Journal of Agriculture Science & Technology JAGST 22 (6) 2023, 1-19

ORIGINAL RESEARCH ARTICLE

Effects of Temperature Variation on Yield and Quality of Field Crickets (*Gryllus bimaculatus*) and Black Soldier Flies (*Hermetia illucens*)

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ABSTRACT

Insect rearing provides an affordable alternative source of animal nutrition for most small-scale farmers. However, current rearing technology with uncontrolled environmental conditions suppresses insect yields, leading to low adoption of insect production. The objective of this study was to assess the effect of temperature variation, using an adaptive control structure, on the yield of field crickets (*Gryllus bimaculatus*) and black soldier fly larvae (*Hermetia illucens*). Temperature values of 25°C, 27°C, and 30°C constant relative humidity of 50%, and constant air speed of 3 m/s were adopted for the study. Throughout the study, weighing of the insect wet yield was done on a daily basis for larvae and after three days for cricket pinheads. Black soldier fly larvae and adult crickets were harvested at the ages of two weeks and six weeks, respectively, and oven dried at 105°C for 24 hours for subsequent analysis of proteins. Results indicated that black soldier fly larvae reared at 25°C, 27°C, and 30°C had a maximum mean wet yield of 0.216 ± 0.022 g, 0.234 ± 0.019 g, and 0.248 ± 0.016 g, respectively, at the age of two weeks. Similarly, crickets reared at 25°C, 27°C, and 30°C had a mean yield of 0.807 ± 0.167 g, 0.933 ± 0.102 g, and 1.306 ± 0.254 g at the age of six weeks. Dried cricket reared at 25°C, 27°C, and 30°C had 25.566 ± 0.012%, 46.811 ± 0.647%, and 58.216 ± 1.510% protein, respectively. Contrary to this, black soldier flies reared at 25°C, 27°C, and 30°C yielded 42.655 ± 1.732%, 47.121 ± 0.015%, and 62.536 ± 0.014%, respectively. Larval yield recorded significant different yields ($f = 4.935$, $p = 0.03$), whereas crickets failed to record significant different yields ($f = 0.777$, $p = 0.388$) under different temperature levels. A higher temperature regime yielded higher body mass and protein turnover. The findings of this study boost the future prospects of insects as food and feed for enhancing food and nutrition security.

Keywords: Adaptive rearing structure, Environment, Insect feed, Yield

1.0 Introduction

URL: https://ojs.jkuat.ac.ke/index.php/JAGST
ISSN 1561-7645 (online)
doi: 10.4314/jagst.v23i6.1

Food and feed are the fastest-growing global industries. The need for food keeps on rising rapidly, and this demand is inevitable because food is a basic requirement for growth and body development. Statistics indicate that the world population is projected to be over 9 billion by the year 2050, whereas food demand is anticipated to double by 2030 (FAO, 2017). Remarkably, insect rearing is gaining popularity as a major food material across the continent. It is important to note that population growth is not commensurate with the current scale of food production. In developing countries, food shortages, specifically protein shortages, are predominantly caused by unhealthy dependence on conventional livestock sources like cattle. Besides environmental degradation from the release of methane, their production attracts a considerable amount of input and time. Statistics indicate that livestock production occupies close to 70% of agricultural land, and 30% of greenhouse emissions emanating from agriculture partly contribute to climate change (Bjørge et al., 2018). Therefore, insects, considered mini-livestock, are regarded as an alternative and noble source of diet. In recent years, edible insects have been incorporated into the human diet as a novel substitute for conventional sources of food. They are highly nutritious with high levels of fat and protein content; however, their nutritive content is specific to the insect species. Some of the common insects used as food include termites, crickets, locusts, grasshoppers, and black soldier flies, among others (Pandey & Poonia, 2018). In Kenya, Cricket is mostly consumed in Lake Victoria Region and its nutritional composition are 25% fat, 10% carbohydrates, and 47% protein (Osoro et al,. 2023).

Crickets undergo an incomplete metamorphosis (Rumpold & Schlüter, 2013) in their development process (egg-nymph-adult), as illustrated in Fig. 1. Based on temperature and humidity conditions, after ovipositioning, eggs hatch in a period of 9–13 days, and nymphs sequentially have eight to nine instars (Mariod, 2020). For instance, crickets bred at 30˚C undergo their last moult 45 days after hatching (Miech, 2018); it is at this point that harvesting can be done.

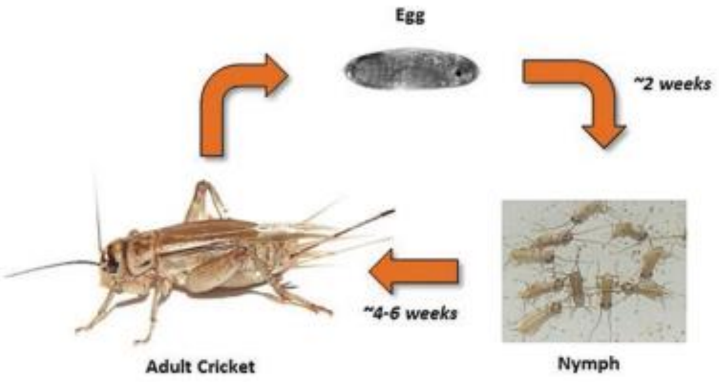

Fig. 1: Cricket life cycle (Mariod, 2020)

Black soldier fly (BSF) larvae can be reared using fermented wheat bran in the ratio of 1200 larvae per a thousand grammes of the substrate (65% moisture) under an incubation temperature of 30°C (Nguyen et al., 2018). As shown in Fig. 2, larvae mature after a period of 14 days, but this period might be elongated based on feed availability and prevailing environmental conditions. In Juja; Kenya, close to 80% of food litters on the environment and can be converted into beneficial resources through insect feeding (Mwangi & Sira, 2011). During the pre-pupae stage, mature larvae migrate (a scenario seen as self-harvesting of pupae) from their feeding source in search of a relatively drier place to pupate (Hoc et al., 2019).

