

BLACK SOLDIER FLY (*Hermetia illucens*) AND HOUSEFLY (*Musca domestica*)
LARVAE AS BIODEGRADATION AGENTS OF DAIRY WASTES AND
SOURCE OF ANIMAL FEED

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Science and Technology

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TECHNOLOGY

APRIL, 2024

DECLARATION

This research thesis is my original work and has never been submitted in part or whole for the award of degree or diploma in any other university or institution.

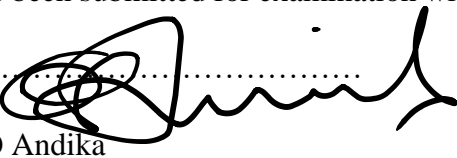
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DEDICATION

I dedicate this thesis to my mother, Mrs. Rose Kilonzi and my sibling Isaac Kilonzi, Jacob Kilonzi, Sarah Kilonzi, Esther Kilonzi and Samuel Kilonzi, Whose unconditional love, sacrifices to encourage me has been the cornerstone of my educational journey.

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ABSTRACT

Accumulation of dairy waste and shortage of nutritious feed remain the major challenges in dairy cattle production. Such wastes may sustainably be biodegraded by black soldier fly larvae (BSFL) and housefly larvae (HFL) into forms which can be used as animal feed. This study was done to compare the capacity of using black soldier fly larvae (BSFL) and housefly larvae (HFL) to manage dairy wastes and use of such larvae as an alternative protein source for animal feed. Larval weight gain, prepupal yield, survival rate, biomass reduction rate, biomass reduction index, bioconversion rate, feed conversion ratio and nutritional composition of resultant BSF and HF prepupae raised on cow dung (CD) and dairy shed effluent (DSE) were determined. In order to ascertain whether the substrates had an effect on black soldier fly larvae (BSFL) and housefly larvae (HFL), analysis of variance (ANOVA) was used, and multiple mean comparisons at $P \leq 0.05$ were done using the Tukey HSD post-hoc test. Housefly larvae reared on DSE had the highest biomass reduction rate of 50.6% and biomass reduction index of 5.06, even though HFL had a shorter development time than BSFL ($P \leq 0.05$). Housefly prepupae reared on DSE had the highest crude protein content of 60.1% of all the HF prepupae counterpart and BSF prepupae reared on DSE and CD ($P \leq 0.05$). Hence HF prepupae could be an alternative source of animal feed. Depending on the needs and purpose, utilization of fly larvae to manage dairy waste is a viable and effective option.

Keywords

Black soldier fly larvae, Housefly larvae, bioconversion, nutritional composition, Feed.

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LIST OF ABBREVIATIONS AND SYMBOLS

ANOVA-	Analysis of variance
FAO	- Food and Agricultural Organization
BSF	- Black soldier fly
BSFL	- Black soldier fly larvae
HF	- Housefly
HFL	- Housefly larvae
GHG	- Greenhouse gas
JOOUST	- Jaramogi Oginga Odinga University of Science and technology
CRD	- Completely randomized design
°C	- Degree Celsius
PH	- Power of hydrogen
DSE	- dairy shed effluent
CD	- Cow dung
HSD	- Honest significant difference
KNBS	- Kenya national bureau of statistics
SDGs	- Sustainable development goals

CHAPTER ONE: INTRODUCTION

1.0: Background Information

Dairy cattle are a major source of food and livelihood in many communities in the world, Africa and in Kenya. Dairy production is expected to increase by 94 percent in 2015-2050 to meet the demand of milk, meat and their by-products for the increasing human population (FAO, 2018). Intensive production on private dairy farms is an option to achieve increasing demand of dairy products. This has led to generation and accumulation of approximately 75,000 metric tons per day of dairy shed effluent and cow dung on such farms in Kenya (Fyfe *et al.*, 2016; Awasthi *et al.*, 2019; KNBS, 2019). Seventy percent of the wastes is typically left untreated thus creating filthy environments with foul odor, promote global warming due to greenhouse gases when stored for a long time, breeding of disease vectors, transmission of parasites and diseases (Kong *et al.*, 2018; Ravindran *et al.*, 2019).

One of the most common wastes in dairy farms is the biodegradable nutrient-rich dairy shed effluent comprising of urine, dung, wash water, residual milk, and waste feed (Fyfe *et al.*, 2016). Currently, management of such waste mainly relies on conventional technologies where it is used for soil enrichment and amendment in crop fields and disposal into fish pond. However, this is time-consuming and restricted, it is associated with high initial and operating cost, requires large areas of land and it enhances spread of parasites and pathogens (Fan *et al.*, 2019). As a result, it is essential to improve management of dairy shed effluent while protecting the environment and achieving food security.

Fly larvae such as BSFL and HFL play an important role in cutting down volumes of organic waste such as pig and chicken manure, fecal sludge, banana peels and municipal waste and converts them into larval body masses that are useful alternative protein source for animal feed (Diener *et al.*, 2011; Čičková *et al.*, 2015; Nyakeri *et al.*, 2017). Black soldier fly larvae and HFL are voracious eaters of organic waste of plant, animal or human origin (Newton *et al.*, 2005; Diener *et al.*, 2009; Myers *et al.*, 2008). Their powerful mouth parts and sufficient digestive enzymes possess the capacity to consume large quantities of waste quicker and efficiently convert them into their own nutritious body masses for use as source of animal feeds. These unique characteristics make both

flies to be more suitable for the management of organic waste such as dairy shed effluent, cow dung and use as animal feed.

The utilization of black soldier fly larvae and housefly larvae in dairy shed effluents and cow dung has a great impact in developing countries like Kenya. Unlike other biodegradation processes such as composting, vermicomposting and biogas production via anaerobic decomposition, it reduces waste up to 50%-60% of the initial amounts of waste (Newton *et al.*, 2005) , converts the wastes into to larval biomass used as source of animal feed and generate by-products such as biodiesel when larval fat is extracted (Zheng *et al.*, 2012).

The larvae could also be utilized to extract chitin for use in the medical sector and as feed for animals (Newton *et al.*, 2005). Khan *et al.*, (2016) demonstrated that housefly based meal increased body weight, carcass weight, breast muscle yield, juiciness and water holding capacity of broiler chicken, nevertheless, black soldier fly based meal improved laying performance where by chicken fed on black soldier fly and housefly larvae have extended egg laying period, lay large numbers of eggs and are more healthier due to improved microbiomes in their gut (Biasato *et al.*, 2020; Heuel *et al.*, 2021).The authors further indicated that nutritional value of the larvae meal vary depending on the diet they were reared on, therefore, utilization of BSFL and HFL to manage dairy shed effluent and cow dung requires knowledge on capacity, growth performance and nutritional value of larvae reared on particular substrates. According to Ooninx *et al.*, (2015) larval survival rate and growth rate are influenced by environment and growth medium type (Čičková *et al.*, 2012).

Both flies' larvae have been part of different livestock manure degradation in Kenya however; information on the bioconversion efficiency of the two fly larvae is limited. Hence there is need to explore more comparable information between the BSFL and HFL, which is what this study seeks to achieve by assessing the capacity of sustainable use of BSF larvae and HF larvae to manage dairy shed effluent and cow dung based on larval weight gain, prepupae yield, survival rate, percentage biomass reduction, biomass reduction index, bioconversion rate and feed conversion ratio. Moreover, the effect of dairy shed effluent and cow dung on nutritional content of both flies larvae were evaluated to ascertain their potential for use alternative source of livestock feed.

1.1: Statement of the problem

Dairy shed effluent is the most common waste in dairy cattle production consisting of urine, dung, wash water, residual milk and waste feed. Approximately 75,000 tons of dairy shed effluent is produced in Kenya daily and even greater quantities of such wastes are expected to increase as dairy sector expands to meet the demand of food for the growing global population (Fyfe *et al.*, 2016; Awasthi *et al.*, 2019).

Seventy percent of such waste is left untreated thus creating filthy environments with obnoxious odor; promote global warming due to greenhouse gases emission, breeding of disease vectors, transmission of parasites and diseases. Furthermore, open lagoons and dumpsites are expensive, labor intensive and waste agricultural land (Ravindran *et al.*, 2019), time needed to create finished compost varies greatly depending on the waste's composition, how frequently it is aerated, how much moisture is present and how hot or cold the environment is (Bullock *et al.*, 2013).

The procedures of composting do not address the problem of lost natural nutrients that can be recovered through the insect larvae bioconversion process (Barry, 2004). However, the ability of dairy shed effluent and cow dung to enhance growth performance and their influence on bioconversion efficiency of black soldier fly (BSF) and housefly (HF) larvae is not known.

Utilization of insect larvae such as black soldier fly (BSF; *Hermetia illucens*) and housefly (HF; *Musca domestica*) could fit the dairy waste management role since nutrients would be recaptured efficiently; volumes of waste reduced in valuable organic fertilizer and larvae utilized as livestock feeds contributing to improved food security (Diener *et al.*, 2009; Čičková *et al.*, 2015). Therefore, this study aimed at assessing the capacity of black soldier fly and housefly larvae in management of dairy shed effluent, cow dung and determine their potential use of such larvae as an alternative source of animal feed.

1.2: General Objective

To contribute to management of dairy wastes using BSFL and HFL, and provide alternative source of animal feed for improved food security.

1.2.1 Specific Objective

- i. To determine the growth performance of BSFL and HFL fed on dairy shed effluent and cow dung.
- ii. To assess the bioconversion efficiency of BSFL and HFL fed on dairy shed effluent and cow dung.
- iii. To determine the nutritional composition of BSF and HF prepupae fed on dairy shed effluent and cow dung.

1.3: Hypothesis

- i. Dairy shed effluent and cow dung do not enhance growth performance of BSFL and HFL.
- ii. Dairy shed effluent and cow dung do not influence bioconversion efficiency of BSFL and HFL.
- iii. Dairy shed effluent and cow dung do not influence nutritional composition of BSF and HF prepupae.

