temperature is higher than 30°C, humidifier will also be turned on until the temperature cools down to 30°C. The heating lamp will be used to make the temperature higher if the temperature falls below 30°C. On the testing area, the normal temperature of the room is on 34°C and on 80% humidity the temperature is still on 32°C, most likely the heating lamp will not be turned on due to the fact that the humidity already reaches the limit of the environment for microclimate.

3.2. **Control system.** In order to control the microclimate surrounding BSF eggs, some output devices are needed to alter the temperature and humidity into the desired condition. An ultrasonic mist maker (humidifier) is used to alter the humidity and to make the temperature colder, and heating lamp that emits heat is used to warm the environment if needed [21]. As shown in Figure 3, DHT22 sensor is directly put on BSF environment to capture temperature, humidity and moisture and send the obtained data to Arduino. If the input does not meet the desired condition, Arduino will then compute a treatment logic to turn on the corresponding output device for a certain amount of time. That treatment logic will then pass to a relay module that is also connected to an electricity source. Relay module will channel a certain amount of electricity to the corresponding output device to execute the treatment process. The input sensors will begin to read the environment condition again after a time delay that was set before. Table 1 below detailed the variable condition and the treatment that are run under certain conditions.

Table 1. Condition rules for treatment control

Variable	Condition	Treatment	
		Mist maker (Humidifier)	Heating lamp
Temperature	$< 30°C$	OFF	ON
	$> 30°C$	ON	OFF
Humidity	$< 70\%$	ON	OFF
	$> 80\%$	OFF	ON
Temperature & Humidity	$> 30°C$ & $> 80\%$	OFF	OFF
	$< 30°C$ & $< 70\%$	ON	ON

For example, we set the temperature threshold range to match the optimal temperature condition, which is 30°C [7]. If the Arduino reads the current temperature to be 25°C, the corresponding output device, which is heating lamp, will be turned on for certain amount of time until the current temperature on BSF egg environment falls in the pre-determined threshold range (30°C).

If the temperature of BSF egg environment is hotter than 30°C, or if humidity level falls below the predetermined humidity threshold (70%), then humidifier as the corresponding output device will be turned on until the temperature is below 30°C and the humidity level is above 80%.

3.3. **Performance comparison.** Comparison will be made by comparing maggot mass on the regular cage boxes with the cage boxes that are equipped with IoT devices as shown in Figure 4. The process will be waited for 15 days to make sure all of the eggs have been hatched into maggot and all the porridge inside the box dried or it has reached 15 days.

with coverlid without coverlid

Figure 4. Cage boxes comparison

Weight or total mass of maggots produced from each cage box will be the measurement parameter and performance indicator for this comparison. The mass of maggots is used as the measurement because it is much easier to weigh the maggot than weigh the egg itself.

As shown in Figure 4, cage boxes on the left that are equipped with IoT devices are covered with coverlid that prevent water mist and head artificially produced to escape from the environment. The coverlid also prevents the regular cage boxed from getting the effect of the IoT devices, so the microclimate of the regular cage boxes will be natural.

Each cage boxes consist of 3 separate boxes. Each box was given 3 grams of BSF egg, and after 15 days, it became maggots that are ready to be harvested. The combined weight of these maggots from each cage boxes is the parameter that will be compared. If the cage boxes with coverlid (which equipped with IoT devices) produce more maggots than the regular cage boxes, then the IoT system is working successfully on increasing the BSF success hatch rate.

The aim of this comparison is to find out which cage boxes produce more maggot. The cage boxes that hatched more eggs will automatically produce more maggot. Cage boxes that are equipped with IoT devices are expected to produce more maggot because of the optimal microclimate created with the help of the IoT technology.

4. **Experiment Result.** Each cage box is given the same amounts of eggs that are collected from adult BSF cage. Eggs are collected every day and evenly distributed into cage box with IoT device and without the IoT device for fair comparison. On each box in every cage it has about 3 grams of BSF eggs. After all the eggs are hatched into maggot, they will be fed organic feed for 7 days before separated with its feed and weighted. Comparison of maggots produced in each cage that depicted the IoT performance is presented in Table 2 as follows.

Table 2. Performance comparison

Cage box	Total weight of maggot (after 15 days)
With IoT technology	10.1 kg
Without IoT technology	9.2 kg

The comparison result, as shown above, supported the hypothesis that cage box which microclimate controlled with IoT technology produces more maggot the cage box in natural microclimate (without IoT technology). The weight of the maggot is measured on every box after waited for 15 days and weight on every box was summed into the other box on the same cage. With the result the cage with using microclimate can help to improve the production of BSF maggot about 9% to 10% of production.

The temperature and humidity values are recorded in every 30 minutes and there are at least 48 transactions or every treatment changes from ON to OFF or vice versa are also counted as 1 transaction. Some data in sample condition are shown in Table 3.

Table 3. Data analysis

No	Time	Temp. °C	Humidity %	Humidity treatment	Temperature treatment
1	00:00	34	70	1	0
2	00:30	33	74	1	0
3	01:00	34	78	1	0
...	...	...	...	...	...
47	23:30	29	81	0	1
48	00:00	32	75	0	0

Data shown in Table 3 are sample data from 00:00 until 00:00 on the next day. At number 48 the humidity treatment is 0 or OFF because the humidity is still on 75% and when the humidity is 80% the treatment will be turned OFF and will turn on again after the humidity is low enough until reaching 70%. Humidity treatment on the table means the water atomizer or mist maker is to be turned ON to make the humidity higher. With the mist maker turned on, the temperature will also be taking effect, it will slowly decrease until the desired temperature and humidity conditions are achieved.

5. **Conclusions.** Result from this experiment shows that IoT technology usage on Black Soldier Fly egg environment can indeed improve the BSF larvae/maggot production. With the increase in the number of successfully hatched BSF eggs, the number of adult BSF flies will also be increased, and the amount of BSF larvae increased on every iteration will also increase exponentially. IoT technology can be used to deal with the temperature and humidity problem of BSF egg environment by creating an artificial microclimate to create an optimal climate condition.

Artificial microclimate is made using mist maker and heating lamp to keep temperature and humidity at the optimal level for the eggs to hatch. The temperature is kept below 30°C and the humidity level is maintained between 70% to 80% for the eggs to stay warm and hydrated to hatch. Mist maker will automatically be turned on when the humidity level is below 70% and turned off after 80% of the humidity level is reached. The heating lamp will also automatically be turned on when the temperature is below 30°C and turned off after reaching 30°C.

This implementation of IoT technology to improve BSF production can be further developed and adjusted to match the size, weather, and physical condition of each Black Soldier Farm for optimal result. Perhaps artificial intelligence algorithms and monitoring applications can be added in the future work to help maximize the result of increasing BSF larvae production.

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