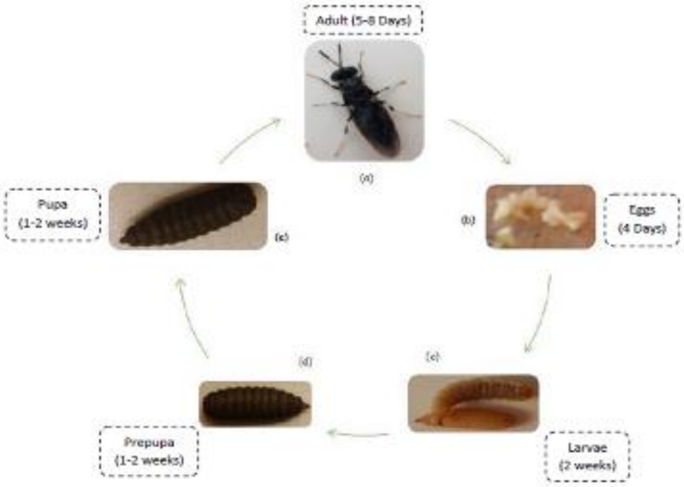

Fig. 2: Black soldier fly life cycle (Mutafela, 2015)

Ideally, environmental conditions occur in a particular combination or mix. Besides other factors such as feed content, the net effect on an insect's performance is the joint contribution of a number of weather variables. Broadly, some of the factors influencing insect rearing include temperature, lighting (intensity or photoperiodism light-dark cycles), ventilation, housing properties, oviposition site, and feed used (Lemoine & Shantz, 2016; Miech, 2018; Holmes et al., 2012). Seasonal variation in temperature, amongst others, directly influences insects' activity and performance. The intermittent changes in temperature affect physiological cycles and, consequently, the metabolism of the organism (Niehaus et al., 2012). The nature of the existing insect rearing structures has contributed immensely to the low adoption of food-insect production. Although modified structures such as greenhouses have been used to rear insects, fluctuations in prevailing rearing conditions have continually suppressed insects' growth. Similarly, the established rearing structures have allowed the rearing of a single insect family, thus making it costly when there is a need to rear more than one family of insects. Previous studies indicate research workers have needed to construct different structures for different insects (Orinda et al., 2017).

The adaptability or acclimatisation of insects to environmental thermal changes differs significantly. In a bid to ascertain economic and environmental sustainability, it is critical to improve the performance of insect rearing systems. Temperature affects insect physiology (metabolic rate and growth rate), and hence body composition. In the absence of periodic fluctuations in environmental conditions, insects are known to thrive well in terms of growth rate index, reproduction, less mortality, and improved egg eclosion (Tomberlin et al., 2009). As such, rearing conditions should be adjustable throughout the rearing period so as to achieve the expected yield results. BSF adults feed on water, powdered milk, and sugar solution uptake and are not disease vectors of any kind. According to Thinn and Kainoh, BSF uptake of sugary substances and milk protein enhances adult life span, oviposition period, and egg count (2022). Initially, larvae consume as many organic nutrients as possible and deposit them as fat and protein for metabolic use during pupa and adult stages. It is necessary to stabilise rearing conditions through a modification of a housing structure.

Water stress undermines insects' growth rate (McCluney & Date, 2008). The physiological functions of water play a crucial role in sustaining membrane fluidity and prolonging periods of insects' activity and biochemical gradients, all of which might be compromised under a desiccating condition. Experimental data indicates that crickets reared under conditions of limited access to water availability showed variation in the final dry matter content. Crickets provided with water for 4 hours and 24 hours a day recorded growth rates of 0.8 mg per day and 2.2 mg per day, respectively. Literature indicates that crickets' rearing temperature dictates insects' growth rate (Booth & Kiddell, 2007). Field crickets (*A. domesticus*) reared at 25˚C exhibited a growth rate of 0.5 mg per day, whereas those reared at 28˚C recorded a growth rate of 1.0 mg per day. A similar delay of more than twelve weeks of growth period on the reared crickets was also observed under a rearing temperature range of 17˚C to 22˚C (Kinyuru & Kipkoech, 2018). Therefore, this scenario is an indication that the availability of water is a key determinant that could either lower or enhance the growth of an organism. The rate of metabolic processes is temperature-dependent, and this therefore postulates that ambient temperature proportionally affects their physiological rates (Bulgarella et al., 2015). Under laboratory conditions with a temperature-controlled mechanism, BSF egg to pre-pupa may take 22 days and 40 days from egg to adult at 27˚C (Čičková et al., 2015). Besides, the egg-to-post feeding stage could last up to 18 days when BSF larvae are reared at 30˚C. However, black soldier fly maturity could be delayed up to 4 months under severe or less conducive conditions (Čičková et al., 2015).

This study therefore envisaged the use of an adaptive rearing structure with controlled temperature, humidity, and air flow to suit insects' requirements. The study evaluated the net effect of different temperature levels with a view to establishing the most appropriate for optimum insects' mass gain and protein content.

2.0 Materials and methods

2.1 Study site

The study was conducted from August 2021 to January 2022 at the Department of Agricultural and Biosystems Engineering, Jomo Kenyatta University of Agriculture and Technology (JKUAT), Kenya. JKUAT is located in Juja, Kiambu County (37.01393°E longitude, 1.09282°S latitude, and 1530 m altitude). According to the published data, Juja has a mean annual temperature of 18.9°C, which fluctuates from a minimum of 13.6°C to a maximum of 26.1°C (Ronoh et al., 2010; Watako et al., 2001). Besides, the prevailing relative humidity ranges from 15 to 80% and experiences two rainfall patterns a year, with cold and rainy seasons being experienced between April and August and between October and December.