1.4: Justification

Technologies employed in management of dairy waste vary accordingly. The conventional methods of dairy waste management such as composting, application on farm land are associated with nutrients leach, contamination of water streams and dams, breeding zones for disease vectors, offensive odor and high potential to cause greenhouse gas emission. In bioconversion technology involving degradation of dairy wastes using fly larvae in a secure environment offers an alternative, sustainable, eco-friendly and modern method of recycling dairy wastes. The resultant larvae and prepupae provide alternative animal feed while the residue waste could be used in crop and vegetable farming as it is highly nutritious organic fertilizer that could replace significant amount of inorganic fertilizer for increased sustainability, food production and hence improved food security.

1.5: Significance of the study

The study is important as it contributes to the existing body of knowledge on BSFL and HFL as biodegradation agents, sources of livestock feed and also relevant to the global Sustainable development goals (SDGs) and Kenya's Vision 2030. At the global level, the study directly and indirectly contributes to eight out of the seventeen SDGs. This include: SDG 1 - Poverty eradication in all its forms everywhere; SDG 2 - Food security, improved nutrition and promotion of sustainable agriculture; SDG 3 - Healthy living and promotion of well-being; SD6 - Sanitation for all; SDG12- sustainable consumption and production patterns; SDG 13 – Combating climate change and its impacts; SDG 14 – Conservation and sustainable use the oceans, seas and marine resources for sustainable development and SDG15 –Protection, restoration and promotion of sustainable use of terrestrial ecosystems, forests and halting biodiversity loss.

Adoption of BSFL and HFL technology for biodegradation agents of dairy shed effluent and cow dung and source of livestock feeds such as chicken and fish at both small and large scale can contribute to a source of income for most families through the selling of the harvested prepupae, organic fertilizer and farmed livestock. This contributes to both poverty reduction (SDG1) and also serves to improve environmental sanitation through waste reduction (SDG6).

1.6: Scope of the Study

Utilization of insect flies in management of organic waste is gaining great attention in Kenya and in the world. There has been a corresponding interest in the need to understand the capacity of black soldier fly and housefly larvae in managing and biodegrading organic waste into useful products. In a view to this, this study focuses on comparing bioconversion efficiency between black soldier fly and housefly larvae putting into consideration parameters such biomass reduction percentage, bioconversion rate, feed conversion ratio and biomass reduction index. Growth parameters of both fly larvae were also evaluated. The study consists of two experiments, one for BSF as treatment and two substrates; dairy shed effluents and dung. The second experiment consists of housefly larvae with the mentioned substrates. The experiments were replicated thrice. Moreover, comparative nutritional composition was conducted. The study was conducted at JOOUST located in Bondo, Siaya county Kenya.

1.7: Limitation of the study

Growth and development time of Black soldier fly larvae and housefly larvae are different, with larvae of housefly pupating after 7-10 days and black soldier fly 25 days. Therefore, the house fly experiment was conducted in three batches while maintaining the amount of substrate constant. Abundance of housefly and black soldier fly was greatly affected by weather condition, for instance on rainy weather housefly are abundant as opposed to black soldier fly.

1.8: Definition of term

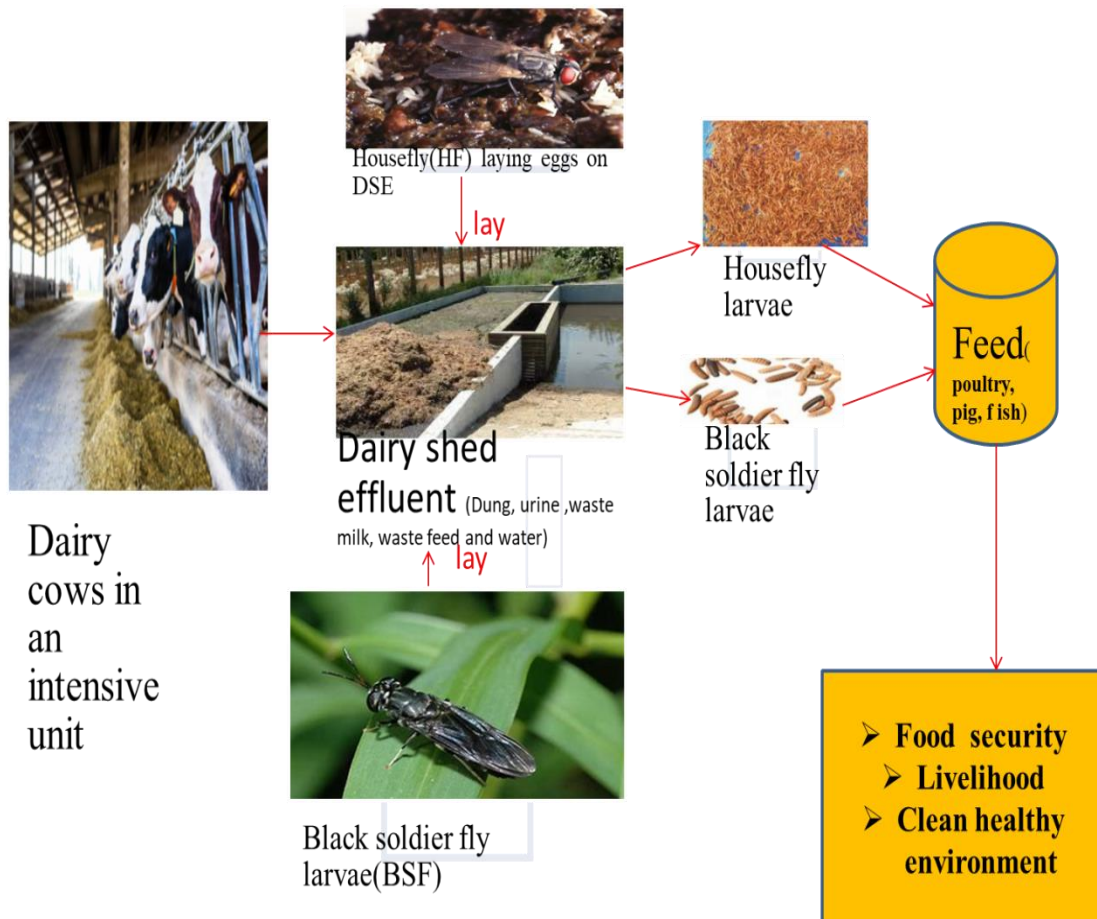
Frass -mixture of substrates left overs, larvae excrete and exoskeleton.

Dairy shed effluent-is a combination of dairy cattle urine, dung, wash water, residual milk, and waste feed (Fyfe *et al.*, 2016).

Dairy wastes- wastes that comprise of dairy shed effluent and cow dung in this study

CHAPTER TWO: LITERATURE REVIEW

2.0 Conceptual framework



2.1: Challenges of organic waste

Poor waste disposal rates as the world's second-worst environmental issue in cities of low- and middle-income countries, right behind unemployment (Diener *et al.*, 2009; Hoornweg and Bhada-Tata, 2012). Among this waste is the dairy shed effluent (Fyfe *et al.*, 2016). Programs that place an emphasis on reducing consumption, reusing, and recycling of resources have replaced open-air dumping and burning in the management of solid waste (Mutafela, 2015). As a result, inorganic materials that are deemed valuable, such as glass, paper, plastic, and metal, are disposed of through recycling, and the practice has grown to be a significant source of money and employment for the unorganized sector in the majority of developing nations (Diener

et al., 2009; Diener *et al.*, 2011) However, the issue is with organic waste, which accounts for between 50% and 90% (44-65% in Kenya, according to NEMA, 2015 of all waste and whose recycling or reuse is negligible(Henry *et al.*, 2006; Hoornweg and Bhada-Tata, 2012). This is especially true in developing nations, where lack of resources prevents the installation of effective technology and equipment that can burn organic waste to provide energy. Therefore, the majority of the garbage is put in open compost heaps where it will naturally degrade and be eaten by scavenger animals (Barry, 2004; Diener *et al.*, 2011; Taiwo and Etoo 2013)

2.2: Dairy shed effluent

Dairy shed effluent is biodegradable nutrient-rich comprising of urine, dung, wash water, residual milk, and waste feed (Fyfe *et al.*, 2016). Its' management in large dairy farms is a great challenge since its production is not deliberate but an inevitable byproduct. Existing management method of dairy shed effluent creates filthy environments with obnoxious odor, produce greenhouse gases such as methane that promote global warming since these processes take approximately three to six months, breeding of disease vectors, transmission of parasites and diseases (Kong *et al.*, 2018; Ravindran *et al.*, 2019). Furthermore, open lagoons and dumpsites are expensive, labor intensive and waste agricultural land (Ravindran *et al.*, 2019).

The amount of time needed to create finished compost varies greatly depending on the waste's composition, how frequently it is aerated, how much moisture is present and how hot or cold the environment is (Bullock *et al.*, 2013) Due to competition from alternative sources like inorganic fertilizer, wind, electricity, and solar, as well as unfair policies and regulations that provide incentives and subsidies to these alternative sources of energy, the market for compost products (organic fertilizer and biogas) is also insufficient (Rouse *et al.*, 2008). Once more, the procedure does not address the problem of lost natural nutrients that can be recovered through the bioconversion process(Barry, 2004). However, insects are increasingly used for biodegradation of animal wastes and provision of alternative protein sources for feed formulation. However, insects are increasingly used for biodegradation of animal wastes and provision of alternative sources of animal feed.

2.3: Potentials of using black soldier fly larvae (*Hermetia illucens*) for management of organic waste.

Black soldier fly (*Hermetia illucens* (L.) larvae is a dipteran from the Stratiomyidae family. The larvae are notable for being ferocious eaters of organic matter with an animal or animal origin, such as cow dung, human waste, vegetable waste, and brewer's waste (Myers *et al.*, 2008; Banks *et al.*, 2014; Nyakeri *et al.*, 2017). The larvae are said to have a powerful mouthpart and several enzymes, including lysozyme, amylase, lipase, and protease, according to Kim *et al.*, (2021).

