Optimizing temperature and humidity of an engineered, semi-automated black soldier fly (*Hermetia illucens*) farm

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Introduction

The process of rearing insects has the potential to reduce the harmful effects of food waste. Crops grown for livestock feed use a significant amount of land, water, and energy as opposed to crops grown for human consumption. In addition to the excessive resource use in agriculture, consumers discard roughly 30–40% of food, amounting to 1.3 billion tons of food wasted per year.

Insect larvae have gained a substantial amount of attention due to their ability to recycle organic waste into high quality protein, which can replace standard livestock feed with greater nutritional benefits and a higher feed conversion efficiency. Rearing insect larvae also adds a localized source of protein production, thus reducing the price of protein production by limiting the need for importations from outside sources.

Black soldier flies (*Hermetia illucens*) are one of the most ideal insects to rear for livestock feed. In the larval stage, black soldier flies (BSF) can digest fecal sludge, municipal waste, and food waste. As a species, BSF do not bite, sting, and are not destructive to plants. Considering these factors, BSF are a preferable candidate as an alternative protein source for livestock (Law & Wein, 2018).

Since ectotherms, like BSF, are unable to regulate their internal body temperature, they are more reliant on environmental temperature and humidity. BSF are extremely tolerant to temperature and humidity, but to ensure a greater reproductive rate and a higher yield, the optimal range of tolerance must be met. BSF's have an optimal temperature range of 70.6–87.1 °F and an optimal humidity range of 33.2–60.4%. Therefore, the purpose of this project was to engineer a semi-automated black soldier fly farm and maintain its internal temperature to be between 70.6 and 87.1 °F and a humidity between 33.2% and 60.4% (Barrett et al., 2023) so that it will be able to maintain a stable BSF population.

Materials and Methods

To guarantee that the correct abiotic conditions are met for each life stage, the farm was constructed in three layers. Using Autodesk Fusion and Autodesk CAD, a prototype was designed. The top layer was designed for BSF adults to mate and oviposit (deposit eggs) on two egg holders, as shown in Figure 1. The middle layer was designed to feed BSF larvae, the bottom layer was designed to hold the pupating larvae, and the chimney was designed to allow emergent adults to travel back to the top layer. Both the Fusion model and the actual model can be found in Figure 2.

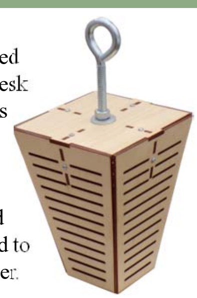


Figure 1 (above): Egg holder with an eyebolt attached.

Materials and Methods (continued)

The entire structure was built with four 4′ × 8′ sheets of plywood at a thickness of 11/32″, four 2″ × 2″ × 6′ pine posts, four 4″ × 4″ × 8″ pine posts, corrugated sheet metal, mosquito netting, 1″ hinges, magnet catches with strikes, and cabinet knobs. The components of the egg holder were made from Baltic birch plywood laser cut using the Hobby Series Full Spectrum Laser and attached to the top layer with four 5.25″ length eyebolts. All wooden components were coated with PolyWhey® wood sealant to prevent warping.

The completed farm was transported to the Hydrofarm where it was placed within a 252 square foot area framed by PVC pipes and covered with polyurethane fire rated plastic for insulation. The area was heated using 50 feet of PEX tubing heated to an average of 180 °F. An Inkbird temperature controller was used to control the heat. Modifications were then made through five prototypes to maintain the temperature and humidity in the flies' optimal range, summarized in Table 1.

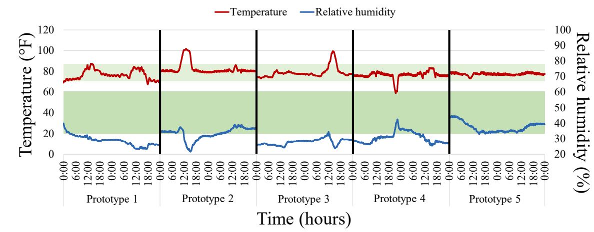
Figure 2 (above): Autodesk Fusion model (left) and the actual model (right). The actual structure has a height of approximately 5 feet 11 inches.

Prototype	Description of modifications	Dates
1	• Heating system target temperature set for 72.5 °F	February 2–4, 2023
2	• Heating system target temperature set for 84.5 °F • One 12 V, 1.4 A NIDEC Beta V™ fan installed to run when temperature reaches 86 °F	February 8–10, 2023
3	• Added one 12 V, 0.28 A NIDEC Beta V™ fan for temperature regulation	February 25–27, 2023
4	• Heating system target temperature set for 82 °F • Moved structure closer to outside air • Water added to a plastic bin for humidity regulation	March 3–5, 2023
5	• Filled a large drum with water and attached a float valve from the drum to the plastic bin for humidity regulation	March 24–26, 2023

Table 1 (above): Summary of each prototype's modifications and subsequent dates of data collection.

Results

For each prototype, data was collected using a wireless Govee thermometer hygrometer placed in the top layer of the farm. Collected data is presented in Graph 1 and a summary of the percent of time each prototype is in range of ideal conditions can be found in Table 2.



Graph 1 (above): The temperature and relative humidity of the farm had been measured every minute over a span of 48 hours. The green shaded areas represent the BSF's optimal temperature and humidity range.

Prototype	1	2	3	4	5
Temperature in range (%)	90.4	88.8	91.6	95.4	100
Relative humidity in range (%)	6.59	62.2	0.94	23.2	99.2

Table 2 (above): The percent of time each prototype fell within the BSFs' optimal range of tolerance.

Conclusions

The goal of maintaining a temperature and humidity within the BSF's optimal range of tolerance was met with Prototype 5, which maintained temperature range 100% of the time and the humidity range 99.2% of the time. Further data should be collected during the summer months to verify the reliability of the current convection unit installed for higher outside temperatures. Additionally, the entire structure of the farm should be tested to determine whether the current design can regenerate continuous generations of BSF while producing a sustainable yield of larvae to provide an alternative source of protein for livestock feed.

References and Acknowledgements

Barrett, M., Chia, S. Y., Fischer, B., & Tomberlin, J. K. (2023). Welfare considerations for farming black soldier flies, *Hermetia illucens* (Diptera: Stratiomyidae): A model for the insects as food and feed industry. *Journal of Insects as Food and Feed, 9*(2), 119–148. https://doi.org/10.3920/JIFF2022.0041

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