2.2 Developing an adaptive rearing structure for production of crickets and black soldier flies

A double-room rearing structure was constructed and roofed using iron sheets, each occupying a space of 2 m long, 1 m wide, and 3 m high, and partitioned using a greenhouse net (Miech, 2018). A cabinet chamber was used to rear crickets and BSF interchangeably inside the first partition, whereas a control set-up was placed in the second partition (Fig. 3). The foundation level was dug and excavated using a spade, and later filled to a uniform level with concrete. The foundation of the structure was cemented so as to enhance hygienic conditions within the structure's environs. An air entrance channel was demarcated on the lower left wall section of the adaptive rearing cabinet, whereas an air exit tunnel was positioned on the upper opposite wall section. A heating element (1000 W) and axial fan were installed inside the air entrance channel in that order. The fan (REC-21725 A2 W, USA), with a specification of 1.2 kW (Finkelman et al., 2006), drove both air and heat into the rearing chamber. The heating element, which had an on/off activation mode controlled using a thermostat, was in active mode only when the room temperature was below a predetermined set point. On the other hand, a 4-litre humidifier (XY-30, China) was installed adjacent to the window opening and was on active mode when in need.

As illustrated in Fig. 3, temperature, relative humidity, and wind speed sensors were positioned inside the rearing chamber and in the outdoor area. Different researchers pointed out that insects such as crickets and black soldier flies can be reared within a temperature range of 25˚C to 30˚C (Tomberlin et al., 2009; Booth & Kiddell, 2007). Temperature levels of 25°C, 27°C, and 30°C were adopted inside the adaptive chamber with a constant airspeed of 3 m/s (Tapanen, 2018) and a relative humidity of 50% (Mellberg & Wirtanen, 2018). Since different insects require varying rearing conditions, embracing an adaptive rearing system allows farmers to select desirable conditions that would favour a given insect.

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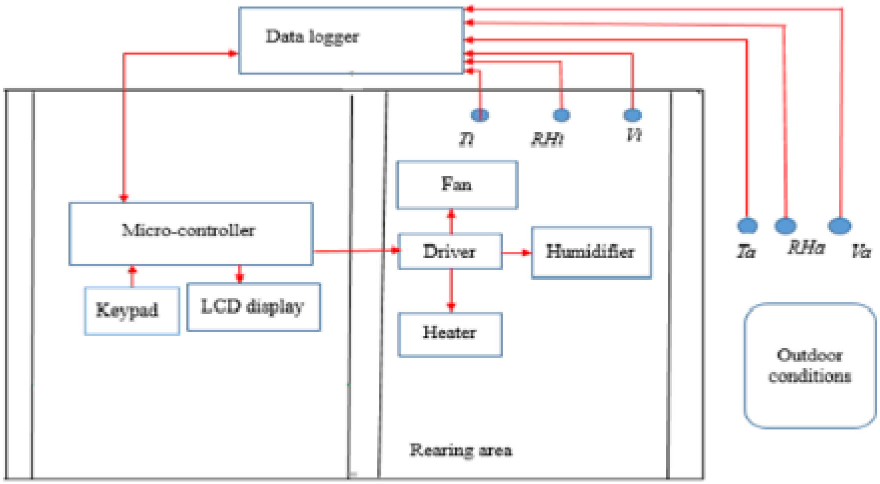

Key: *Ti* is temperature in the rearing area (˚C), *Ta* is temperature at the outside area (˚C), *RHi* is relative humidity inside the rearing area (%), *RHa* is relative humidity of outside air (%), *Vi* is air speed of outside air (m/s) and *Va* is air speed inside the rearing area (m/s).

Fig. 3: Schematic of an adaptive insect rearing structure and data acquisition set-up

Data loggers (HOBO Pro Series) facilitated data collection and relay from the variable's sensors throughout the rearing period (Finkelman et al., 2006). As shown in Fig. 4, these logging devices feed in input variables every 15 minutes (Holmes et al., 2012). In the preparation chamber, a programmed microcontroller (Metrilog T707) inputs temperature, relative humidity, and ventilation feedback (Ionescu-Mălăncuş et al., 2013). Besides, the keypad and LCD display were connected as microcontroller inputs and outputs, respectively. Inside the rearing enclosure, the humidifier, heating coil, and fan acted as the actuating devices for water droplet production, heat, and air circulation, respectively (Hermawan et al., 2017).

Fig. 4: Own-developed insect rearing chambers (a) Adaptive chamber (b) Control chamber

As shown in Fig. 5, the performance of the system was varied at different input set points while monitoring the control output. The output signal from sensors 1 and 2 located within the rearing chamber indicated there was a constant temperature level, whereas the output from outdoor sensor 3 depicted a fluctuating pattern. These data indicate that, under natural conditions, temperature fluctuation is detrimental to insects' growth and thus not suitable for sustainable production.