Bonelli *et al.*, (2019), indicated that the larval mid-gut is comprised of distinct anatomical regions with varying luminal pH and specific morpho-functional features. The mid-gut is comprised of cells that are important in digestion and absorption of nutrient, pH regulation in the mid-gut and endocrine regulation of the epithelium. They also revealed that, protein, carbohydrates and lipid are digested at certain chambers of the mid-gut. The study reveals further those lysozyme activities coupled with strong acidic luminal middle tract act a crucial role in denaturing pathogenic microbes present in the substrates. These properties qualify black soldier fly larvae in degradation of organic waste into their body mass and in turn used as an alternative source of animal feed.

2.4: Potentials of using house fly larvae (*Musca domestica*) in management of organic waste.

Housefly larvae (*Musca domestica*) are commonly utilized for recycling animal manure. It has relatively short life cycle and requires non-specific rearing requirements. In a study done by Čičková *et al.*, (2012) demonstrate that houseflies larvae (*Musca domestica*) are able to recycle approximately 600kg of pig cow dung per week. The authors suggested that different pig manure (centrifuged slurry, fresh manure, manure with sawdust, and manure without sawdust) influence diverse larval development, survival rate (46.9 %), in manure without sawdust, to 77 % in centrifuged slurry), Larval development took 6–11 days, depending on the manure type. One kg of wet manure yielded between 44-74g of pupae and the weight after degradation decreased 180-650 g among manure types. These capabilities qualify housefly larvae as an alternative agent of biodegrading organic waste into their body masses and in turn used as an alternative source of animal feed.

2.5: House fly larvae and Black soldier fly larvae comparison in organic waste management

A study conducted by Ong *et al.*, (2017), comparing reduction in four different rice waste show black soldier fly (BSFL) had a greater reduction rate (3.26g/10 larvae/day) than housefly(HF) larvae. However, in a fixed period four sets of housefly larvae were produced thereby generating more mass biomass than BSFL, 11.96g of BSF but 22.62g of house fly larvae from 500g of rice waste.

Another study show that housefly have the ability to reduce pig manure by approximately 18-65% (Čičková *et al.*, 2012) while black soldier fly can degrade it to approximately 50-56% (Newton *et al.*, 2005). The authors suggested that substrate types, strains, larval density, feeding rate and feeding frequency affect biomass reduction rate and bioconversion rate of the organic substrate. According to the authors report variations in the make-up of the pig manure factoring in moisture content are largely due to different production systems ranging from intensive to extensive

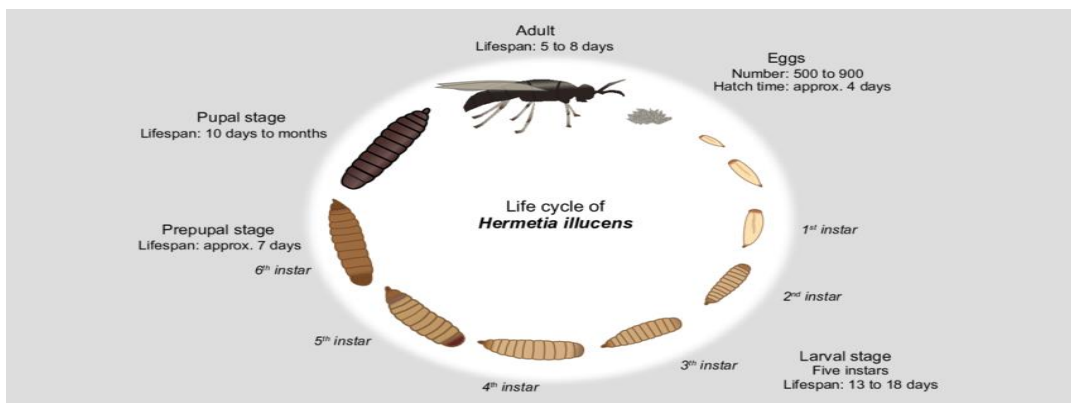


Figure 1. Life cycle of BSF

2.6: Ecological requirement of BSFL and HFL.

Both BSF and HF lifecycle stages require different ecological condition. These conditions include; optimal temperature, relative humidity (RH) and light intensity. The larval stage requires high temperature ranging between (26-35)°C and are photophobic. Both flies pupate in a dry environment, with a low humidity.

Table1: Requirements of the Black Soldier Fly at different stages of the lifecycle

lifecycle stage	Duration	Temperature(⁰ C)	RH(%)	Light intensity
Eggs	0	Above 26	Above 60	
Larval stage	0 – 4	26 -29	65 – 75	Photophobic
Larval stage	4 -14	26 – 35	65 – 75	Photophobic
Pre-pupa/pupa	10 - 14	25 – 30	Low	Photophobic
Adult	5 – 8	27 – 30	30 – 90	Photophilic

(Source:(Mutafela, 2015).

2.7: Biomass/substrate reduction rate and bioconversion efficiency

Bioconversion efficiency of substrate into larvae biomass is affected by several factor such as substrate types, fly strain larval density, feeding regime and feeding frequency. A study by Čičková *et al.*, (2012) show that reduction rate of pig manure was estimated for HF to be 18-65%. According to Newton *et al.*, (2005), BSF reared on pig manure show a reduction rate of 50-56%. The later reported that the swine manure composed of varied components including moisture content due to different production sections. They further reported that one kilogram of cow dung could be converted to larval biomass 22-27g by HF and 155g of BSF.

2.8: Growth performance of BSFL and HF reared on different substrates

Growth performance and development time is linked to biotic and abiotic factors such as temperature, relative humidity photo phase, diet, density and strain. Due to the short life cycle of HF larvae they grow in shorter period than BSF larvae and their prepupae weight is less than that of BSF prepupae (approximately a fifth of BSF prepupae)(VanHuis *et al.*, 2020).

2.9: Nutritional composition of black soldier fly and housefly larvae

Several studies have been conducted to assess the chemical composition of black soldier fly larvae (BSFL). Crude protein, fat and minerals have received a considerable attention in comparison to other parameters. The nutritional composition of BSFL is mostly influenced by the substrates the larvae fed on and the processing method (Newton *et al.*, 2005; Driemeyer, 2016).

A research conducted by Makkar *et al.*, (2014) shows that prepupae of housefly have a high crude protein and lower lipid content compared to black soldier fly. Both housefly and black soldier fly have been used as sources of protein for fish, chicken and pig with several studies showing BSF being used as feed for fish and shrimp as opposed to HF.

2.10: Potentials of HFL and BSFL utilization as Animal feed

Both HF and BSF can be used as feeds or an ingredient in feed formulation for fish, poultry and pig, especially protein source. van Huis *et al.*, (2020) indicated that BSF has been widely examined in fish, poultry, pigs and shrimp while less the case of HF. Prepupae from HF have less fat and higher crude protein than those from BSF (Makkar *et al.*, 2014). According to a study on HF raised on cattle manure by Hussein *et al.*, (2017), prepupae contained 60% protein.

The author also indicated that HF have steady amino acid profile and included 39% and 57%, of saturated and unsaturated fatty acids respectively. Additionally, HF larvae are an abundant supply of calcium and phosphorus in the ratio a 1:2. The author claims that the superiority of the nutrients nearly resembles that of fishmeal, offering the possibility of substituting it with a different sustainable source of protein. Contrastingly, BSF have abundance of lauric acid that is virtually absent in HF. This fatty acid has a healthy benefit to the feeding animals (Gasco *et al.*, 2018) and is an important source of fat in poultry diets (Kierończyk *et al.*, 2020; Schiavone *et al.*, 2017). Due to highly mineralized exoskeleton of the BSF prepupae, its digestibility is lower than that of HF prepupae especially when used as diet for monogastric animals. The other advantage of HF prepupae over BSF prepupae is dried prepupae are small in size and thus could be used directly in feed although in developing countries like Kenya grinding BSF prepupae generates a value added product (Kenis *et al.*, 2018).

Khan *et al.*, (2016) demonstrated that housefly based meal increase body weight, carcass weight, breast muscle yield, juiciness and water holding capacity of broiler chicken. Nevertheless, black soldier fly based meal improved laying performance where by chicken fed on black soldier fly and housefly larvae have extended egg laying period, lay large numbers of eggs and are more healthier due to improved microbiomes in their gut (Biasato *et al.*, 2020; Heuel *et al.*, 2021).

CHAPTER THREE: MATERIAL AND METHODS

3.0: Research site

The research was done at JOOUST, which is home to the Africa Center of Excellence for Sustainable Insect Use as Food and Feed (INSEFOODS). It is situated around 62 kilometers (39 miles) west of Kisumu in Bondo Town, Siaya County in western Kenya. The main campus of the institution is located at 0°05'38.0"S and 34°15'31.0"E. (Latitude: -0.093889; Longitude: 34.258611). A 21°C/70.6F average temperature, 57% relative humidity, and 2155mm of precipitation are the weather conditions in Bondo.