URL: https://ojs.jkuat.ac.ke/index.php/JAGST
ISSN 1561-7645 (online)
doi: 10.4314/jagst.v23i6.1

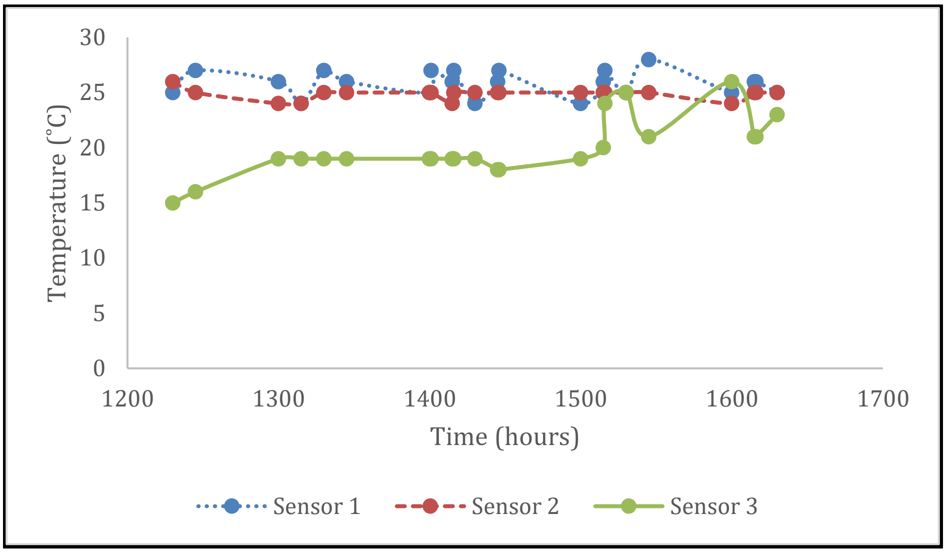

Fig. 5: Variation of indoor and outdoor temperatures with time

2.3 Feeding of black soldier flies

Three experiments were set up in the adaptive chamber at 25°C, 27°C and 30°C at different intervals, while the relative humidity and fan speed were maintained constantly at 50% and 3 m/s in all the experiments. Wheat bran and chicken waste (Surendra et al., 2016; Ortiz et al., 2016) were thoroughly mixed using a recyclable plastic container in the ratio of 1:2 (an observed ratio formally adopted at the JKUAT BSF rearing facility) and water added to attain a moisture content of 70% (Ortiz et al., 2016). A 70% moisture content of substrate was achieved by mixing 10 g of dry bran meal with 18 ml of water (Holmes et al., 2012). Thereafter, these substrates were equally distributed into six symmetrically cut ten-litre plastic containers. On day 1 of the experiment, four-day-old BSF larvae fed with approximately 500 mg of bran meal for the first four days of life (approximately ½ kg of fermented bran meal plus larvae) were collected from the JKUAT insect farm using a colourless plastic bucket (Star Plastic Company Limited, Kenya) and equally distributed into the prepared substrate in each of the containers. The larval density in each plastic container was 300 per container in the growth chamber (Myers et al., 2008; Holmes, 2010). Three containers were numerically marked and placed on top of the shelves inside the adaptive chamber, after which this chamber was closed. Similarly, three of the remaining containers were placed in the adjacent room under the prevailing or ambient environmental conditions, as shown in Fig. 5. Since rearing conditions directly influence mass gain, the magnitude and variability of ambient conditions falling outside desirable ranges inform the need for a controlled rearing structure. Close monitoring was done twice a day, mid-morning and mid-evening, to ascertain the proper functioning of the system, and besides, water was sprinkled regularly with a few sprays to a moisture content of 70% with the help of a moisture metre (MD7822, China) to elevate the moisture content of the drying feed substrate. Prior to the post-feeding stage, larvae only consumed a mixture of chicken poop and bran meal (Surendra et al., 2016). The bran meal contained 56% carbohydrates, 3.5% fat, 15% protein, and 12% moisture content (Preuckler et al., 2014). The post-feeding stage in BSF larvae is usually indicated by a colour change from cream to black, and this colour change marks the end of feed replenishment. The control experiment was simultaneously carried out under the prevailing ambient weather conditions. Similar nutrient content and feed replenishment rates employed in the adaptive chamber were used in the control set-up. Larvae were harvested at the age of two weeks and weighed before the stage of the oven drying process.

2.4 Feeding of crickets

Similarly, three experiments were set up in the adaptive chamber at 25°C, 27°C, and 30°C at different intervals, while the relative humidity and speed of the fan were maintained constantly at 50% and 3 m/s in all the experiments. A 40-litre basin was placed inside the adaptive chamber, with egg trays symmetrically placed inside. Feed and moist cotton wool troughs were placed on top of egg trays. Commercial chicken feed (starter mash), purchased from the local manufacturer and labelled to contain 21% crude protein, 87% dry matter, 4% fat, and 5% ash content, was used as cricket feed (Miech et al., 2016; Kinyuru & Kipkoech, 2018). The starter mash was placed into the feed trough. The cotton wool soaked with water prevented drowning, while egg trays provided hideouts. On day 1 of the experimental run, the first batch of one-week-old crickets was collected using plastic containers from the JKUAT cricket farm. Fifty (50) cricket pinheads were released into the rearing chamber. Feed and water, as described above, were provided. On the third week, kale leaves were provided to the crickets to boost nutrient availability until harvesting at the age of six weeks (Ssepuuya et al., 2020). A control experiment consisting of a basin with a similar arrangement was also placed in the open, and the insects were managed in a similar manner as the experiments. Ambient weather conditions dictated the growth of crickets in the control set-up. Similar nutrients and water were sufficiently provided while monitoring their growth until maturity.

2.5 Sample collection and analysis

From each experimental unit, insect growth was examined daily by randomly weighing and counting insect samples (Lundy & Parrella, 2015). On a high-precision weighing scale (HTZ, Germany), thirty (30) BSF larvae (Myers et al., 2008) were randomly picked, weighed individually each day, and recorded for the purpose of mean weight analysis. Immediately after weighing, these larvae and cricket's nymphs returned to their corresponding rearing containers. This process was done regularly until the target stage was completed or the weight increase reached a terminal point (two weeks for larvae and six weeks for crickets). Weighing, by scales, signified the amount of biomass assimilated over a stipulated period of time, whereas counting indicated cases of mortalities within the rearing unit.