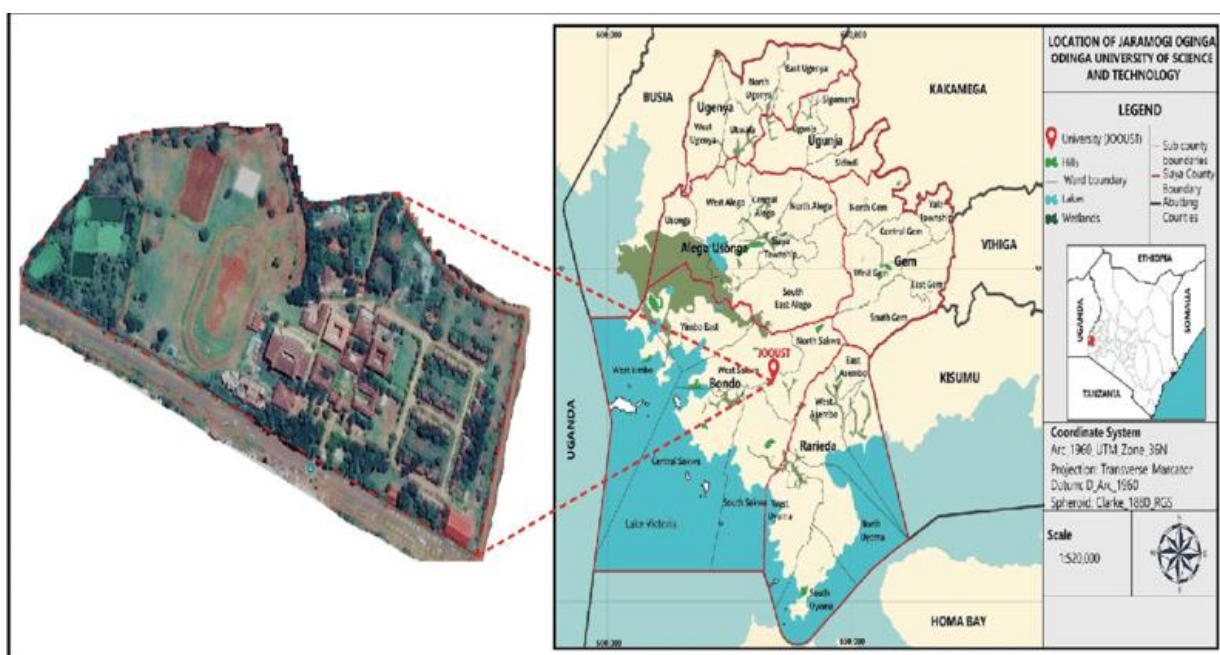


Figure 2: Map of JOOUST -research site

3.1: Source and preparation of dairy shed effluent and cow dung

Dairy shed effluent and cow dung were obtained from Jaramogi Oginga Odinga University of Science and Technology (JOOUST) dairy unit at Siaya Campus. To avoid the risk of contamination, the substrates were obtained directly from the cattle dairy shed. Dairy shed effluent refer to mixture containing urine, dung, cleaning water, leaked milk, and waste feed while cow dung refers to fresh pure dung without any other substance. The cattle were regularly inspected and attended by a veterinary officer, so the substrate could be free from pathogenic contaminants. The substrate were ground using an electric blender to uniform sized particles(1.0-5.0 mm) for maximum accessibility and consumption (Brits, 2017). in addition, uniform particles improve

degradation ability of insect larvae narrowing the chance of variations occasioned by surface area (Brits, 2017).

3.2: Source of eggs and larvae

Feeding containers containing stale chick mash were separately introduced to black soldier fly and house fly to attract female fly lay eggs. The containers were collected after one day and taken for the hatching, with temperature maintained between 25-32 degrees Celsius. Larvae that emerged from the eggs were separated from residue using 2mm sieve and allocated to feeding containers. The new larvae were fed for two days to fasten development. A perforated mesh net measuring 1.2 mm wide was used to separate larvae from residues on the third day.

3.3: Study design

The experiment involved two treatments namely dairy shed effluent and Cow dung arranged in a completely randomised design (CRD) and replicated three times. A total of 200 BSFL and 200 HFL were introduced into each feeding containers respectively. The feeding containers were filled once with 750g of dairy shed effluent, cow dung and monitored until they turn in prepupae. Amount of substrate offered relative to the understanding that each larva takes approximately 150mg/day (Banks *et al.*, 2014; Ong *et al.*, 2017). The containers were closed with mesh net to prevent stray flies from laying eggs on the substrate. Hence, a total of 12 feeding containers and 1200 larvae were utilized for the whole experiment. While moisture content of cow dung was adjusted to 74% and dairy shed effluent 89.6% moisture content to ease movement of the larvae. The moisture contents of the substrates were within the recommended range of 70-90% for optimal growth and development (He, 2010). This experiment lasted 10 days and 25 days for HF and BSF respectively at constant ambient conditions. The quantity of substrate consumed by 200 larvae was obtained from the difference between the substrate offered and residue after 25 days of experiment for BSFL and 10 days for HFL.

3.4: Larvae sampling and measurement

Sample size was determined with respect to this formula

$$n = \frac{Z^2 pq N}{e^2 (N-1) + Z^2 pq} \dots\dots\dots (1)$$

Where n is the sample size, Z is a normal reduced variable at 95% confidence level sourced from the standard normal distribution table corresponding to 1.96, p is a sample proportion = 0.5, q = (1- p) and e is the margin error =10%/0.1

$$n = \frac{1.962 \times 0.52 \times 200}{0.12 (200 - 1) + 1.962 \times 0.52} = 65$$

From each feeding container, 65 larvae were randomly chosen, counted, weighed in grams on an electronic scale, recorded, and put back into the appropriate container with respect to the above formula. At four-days interval, the procedure was repeated was applied until the prepupal stage was attained (Myers *et al.*, 2008).

Ethical issues

Black soldier fly is not considered as insect pest, however, housefly is considered as a mechanical vector, therefore the experiments was run in enclosed sterilized net cages to avoid escape and likelihood of being contaminated. The experiment ended at the prepupal stage which is not a mechanical vector therefore, there was no livestock and human involved during the experiment. The adult flies were provided with water and sugary fluid in their cages as per the animal welfare consideration, additionally, appropriate environmental conditions were maintained consisted to their natural environment. The experimenter put on protective gears whenever handling the flies, larvae and substrates. The harvested prepupae were immersed into hot water at 70⁰c for 10 seconds to avoid subjecting them to slow death.

3.5: Data collection instruments

Data was collected through observation, measurement and calculation since it is quantitative data. The following instruments were used for data collection: electronic weight scale in grams, oven, thermo-hydrometer, calculator, data sheets and laptop.

3.6: Growth performance of BSFL and HFL

Hypothesis one: H₀ = Dairy shed effluent and cow dung had no effect on growth performance of BSFL and HFL

Independent variables: substrate offered: Dairy shed effluent and cow dung

Dependent variables: black soldier fly larvae and housefly larvae growth performance (mean weight gain of larvae, mean weight of prepupae and survival rate).

Based on sampling formula 1, growth performance of BSFL and HFL were measured and recorded as explained below:

Mean larval weight and prepupae yield of black soldier fly and housefly

Mean larval weight was examined to show the effect of each feed substrates. Mean larval weight (g) of larvae was estimated by dividing the total weight of 65 randomly selected larvae from each container divided by the number of larvae sampled. Wet weight increase was estimated from the difference between current and initial larval weight. The above procedure was carried out at four days interval. Prepupae were harvested at the end of the experiment by sieving through a 3 mm and 5mm wide mesh sieve for housefly and black soldier fly respectively to obtain wet weight using an electronic weighing scale.

Survival rate

Survival rate (%) of BSFL and HFL was calculated by dividing the number of live larvae at the end of trials by 200 initial number of larvae per treatment (Oonincx *et al.*, 2015).

3.7: Effect of feed substrate on biomass reduction rate, biomass reduction index, bioconversion rate and feed conversion ratio

Hypothesis two: H₀ = Dairy shed effluent and cow dung had no effect on growth performance of BSFL and HFL

Independent variables: substrate offered: Dairy shed effluent and cow dung

Dependent variables: black soldier fly larvae and housefly larvae bioconversion efficiency (biomass reduction rate, biomass reduction index, bioconversion rate and feed conversion ratio)

The efficiency of the BSFL and HFL to consume and reduce organic matter content in the feed substrates at a uniform feeding rate of 150mg/l/d was determined by calculating biomass reduction rate, biomass reduction index, bioconversion rate and feed conversion ratio (Banks *et al.*, 2014 ;Ong *et al.*, 2017). Notably, larval development time was maintained constant while computing biomass reduction rate and bioconversion rate.

Biomass reduction rate (%) is the amount of substrate consumed, expressed as a percentage:

$$\text{Biomass reduction rate} = \frac{(\text{Total feed offered} - \text{residue remains})}{\text{Total feed offered}} \times 100$$

Biomass reduction index was obtained by dividing the reduction percentage by the number of days (t) the reduction process has taken. A higher reduction index relates to a high reduction efficiency (Diener *et al.*, 2009)

$$\text{Biomass reduction index} = \frac{\text{Biomass reduction rate}(\%)}{\text{Time}(\text{days})}$$

Bioconversion rate- this is the measure of the ability of larvae to consume a particular substrate and it is presented as a percentage:

$$\text{Bioconversion rate}(\%) = \frac{\text{Total prepupal biomass}}{\text{Total feed offered}} \times 100$$

Feed conversion ratio is the amount of feed in kilograms needed to make 1kg of animal product and this is determined as:

$$\text{Feed conversion ratio} = \frac{\text{Total feed consumed}}{\text{Total prepupal biomass}}$$

3.8: Nutritional Composition of BSF and HF Prepupae

Hypothesis three, H₀= Dairy shed effluent and cow dung have no effect on Nutritional composition of BSF and HF prepupae

Independent variables: substrate offered: dairy shed effluent and cow dung

Dependent variables: nutritional composition of BSF and HF prepupae.

3.9: Harvesting, preparation and Nutritional analysis of BSF and HF prepupae

Prepupae of BSF and HF were separated from substrates cleaned with cold water and immersed in hot water at 70⁰c for approximately 15 seconds to avoid subjecting them

to slow death. The prepupae were dried in a greenhouse at an average temperature of 34°C for four days. A mortar and pestle was used to crush dried samples. Ten grams of dried sample were collected separately from each replicate for every feed substrate and analysed for Dry matter (DM), Ash content, Crude protein, Crude fiber, ether extract, calcium, phosphorus, magnesium and zinc with respect to the Association of Analytical Chemistry(A.O.A.C) guidelines AOAC (1998).

Crude protein was determined following the Kjeldahl method that involved digesting prepupae meal samples in concentrated sulphuric acid using Digester 1009 (Foss Tecator, Höganäs, Sweden) and nitrogen content was obtained using kjeltic 220 Auto Distillation (Tecator). Crude protein was determined by multiplying nitrogen content with a factor 6.25

Calculation of results was computed based on the formula below.

Reporting as x protein as follows:-

%N is nitrogen

N = Normality of acid

T = Titration volume for sample (ml)

B = Titration volume for blank.