From the onset of hatching, BSF larvae were measured in groups since the weight of each larva was minute before the age of one week. However, for subsequent observations, individual weights were measured using the high-precision weighing scale (indicate brand and precision level). Ten (10) cricket pinheads were weighed individually every three days, and this process was repeated until maximum yield gain was attained at up to the age of six weeks (Miech et al., 2016). The protein content of the harvested insect samples was determined after harvesting at six weeks for crickets and two weeks for BSF larvae, respectively. After drying the sample in the oven at 105˚C for 24 hours in the JKUAT food science lab, the micro-Kjeldahl technique was used to determine the protein content by employing a nitrogen conversion value of 6.25 (Udomsil et al., 2019). SPSS software (version 20) was used to analyse the data obtained. Group means were generated based on the different rearing temperatures. The statistical level of significance for different treatments was obtained using the Student's t-test.

3.0 Results

As shown in Figures 6–7, the growth variations of insects under ambient conditions versus those reared under regulated conditions were distinctly clear. In the adaptive setup, insects' mean yields were superior as compared to those reared under natural conditions.

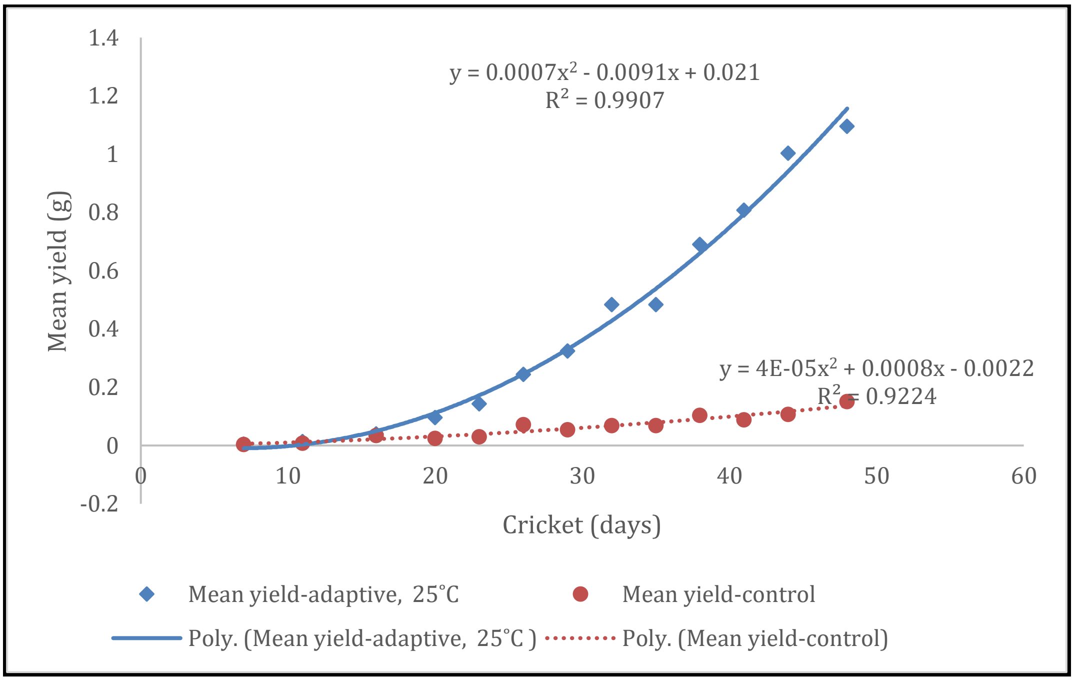

Fig. 6: Crickets' mean yield at 25̊C

URL: https://ojs.jkuat.ac.ke/index.php/JAGST
ISSN 1561-7645 (online)
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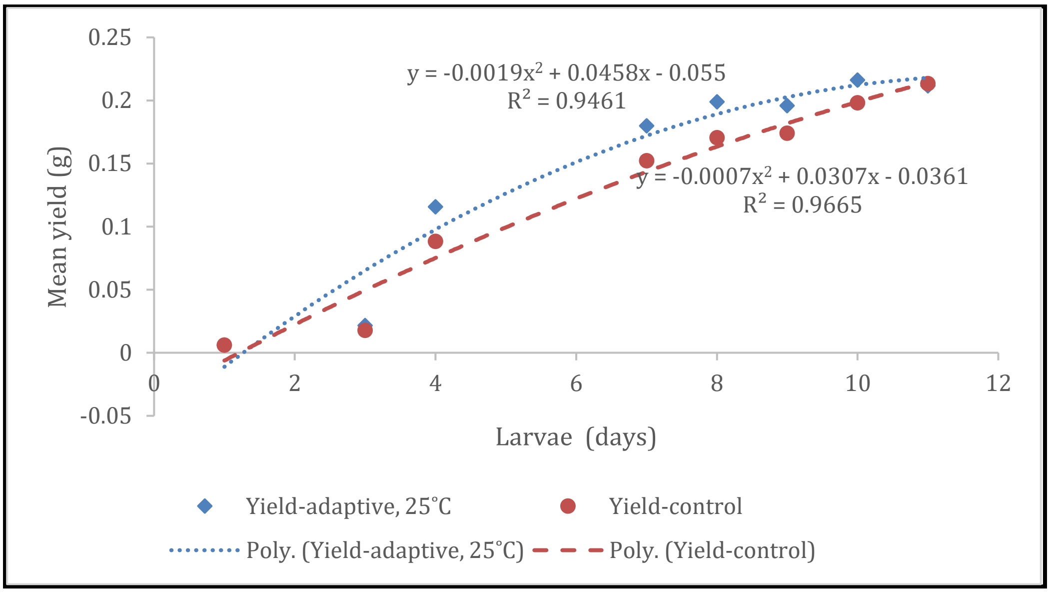

Fig. 7: Black soldier fly's mean yield at 25°C

As shown in Fig. 8, different temperature levels orchestrated distinct growth performances. At day four, BSF reared at temperature levels of 25℃, 27℃, and 30℃ recorded a mean weight of 0.063 ± 0.046 g, 0.115 ± 0.030 g, and 0.131 ± 0.044 g, respectively (F = 34.198, p = 0.0). On the 14th day (10th day of the experimental run) of the larval stage, the maximum average weight at 25°C, 27°C, and 30°C were 0.216 ± 0.022 g, 0.234 ± 0.019 g, and 0.249 ± 0.016 g, respectively (Table 1).