F = Conversion Factor for Nitrogen to

$$\%N = \frac{(T-B) \times N \times 14.007 \times 100}{\text{Weight of sample in g}}$$

Protein (6.25).

$$\% \text{Protein} = \% N \times F$$

Crude Fibre (CF)

Crude fibre of each prepupae meal was determined using the fibre analyser (ANKOM 220, Macedon, NY, USA).

Ether extract

Soxhlet fat extraction apparatus (extractor, condenser and flask 150m) and accessories were used to determine Crude lipid and were extracted using petroleum ether boiled within a range of 40 to 60 °C.

Ash determination

Muffle furnace (Nabertherm, Lilienthal, Germany) was used to determine Ash content by completely igniting the organic components of the samples at 600 °C for three hours.

$$\% \text{ Ash} = \frac{\text{weight of Ash}}{\text{weight of sample}} \times 100$$

Nitrogen-Free Extracts (NFE)

Nitrogen-free extract (NFE) was determined by subtracting the percentages of moisture, ash, lipid, crude protein and fiber from 100%. It includes errors accumulated from other determinations since it is determined by difference.

Results and calculations

$\%NFE = 100 - (\% \text{ Moisture} + \% \text{ Crude Protein} + \% \text{ Lipid} + \% \text{ Ash} + \% \text{ Crude Fibre})$.

$\%NFE = \dots\dots\dots$

Mineral analysis

Determination of calcium

Calcium ions were obtained with the use of an Atomic Absorption Spectrophotometer (AAS).

Wavelengths of electromagnetic radiation (422.7nm) from a light source were used to detect the elements in the sample. Different elements in the samples were absorbed differently and these absorbance were measured.

Determination of magnesium

Magnesium ions were obtained with the use of an Atomic Absorption Spectrophotometer (AAS). Wavelengths of electromagnetic radiation (285.2nm) from a light source was used to detect the elements in the sample. Different elements in the samples were absorbed differently and these absorbance were measured.

Determination of phosphorus

Phosphorus was determined with the use of UV-visible spectrophotometer, a beam of light from a visible and UV red light source separated into its component wavelengths by a prism. Each single wavelength beam in turn is split into two equal intensity beams by a half-mirrored device. One beam with a magenta color, passed through a small transparent container (cuvette) containing a solution of the compound being studied in a transparent solvent. The other beam with a blue color passed through an identical cuvette containing only the solvent. The intensities of these light beams are the measured by electronic detectors and compared.

Determination of zinc

Zinc ions were obtained with the use of an Atomic Absorption Spectrophotometer (AAS). Wavelengths of electromagnetic radiation (213.9nm) from a light source was used to detect the elements in the sample. Different elements in the samples were absorbed differently and these absorbance were measured.

3.10: Data Analysis

Microsoft Excel was used to capture and store the data. Prior to analysis all data was subjected to shapiro-wilk test for normality check. Analysis of variance (ANOVA) was used to test whether biomass reduction rate, biomass reduction index, bioconversion rate, feed conversion ratio, prepupal weight, survival rate and nutritional composition differed significantly between BSFL and HFL. Differences in mean were separated using Tukey HSD post hoc procedure for multiple comparisons, the mean value between treatments at a 95% confidence level. Correlation analysis was done to test the effect of time (days) on mean weight over the period of eight days of larval development. R statistical software was used to compute all analyses (R version 4.2.0).

CHAPTER FOUR: RESULTS

4.0: Growth performance of BSFL and HFL.

4.0.1: Effect of feed substrate on mean larval weight

Whereas there was a positive correlation in the mean weights of HFL and BSFL reared on CD and DSE over the eight-day developmental period, this was not significantly dependent on time ($P \geq 0.05$) (Figure 3). Substrates type influenced the mean weight of BSFL and HFL over 8 days of development ($P \leq 0.05$). Housefly larvae fed on CD had a significantly lower mean weight than BSFL ($P \leq 0.05$) while HFL fed on DSE had a significantly less mean weight than BSFL ($P \leq 0.05$). The mean weight of HFL fed on

DSE resulted in a significantly higher larval mean weight than the mean weight of HFL fed on CD ($P \leq 0.05$). Similarly, mean weight of BSFL fed on DSE was greater than BSFL fed on CD ($P \leq 0.05$).

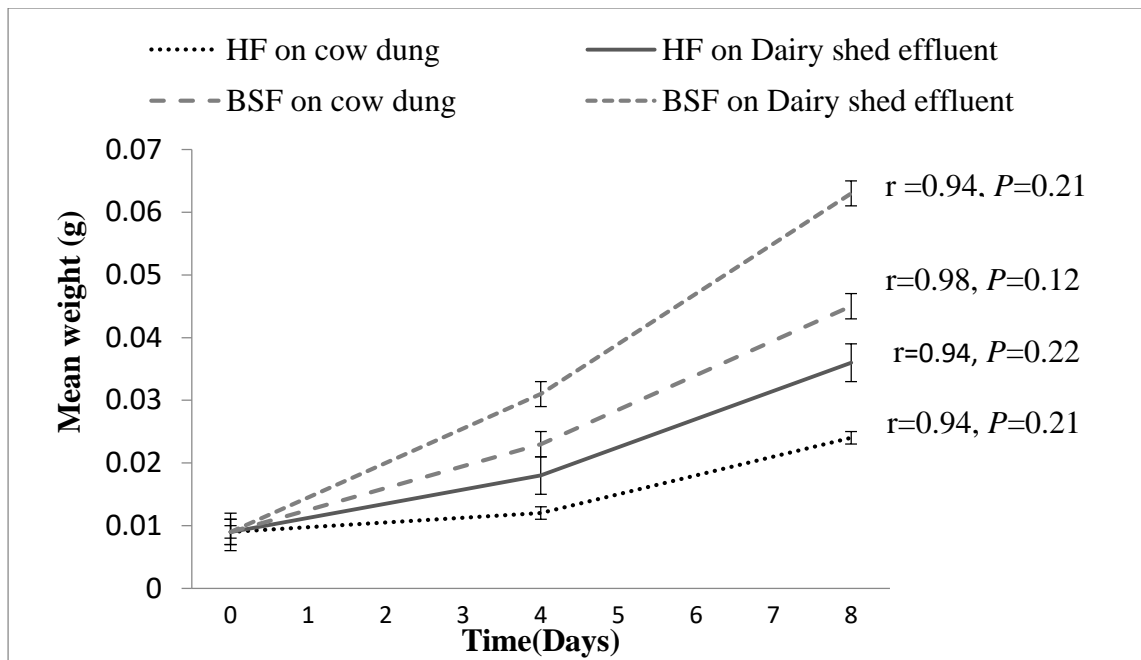


Figure 3: Mean weights of black soldier fly and housefly larvae fed on cow dung and dairy shed effluent over a period of eight days.

4.0.2: Effect of feed substrates on mean wet weight of prepupae

The substrate type used to feed HFL and BSFL significantly affected prepupae mean wet weight ($P \leq 0.05$) (Figure 4). Housefly prepupae fed on CD yielded 22.36 g lower prepupal wet weight than BSF prepupae ($P \leq 0.05$) while HF fed on DSE had 30.52 g lower mean prepupal wet weight than BSF ($P \leq 0.05$). Rearing of HF on CD also contributed to 2.91 g lower prepupal wet weight than HF fed on DSE ($P \leq 0.05$) while BSF fed on CD had 11.07 g significantly lower mean prepupal wet weight than BSF fed on DSE ($P \leq 0.05$).

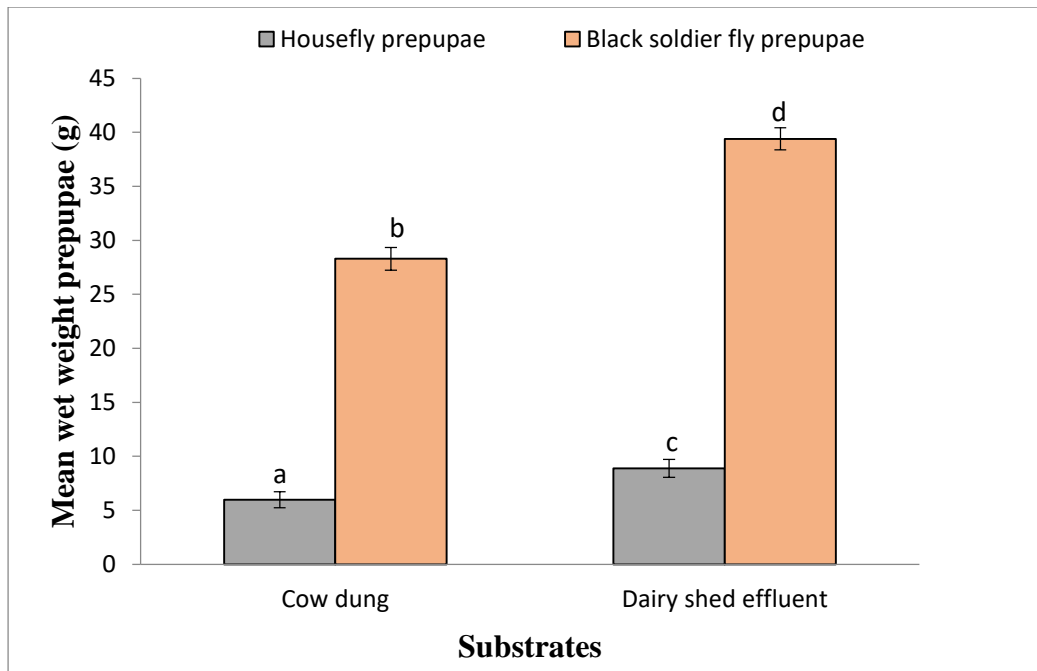


Figure 4: prepupal weight of housefly and black soldier fly fed on cow dung and dairy shed effluent.

4.0.3: Effect of Substrates on survival rate

Survival rate of HFL and BSFL was significantly dependent on the type of substrates used ($P \leq 0.05$) (Figure 5). Feeding of HFL on DSE resulted in 9.67% higher survival rate than BSFL ($P \leq 0.05$) while survival rate of HFL fed on CD was significantly higher than BSFL ($P \leq 0.05$) reared on the same substrate. Similarly, BSFL fed on CD had 8% higher survival rate than BSF fed on DSE ($P \leq 0.05$). Contrastingly, there was no difference in survival rates of HF reared on CD and DSE ($P \geq 0.05$).