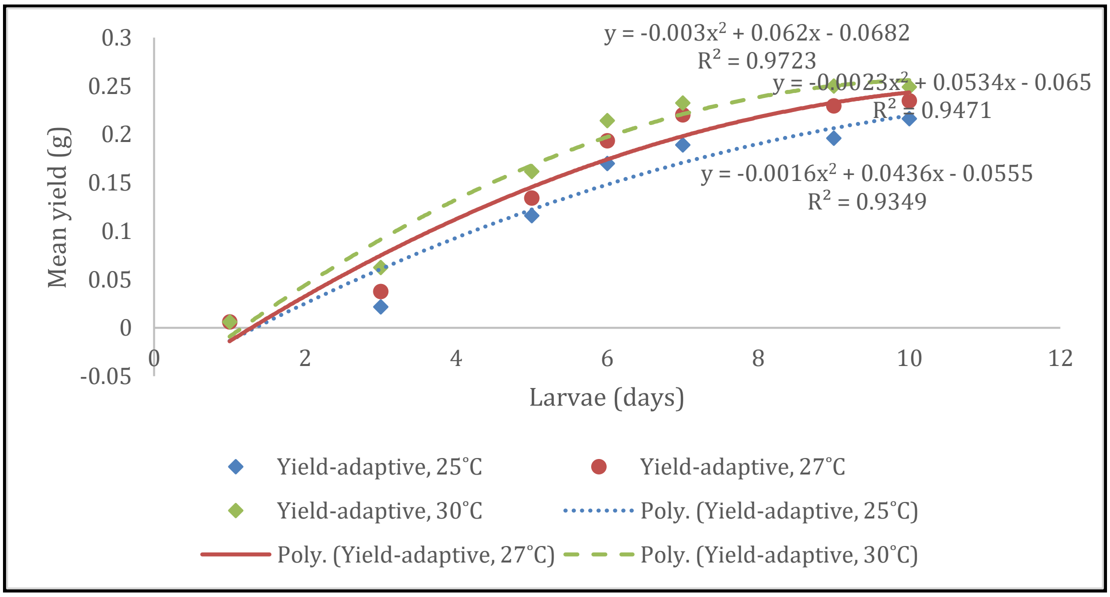

Fig. 8: Black soldier fly's larvae mean yield at 25°C, 27°C and 30°C

The cricket mean yield exhibited varying growth characteristics from the two rearing chambers. On the 16th day, crickets from the adaptive chamber recorded a weight of 0.039 ± 0.022 g, whereas those from the control setup registered a mean weight of 0.034 ± 0.080 g (F = 0.46, p = 0.833). However, on the 29th day of the experiment, there was a significant growth difference in mean body weight, as illustrated in Fig. 9. From the adaptive chamber, crickets had a mean weight of 0.323 ± 0.114 g, whereas those from the control setup had an average body weight of 0.05370 ± 0.027 g (F = 52.954, p = 0.000). After 42 days, the average weight at 25°C, 27°C, and 30°C were 0.807 ± 0.167 g, 0.933 ± 0.102 g, and 1.306 ± 0.254 g, respectively (F = 34.052, p = 0.000).