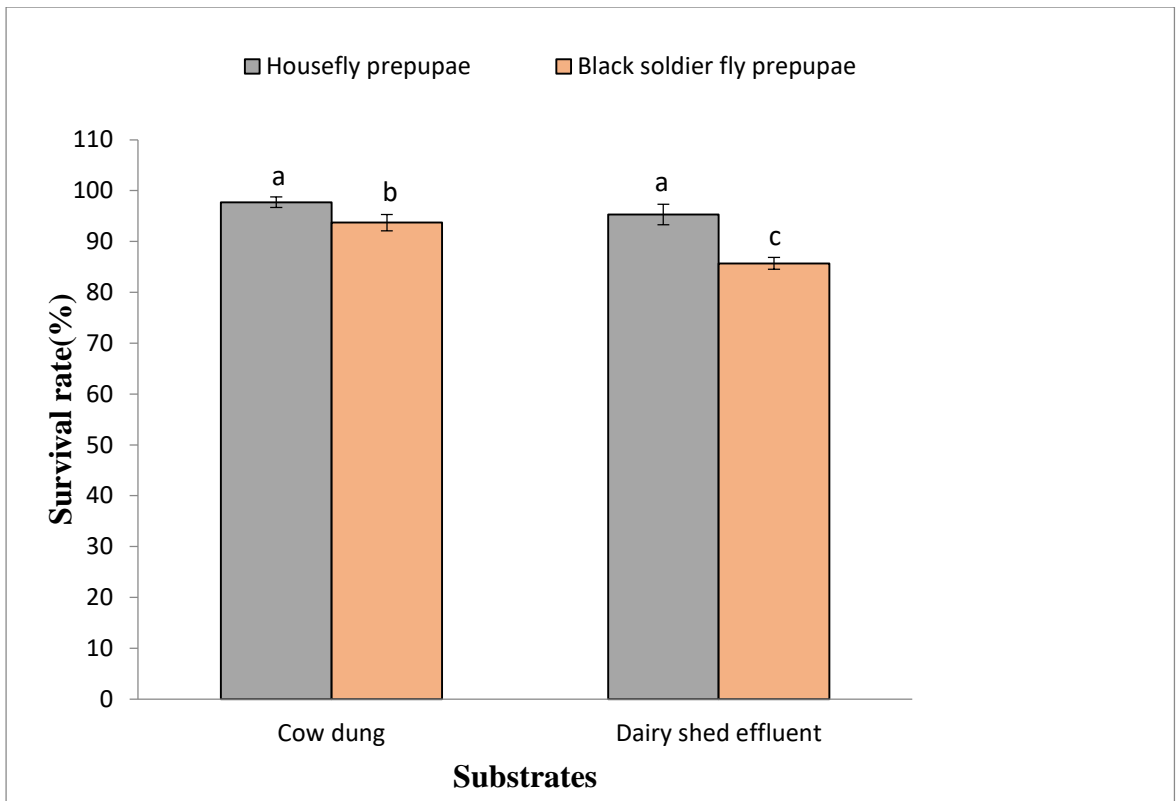


Figure 5: Survival rate of housefly and black soldier fly fed on cow dung and dairy shed effluent

4.1: Bioconversion efficiency of Housefly (HF) and Black Soldier Fly (BSF) Larvae

4.1.1: Biomass Reduction rate

Substrates used to feed HFL and BSFL had a significant effect on biomass reduction rate ($P \leq 0.05$) (Figure 6). There was a significantly higher biomass reduction rate of HFL fed on CD than BSFL larvae fed on CD ($P \leq 0.05$). Similarly a significantly higher biomass reduction rates was observed when HFL was fed on DSE than BSFL ($P \leq 0.05$). Feeding HF on DSE resulted in 5.15% more biomass reduction rate than when HFL is fed on CD ($P \leq 0.05$). Similarly, a significant difference was realized when BSFL was fed on DSE compared to BSFL fed on CD ($P \leq 0.05$).

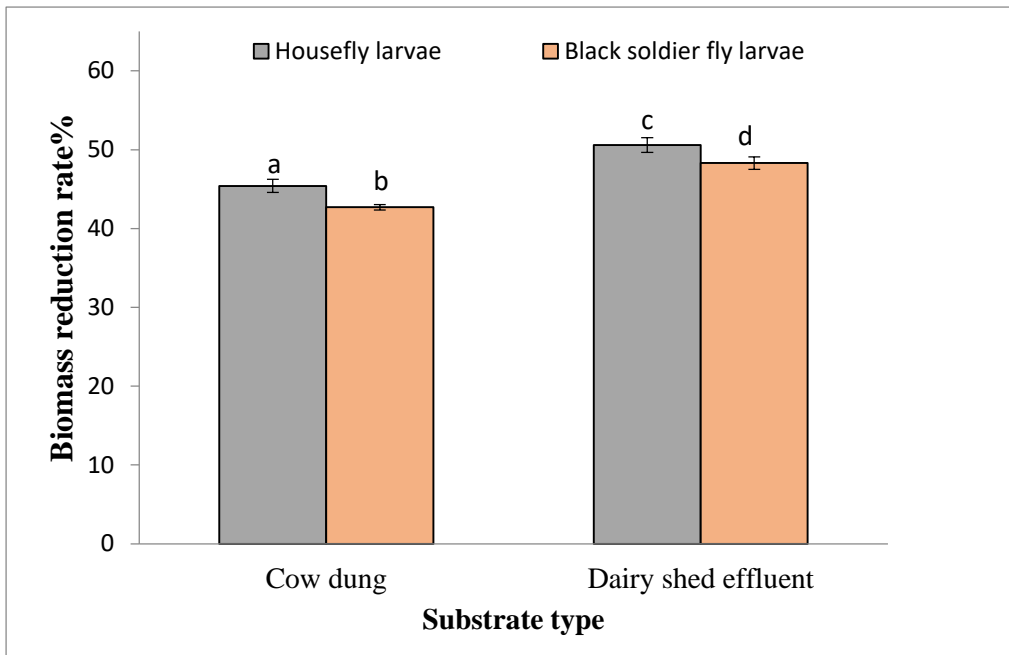


Figure 6: percentage Biomass reduction rate of housefly larvae and black soldier fly larvae fed on cow dung and dairy shed effluent.

4.1.2: Biomass reduction index.

The substrates used to feed HFL and BSFL significantly influenced biomass reduction index ($P \leq 0.05$) (Figure 7). Biomass reduction index of HFL reared on CD was significantly greater than BSFL ($P \leq 0.05$). Similarly, rearing of HFL on DSE resulted in a greater biomass reduction index than when BSFL was used ($P \leq 0.05$). There was also a lower biomass reduction index when HFL was reared on CD compared to DSE ($P \leq 0.05$). Furthermore, BSFL reared on DSE contributed to a significantly higher biomass reduction index compared to BSFL reared on CD ($P \leq 0.05$).

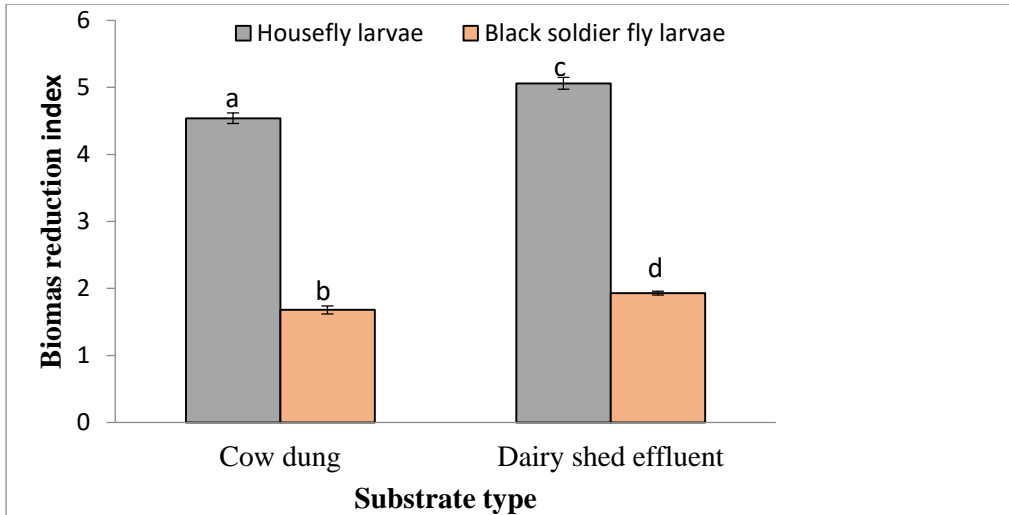


Figure 7: Biomass reduction index of housefly and black soldier fly larvae fed on cow dung and dairy shed effluent.

4.1.3: Bioconversion rate

The substrates used to feed HFL and BSFL affected their bioconversion rate ($P \leq 0.05$) (Figure 8). Bioconversion rate of BSFL fed on CD was 2.98 % higher than HFL ($P \leq 0.05$) while feeding BSFL on DSE contributed to 4.07% higher bioconversion rate than HFL ($P \leq 0.05$). Similarly, BSFL fed on DSE contributed to 1.48% more bioconversion rate than BSFL fed on CD ($P \leq 0.05$), while feeding HFL on DSE significantly yielded to higher bioconversion rate than CD ($P \leq 0.05$).