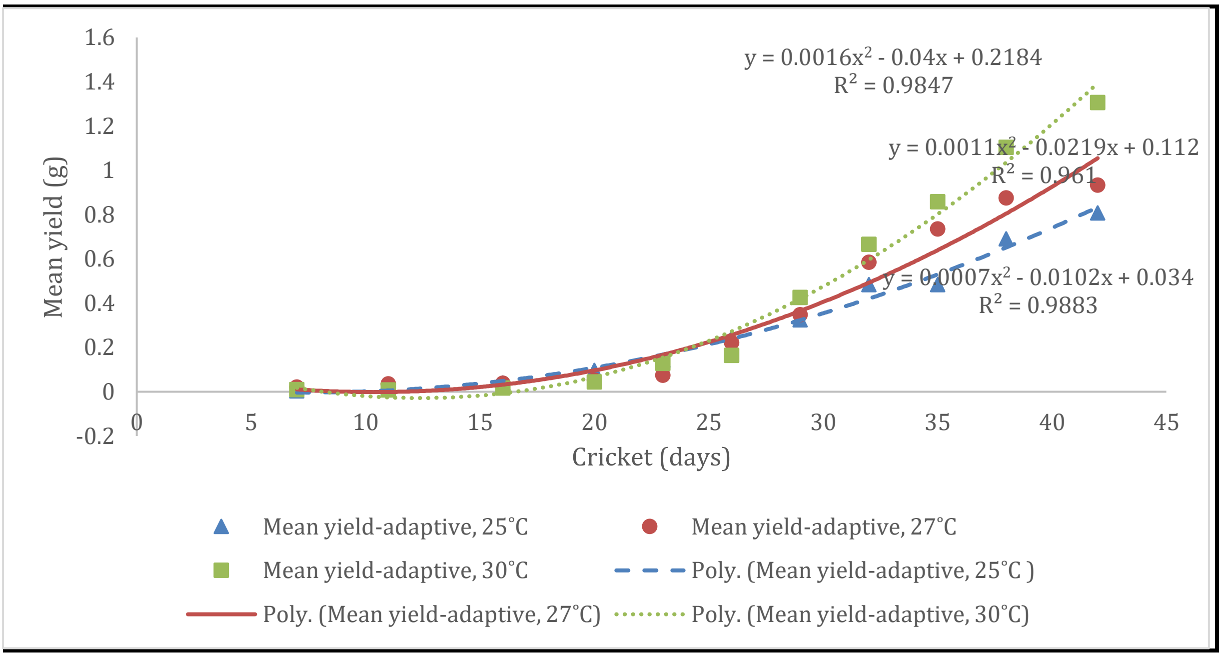

Fig. 9: Crickets' mean yield at 25°C, 27°C and 30°C

From the experiment, the average protein yield of crickets reared at 25°C, 27°C, and 30°C was 25.566 ± 0.012%, 46.811 ± 0.647%, and 58.217 ± 1.510%, respectively (Table 1). However, the protein yield from the control setup was 20.727 ± 0.005%. On the other hand, black soldier fly protein yields also varied with temperature. From the study, the average protein yield of BSF reared at 25°C, 27°C, and 30°C was 42.655 ± 1.732%, 47.121 ± 0.015%, and 62.536 ± 0.014%, respectively. However, those reared in the control set-up had varied mean yields; for instance, during the first experimental run, the obtained BSF yield was 28.043 ± 0.000, whereas the yields from the second and third trials were 30.528 ± 0.143 and 49.160 ± 0.021, respectively. The temperature regime in the control set-up was predominantly outside the chosen range, an indication that fluctuating temperatures produce low protein yields.

Table 1: BSF's and cricket protein (%) at different rearing temperatures

Rearing temperature (˚C)	Protein content (%)	
	BSF Larvae	Cricket
25	42.655 ± 1.732	25.566 ± 0.012
27	47.121 ± 0.015	46.811 ± 0.647
30	62.536 ± 0.014	58.217 ± 1.510
Ambient temperature	28.043 ± 0.000	20.727 ± 0.005
	30.528 ± 0.143	19.719 ± 0.025
	49.160 ± 0.021	21.719 ± 1.004

4.0 Discussion

Overall, crickets and BSF larvae had a higher body weight and protein content at higher temperatures. Among different environmental variables, temperature is a dominant factor influencing insect yield (Chai et al. 2018; Bjørge et al. 2018). Energy assimilation, growth rate, and protein content depend on the prevailing rearing conditions. This study shows that cricket and BSF growth rates are dictated by temperature. For both insects, protein turnover and growth rate peaked at 30˚C compared to those reared at 25˚C. Besides other biotic factors, temperature is a dominant factor influencing insect performance (Bjørge et al., 2018). As anticipated, the growth rates of black soldier flies and crickets were more dominant at 30˚C than those reared at 25˚C. Previously, crickets reared at 28˚C exhibited a faster growth rate than those reared at 25˚C (Booth & Kiddell, 2007). From this study, the growth pattern from the rearing temperature levels assumed a similar and steady curve for the first few instars and thereafter a higher mass gain in the last instars, a confirmation of the findings of the previous research (Bjørge et al., 2018). Comparatively, the growth curves of insects reared at higher temperatures dominated the growth curves of insect samples raised at low temperatures. Environmental conditions define the growth rate of insects. As such, appropriate feeding and desired rearing conditions guarantee a good yield on the farm. Naturally, relative humidity and temperature represent an inverse proportion. Consequently, a rise in temperature lowers the level of the prevailing relative humidity, and vice versa.

The ambient temperature in the control study was observed to go as low as 15°C. This low level can hardly support various insect physiological activities such as locomotion, reproduction, and basic body metabolism. Under a low-prevailing temperature regime, insects tend to hide in crevices in search of warm conditions, thereby limiting their ability to feed on more food substrates. A decrease in ingestion results in a decline in growth rate. Similarly, based on the outdoor conditions, the relative humidity recorded during the study could rise to the saturation point at night or go below the recommended moisture conditions. High-humid conditions lower body temperature or initiate the influx of diseases due to dumpy conditions, whereas low-humid conditions orchestrate the dehydration of insects, thus suppressing growth. From the adaptive chamber, the prevailing conditions of temperature and relative humidity were stable, thus guaranteeing insect growth and development.

Insects reared at 30˚C attained a higher body mass weight compared to those raised at lower temperature levels. Using the SPSS software, statistical results revealed distinct variations from the harvested yield. As of day three of the experimental run, the BSF mean yield from the adaptive chamber was 0.022 ± 0.005 g, whereas those from the control chamber had an average weight of 0.0177 ± 0.005 g (F = 7.856, p = 0.007). Specifically, BSF reared at 30˚C weighed 15% more compared to those reared at 25˚C. However, these findings differ from the findings of Harnden and Tomberlin (2016) in the sense that BSF reared at 30˚C weighed 30% more as compared to those reared at 24.9˚C. The difference could be attributed to the type of diet (grain, beef, and pork) used in the previous treatment. Also, from a different research finding, BSF fed on market waste and chicken feed weighed about 0.20 g and 0.25 g on the 15th day of the experiment, respectively (Diener et al., 2011). The type of feed used also influences the insect's weight gain (Matheka et al., 2021). For instance, BSF reared using cow dung and spent grain attained different body masses at the same temperature level. At 25˚C, BSF fed on cow dung had a mean weight of 0.088 ± 0.004 g, whereas those fed on spent grain had a mean weight of 0.153 ± 0.013 g under the same temperature (Shumo et al., 2019).

Different temperature levels orchestrate distinct growth performances. At 30˚C, BSF fed on cow dung had a mean weight of 0.106 ± 0.027 g, whereas those fed on spent grain had a mean weight of 0.156 ± 0.011 g under the same temperature (Shumo et al., 2019). In comparison, it is evident that BSF reared at a temperature level of 30˚C throughout this study, despite being fed on chicken waste mixed with bran meal, weighed more than those fed using cow dung or spent grain. An independent t-test carried out showed that mean yields between 25˚C and 30˚C were statistically significant (p = 0.03). A p-value less than 0.05 depicts a statistically significant difference in that the independent variable indeed affected the dependent variable. The experimental output did not happen by chance. Specifically, after two weeks, BSF reared at 30˚C weighed 15% more compared to those reared at 25˚C. However, these findings differ from the findings of Harnden and Tomberlin (2016) in the sense that BSF reared at 30˚C weighed 30% more as compared to those reared at 24.9˚C. However, the difference could be attributed to the type of diet (grain, beef, and pork) used in the previous treatment and also to the duration taken to complete the larval stage. The grain meal used contained 50% wheat bran, 20% corn meal, and 30% alfalfa (Harnden & Tomberlin, 2016).

Different temperature levels stimulated different growth rates among cricket samples. Such a gain in weight after 42 days is higher than values reported earlier for field crickets kept in plastic cages and fed on chicken feed. The chicken feed contained 5% ash, 87% dry matter, 4% crude fat, and 21% crude protein (Miech et al., 2016). Previously, field crickets kept in plastic cages under ambient temperatures had a mean weight of 0.59 ± 0.013 g after a period of 49 days (Miech et al., 2016). The mean average weight for such a study almost reached 1 g after 70 days, and this is an elongated period used for rearing purposes (Miech et al., 2016). Previous research indicated that crickets (*A. domesticus*) reared in concrete cages attained a protein content of 36–60% over a period of twelve weeks (Kinyuru & Kipkoech, 2018). However, the delay in maturity could have been due to the prevailing low ambient temperature (17-22˚C).

Thus, the results from the study in a controlled environment indicate that a shorter period used to rear crickets does not affect the protein content.

In a bid to test the significance of the means of weight gained from rearing temperature levels, an independent t-test was carried out. Results indicated that the obtained means were not statistically distinct for cricket development. Crickets raised at 30˚C fail to record a significantly higher mean yield as compared to those raised at a temperature of 25˚C ($t = 0.777$, $p = 0.388$). Such an insignificant statistical difference could be attributed to the fact that the hideout crates safeguarded against severe temperature drifts across the two temperature regimes, as they partly acted as heat pockets. On the contrary, an independent t-test carried out on crickets reared at 30˚C showed a significant statistical difference compared to those reared in the control set-up ($t = 27.51$, $p < 0.000$). The outdoor conditions greatly interfered with the active metabolic activities of crickets raised in such an environment, resulting in a reduction in the insect's growth rate and development. The obtained high growth rate of 0.218 g/week from the study far exceeded the growth of 0.037 g/week earlier recorded by Orinda et al. (2017), who used a greenhouse tunnel to rear crickets. The higher growth rate can be attributed to more stable temperature regimes, which consequently elevated the metabolic rates and moulting rates of the reared crickets. Due to an increase in temperature, accelerated enzymatic activities tend to enhance the completion of developmental stages. These results further uphold the findings of Holmes (2010), who maintained that ectotherms require warmth for enhanced growth and development.

Rearing temperature dictates protein turnover in insects. Low rearing temperature levels translate into low assimilation of protein content in the final body mass. In the experiment, the BSF protein yield varied with temperature. In addition, field crickets raised using chicken feed inside plastic cages yielded a protein content of 23.4% after a period of 70 days (Miech et al., 2016). On the contrary, BSF farmed in the open and fed on food waste attained a protein content of 38.98% (Nyakeri et al., 2017). As such, this is an indication that favourable rearing conditions tend to promote higher nutrient uptake and better assimilation.

5.0 Conclusion

It has been shown from this study that rearing conditions determine insects' growth and development. A temperature range of 25°C to 30°C, a relative humidity of 50%, and an air speed of 3 m/s were adopted for the entire study. According to the study, crickets and BSF grew faster at higher temperatures and slower at lower temperatures. The adoption of insect control structures plays a key role in enhancing the production of farmed insects. It is imperative to modify the existing environmental conditions to suit insect needs through regulation of ambient conditions. Empirical data indicates that in order to produce 1 kg of meat, 7.7 kg of feed is needed for beef, 6.3 kg for sheep, 2.2 kg for chicken, and 1.7 kg for cricket meat. It is clear that cricket converts plants into biomass five times faster than cattle. This low feed and water requirement for crickets, combined with their ability to derive nutrients from bio-wastes, qualifies them as a better option to go by. Conventional livestock contributes more greenhouse gases than domesticated insects. In the wake of a rising population, the release of biodegradable waste from an array of human activities has greatly triggered environmental pollution. Thus, the adoption of BSF insects will mitigate further damage and offer an alternative, cheap source of diet. The protein content of BSF larvae almost equates with the current sources of soybean (48%) and fishmeal (55%), used as animal feeds, and thus may serve as a perfect substitute for animal protein. Explicitly, the inclusion of this substitute will greatly downscale the cost of production of fortified feeds across the entire market, as well as enhance environmental hygiene and sanitation.

6.0 Acknowledgement

6.1 Funding

Our gratitude is expressed to the African Development Bank (AfDB) for the scholarship granted to the corresponding author. The generous research funds received from both AfDB and the National Research Fund (NRF) in Kenya are also gratefully acknowledged.

6.2 Declaration of interest

None

6.3 Conflict of interest

None

7.0 References.

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ISSN 1561-7645 (online)
doi: 10.4314/jagst.v23i6.1