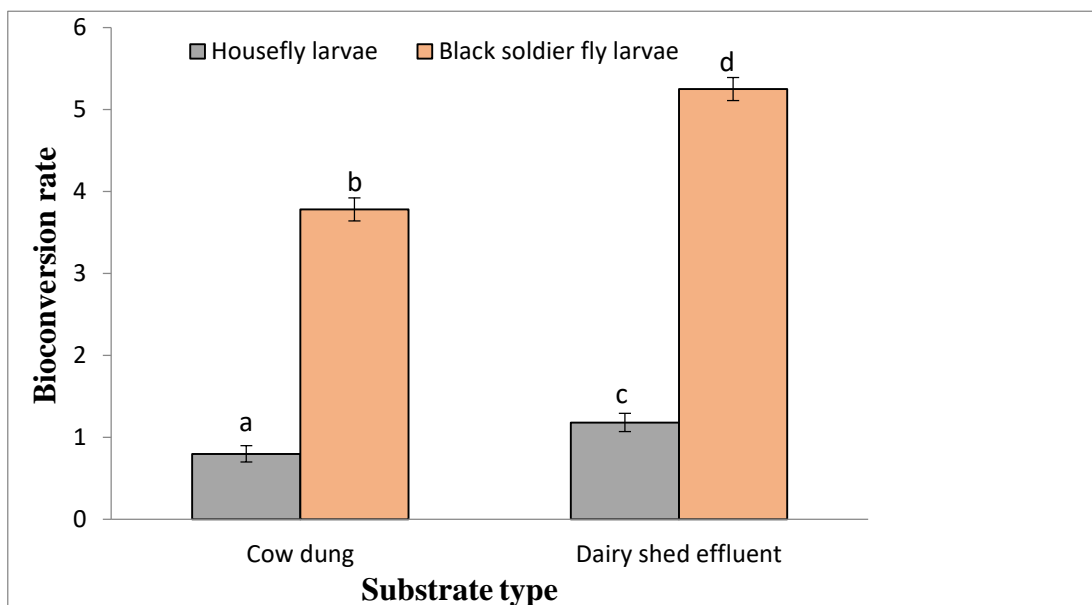


Figure 8: Percentage Bioconversion rate of housefly larvae and black soldier fly larvae fed on Cow dung and dairy shed effluent.

4.1.4: Feed conversion ratio (FCR).

The type of substrates used to feed HFL and BSFL had a significant effect on feed conversion ratio ($P \leq 0.05$) (Figure 9). Feeding HFL on CD resulted into 46.38 higher feed conversion ratio than BSFL ($P \leq 0.05$) while HFL fed on DSE had 34.21 greater feed conversion ratio than BSFL ($P \leq 0.05$). Housefly larvae reared on CD yielded 14.09 significantly higher feed conversion ratio than the HFL fed on DSE ($P \leq 0.05$). Contrastingly, there was no significant difference between feed conversion ratio of BSFL fed on CD and BSFL fed on DSE ($P \geq 0.05$).

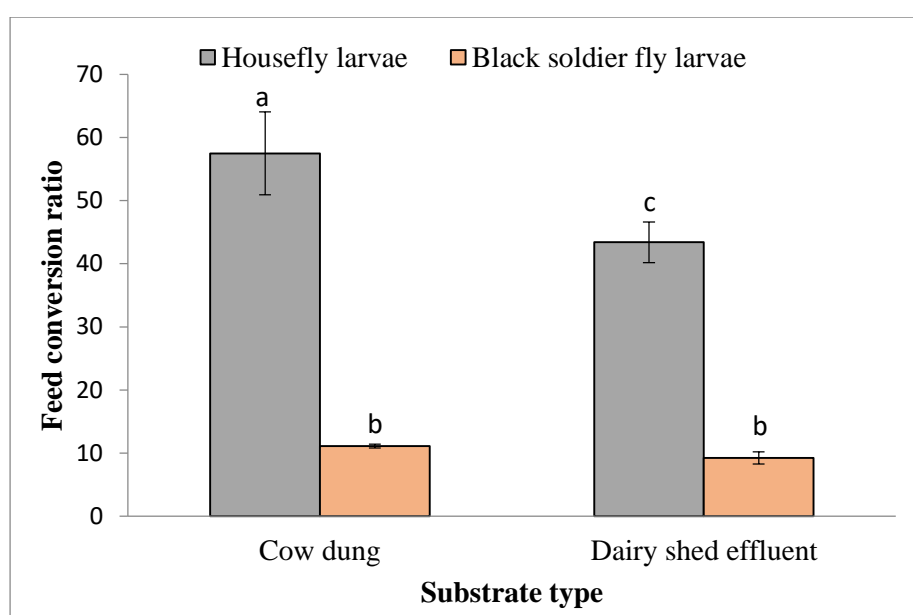


Figure 9: Feed conversion ratio of housefly larvae and black soldier fly larvae fed on cow dung and dairy shed effluent

4.2: Nutritional content of HF and BSF prepupae fed on cow dung (CD) and dairy shed effluent (DSE)

4.2.1: Effect of the feed substrate on nutritional composition of HF and BSF prepupae

Substrate type contributed significantly to variations in the composition of crude protein ($P \leq 0.05$), dry matter ($P \leq 0.05$), crude fibre ($P \leq 0.05$), Ash ($P \leq 0.05$), ether extract ($P \leq 0.05$) content of HF and BSF prepupae (Table 2).

Housefly prepupae reared on DSE contained lower dry matter content than BSF prepupae ($P \leq 0.05$) while HF prepupae reared on CD resulted in a lower dry matter

content than BSF prepupae ($P \leq 0.05$). Cow dung contributed to a lower dry matter content in HF than HF prepupae fed on DSE ($P \leq 0.05$). Contrastingly, there was no difference in dry matter content between BSF prepupae reared on CD and BSF larvae on DSE ($P \geq 0.05$).

Housefly prepupae contained more crude protein than BSF prepupae reared on the same CD substrates ($P \leq 0.05$). Whereas HF prepupae reared on DSE yielded more crude protein than BSF ($P \leq 0.05$), HF prepupae produced from CD had lower crude protein content than HF prepupae from DSE ($P \leq 0.05$). Similarly, feeding BSF prepupae on CD contributed to a lower crude protein content than BSF prepupae fed on DSE ($P \leq 0.05$).

Black soldier fly prepupae reared on CD contained more crude fibre content than HF ($P \leq 0.05$). Contrastingly, there was no significant difference in crude fibre content of HF and BSF prepupae fed on DSE. ($P \geq 0.05$). Rearing of BSF on CD resulted in a higher crude fibre than BSF fed on DSE ($P \leq 0.05$). However, there was no difference in crude fibre between HF fed on CD and HF fed on DSE ($P \geq 0.05$).

Cow dung resulted in higher ash content in BSF than HF ($P \leq 0.05$). Similarly, BSF fed on DSE contained more ash than HF prepupae ($P \leq 0.05$). In addition, HF prepupae reared on CD contained lower ash than HF fed on DSE ($P \leq 0.05$). However, the ash content between BSF prepupae reared on CD and DSE were similar ($P \geq 0.05$).

Black soldier fly prepupae contained more ether extracts than HF prepupae reared on CD ($P \leq 0.05$). Similarly, there was a higher ether extracts in BSF prepupae fed on DSE than HF prepupae ($P \leq 0.05$). However, HF prepupae reared on CD contained more ether extracts than HF prepupae produced from DSE ($P \leq 0.05$) while there was no difference in ether extract between BSF prepupae reared on CD and DSE ($P \leq 0.05$).

Table 2: Percentage of proximate composition of housefly (HF) and black soldier fly (BSF) prepupae fed on Cow dung (CD) and Dairy shed effluent (DSE)

Proximate components	Mean (\pm SE) percentage of nutrient content in HF and BSF prepupae				p-value
	Cow dung		Dairy shed effluent		
	HF prepupae	BSF prepupae	HF prepupae	BSF prepupae	
Dry matter	94.4 ^a \pm 0.10	96.7 ^b \pm 0.06	95.8 ^c \pm 0.19	96.5 ^b \pm 0.10	≤ 0.05
Crude protein	57.1 ^a \pm 0.49	40.0 ^b \pm 0.45	60.1 ^c \pm 0.22	44.0 ^d \pm 0.25	≤ 0.05
Crude fibre	8.61 ^a \pm 0.22	13.3 ^b \pm 0.45	9.49 ^{ac} \pm 0.06	10.3 ^c \pm 0.02	≤ 0.05

Ether extract	15.6 ^a ±0.03	26.3 ^b ±0.10	13.1 ^c ±0.06	26.8 ^b ±0.27	≤0.05
Ash	6.04 ^a ±0.10	14.4 ^b ±0.01	7.54 ^c ±0.04	14.5 ^b ±0.31	≤0.05

Note: Mean (±SE) percentages with different superscript letter (s) in the same row are significantly different at $P \leq 0.05$.

4.2.2: Effect of the feed substrate on mineral content of HF prepupae and BSF prepupae.

Substrates significantly influenced the content of phosphorus ($P \leq 0.05$), calcium ($P \leq 0.05$), magnesium ($P \leq 0.05$) and zinc ($P \leq 0.05$) in both HF and BSFL (Table 3). There was no difference in the content of phosphorus between Housefly (HF) and BSF prepupae reared on CD ($P \geq 0.05$), HF and BSF prepupae reared on DSE ($P \geq 0.05$) and BSF prepupae fed on CD and BSF prepupae fed on DSE ($P \geq 0.05$). However, HF reared on CD had higher phosphorus concentration than HF prepupae fed on DSE ($P \leq 0.05$).

Black soldier fly prepupae fed on CD had higher Calcium content than HF ($P \leq 0.05$) while feeding HF prepupae on DSE yielded lower calcium content than BSF ($P \leq 0.05$). However, there were no differences in calcium content between BSF prepupae fed on CD and BSF prepupae fed on DSE ($P \geq 0.05$), HF prepupae fed CD and HF prepupae fed on DSE ($P \geq 0.05$).

The magnesium content of HF prepupae reared on DSE was higher than BSF prepupae ($P \leq 0.05$), BSF prepupae reared on DSE had higher phosphorus content than BSF prepupae fed on CD ($P \leq 0.05$) and HF prepupae fed on DSE had a higher concentration than HF fed on CD ($P \leq 0.05$). However, there was no difference in magnesium content between HF fed on CD and BSF reared on the same substrate ($P \geq 0.05$).

There was no significant difference in zinc content between BSF prepupae fed on DSE and HF prepupae ($P \geq 0.05$), HF prepupae fed on CD and HF prepupae fed on DSE ($P \geq 0.05$) and BSF prepupae fed on CD and BSF fed on DSE ($P \geq 0.05$). However, HF prepupae fed on CD contained lower zinc content than BSF prepupae fed on CD ($P \leq 0.05$).

Table 3: Percentage Mineral profile (%) of housefly (HF) and black soldier fly (BSF) prepupae fed on Cow dung (CD) and Dairy shed effluent (DSE).

Mineral components	Mean (±SE) content of mineral elements in HF and BSF prepupae				P-value
	Cow dung		Dairy shed effluent		
	HF prepupae	BSF prepupae	HF prepupae	BSF prepupae	

Phosphorus	1.15 ^a ±0.11	1.04 ^a ±0.05	0.78 ^b ±0.00	0.81 ^b ±0.05	≤0.05
Calcium	0.04 ^a ±0.01	0.31 ^b ±0.00	0.10 ^c ±0.00	0.34 ^b ±0.04	≤0.05
Magnesium	0.07 ^a ±0.00	0.07 ^a ±0.00	0.10 ^b ±0.00	0.09 ^c ±0.00	≤0.05
Zinc	0.01 ^a ±0.00	0.04 ^b ±0.00	0.03 ^c ±0.01	0.04 ^{bc} ±0.01	≤0.05

Superscript letters in the same row are significantly different at $P \leq 0.05$.

5.0: CHAPTER FIVE: DISCUSSION

5.1 Growth performance

Dairy shed effluent enhanced larval development of both BSFL and HFL than CD while BSFL reared on DSE had a higher mean larval weight and prepupae weight than BSFL fed on CD; similarly HFL fed on DSE realized a higher mean larval weight and prepupae weight than HFL fed on CD. This suggest that DSE is likely to be an alternative substrate for production of BSFL and HFL since it contains approximately equal protein and ash content as chick mash which is used a conventional substrate for BSFL (Msangi *et al.*, 2022) The higher mean larval weight and prepupae weight of BSFL fed on DSE could have been associated with its superior nutritional composition as opposed to CD. Indeed substrates with superior nutritional value enhance growth and development than those with low nutrient content. Housefly larvae had a greater biomass reduction rate capability on CD and DSE, but in terms of substrate conversion into prepupal weight BSFL generated significantly higher prepupae weight compared HFL in the same time frame. Higher prepupae weight could translate into a higher output in terms of feed production which in turn leads to sustainable and reliable feed production in such farms. Nevertheless, the shorter development time of HFL to prepupae (10 days) in this study is likely to have resulted in the production of three batches of HF prepupae as opposed to one batch of BSF prepupae. Thus, the weight of HF prepupae is likely to be significantly greater than BSF prepupae weight over a constant period. Results of this study are in contrast with the work of Ong *et al.*, (2017) where the capacity of BSFL and HFL to treat rice waste was investigated. In this case HFL yielded higher weight ($22.62 \pm 0.84\text{g}$) compared to BSFL ($11.96 \pm 0.81\text{g}$) within 20- 25 days.

Housefly larvae had a prolonged survival rate when reared on CD and DSE than BSFL implying that they can survive on substrates with a wide range of moisture content than

BSFL. Survival rate of BSFL fed DSE was lower than when fed on CD indicating that BSFL survive best on substrates with 60-70% moisture content as opposed to HFL which survives beyond aforementioned range to even 90% moisture level. Since all other factors were maintained at ambient condition except moisture content so variation in survival rate was accounted for by moisture content. The survival rate (87-97%) demonstrated in this study is higher than in a previous study reported by Ong *et al.*, (2017) after assessing survival rate (46-83%) of BSFL and HFL on four types of rice waste.

5.2 Bioconversion efficiency

A lower biomass reduction rate was observed when CD was offered to HFL and BSFL compared to dairy shed effluent thereby contributing to high crude fibres content (appendix 1). Substrates that contain more lignin are known to lower capacity of insect larvae to digest such materials (Zheng *et al.*, 2012). However, acid detergent fiber analysis was not determined in the current study. Biomass reduction rates reported were in the range computed by Jucker *et al.*, (2020) of 28-72% realized after rearing black soldier fly larvae on cricket waste, chopped cricket waste, locust waste, chopped locust waste and control without restriction. Contrastingly, Nana *et al.*, (2019) reported higher biomass reduction rate of 53 -80% after feeding black soldier fly larvae continuously on pig manure, chicken manure and kitchen waste at a feeding rate of 100, 160, 220 mg/day/larvae possibly because of different moisture content, nutritional contents of the substrate and batch feeding. Therefore, nutritional composition, feeding regime and moisture contents level of the substrate influenced variation in biomass reduction rate (Gold *et al.*, 2018; Veldkamp *et al.*, 2012). Housefly reared on DSE and CD exhibited a higher biomass reduction than BSFL possibly because of their ability to forage on all available nutrients material including bacteria that occur on substrates (Nayduch & Burrus, 2017)

Biomass reduction index indicates the rate of biomass reduction per day. Housefly larvae fed on CD and DSE contributed to a higher biomass reduction index than BSFL fed on the same substrates possibly because they have a shorter development time of 10 days that translates in a faster reduction process as opposed to 25 days in BSFL. A higher reduction index relates to higher reduction efficiency (Diener *et al.*, 2009) implying that HFL is a better biodegradation agent since it has higher biomass reduction index and takes shorter time to transform CD and DSE into valuable nutritious prepupae

as a source of animal feed. This rapidly reduces accumulation of such wastes on dairy farms hence lowering the risk of disease transmission to livestock and human, reducing methane foot print and survival of nuisance flies that contribute to a filthy environmental condition.

Bioconversion rate indicates the efficiency of feed consumption in an animal. A higher value of bioconversion rate implies that the substrate is more consumed as opposed to a lower value (Nyakeri, 2018). In this study, use of both HFL and BSFL resulted in a higher bioconversion rate in DSE than CD probably because DSE is made up of different substrates components that enhance its nutritional value (Joly, 2018;Nyakeri *et al.*, 2019). Low bioconversion rate for BSFL and HFL reared on CD could be associated with a higher crude fibre leading to reduced consumption. Thus, low feed intake is associated with diets containing high fiber content (Manurung *et al.*, 2016). However, BSFL fed on both DSE and CD had higher bioconversion rate than HFL fed on the same substrates. This is due its larger body size which yields high prepupal weight and a superior digestive gut since a higher body mass is associated with a greater digestive capability (Clauss *et al.*, 2013). The bioconversion rates of both larval types demonstrated in the current study were consistent with previous results (1.6-22.9%) observed by Banks *et al.*, (2014) where black soldier fly were fed on fresh human faeces and poultry manure. However, feeding BSFL on faecal sludge, brewers waste, banana peels and food waste resulted in a higher bioconversion rate (14.9-30.2%) than in the current study (Joly, 2018; Nyakeri *et al.*, 2017, 2019). Hence, different bioconversion rate could be attributed to variations in nutrients composition of the feed substrates.

Black soldier fly fed on CD and DSE had lower feed conversion ratio than HFL. This implies that BSFL effectively utilized the feed substrate into larval mass than HFL, perhaps because their palatability and nutritive value of both substrates are more suitable for BSFL than HFL. These results agree with Mutoyoba *et al* (2011), Nyakeri, (2018), Oonincx *et al.*, (2015) and Tschirner & Simon, (2015). Low values of feed conversion ratio indicate high conversion efficiency of substrates into larval biomass while a high feed conversion ration suggest that the substrate is digestible but of low nutrient content and therefore it is mostly defecated. However, Banks *et al.*, (2014) and Manurung *et al.*, (2016) argued that larvae fed on substrate of low nutritive value have a tendency of consuming more to compensate for nutrients deficiency. This possibly explains why HFL had a high feed conversion ratio when fed on DSE and CD.

However, the feed conversion ratio for BSFL observed in this study was compared to previously reported values of 1.4-2.6 where similar larvae were fed on agro-waste and kitchen remains (Oonincx *et al.*, 2015). Thus, it is possible that efficient consumption of the substrates was not achieved in the current research. Nonetheless, the observed feed conversion ratio was consistent with 2.6-19.0 obtained by Nyakeri *et al.*, (2017, 2019) where BSFL was fed on human waste, agro based waste and food waste. However, feed conversion ratio of HFL observed in this study is the first to be reported.

5.3 Nutritional composition of HF and BSF prepupae fed on both substrates

The HF prepupae reared on DSE had the highest crude protein indicating that prepupae fed on DSE produced higher crude protein than those fed on CD and this suggests that DSE is nutritionally superior to CD. Housefly prepupae could be adopted as an alternative protein source for poultry, pig and fish, since it contains approximately 57-60.01% crude protein and low fat content commensurate to the dietary protein requirement for almost all growth stages of fish species which is in the range 28-56% especially tilapia fry and salmon (Hasan, 2001). However, BSF prepupae meal contained a high ether extract (fat) but low crude protein. This could be because adult BSF do not eat and they need to accumulate fats in their larval stage for pupation, survival of adults to breed and oviposit (Diener *et al.*, 2011).

There is a high lauric acid content in BSF prepupae but it is nearly absent in HF prepupae. This might be an advantage of using BSF prepupae meal as feed compared to HF prepupae meal. Gasco *et al.*, (2018) indicated that such fatty acids provide a healthy perk to feeding livestock and can be an appropriate source of lipid in chicken diets (Kierończyk *et al.*, 2020; Schiavone *et al.*, 2017) however, fatty acid analysis was not done in this study. Moreover, BSF prepupae meal contained more crude fiber content than HF because of it has higher chitin content in the exoskeleton of the prepupae. This lowers palatability and growth performance in monogastric animals like fish, chicken and pig, making HF meal to be a better alternative source of protein as it has more crude protein and low fiber content. Inconsistencies in nutrient composition of HF and BSF prepupae fed on CD and DSE indicate that different substrates lead to varied nutritional composition of resultant prepupae. Due to superior nutritional content of HF prepupae especially high crude protein, it could be adopted as an alternative source of animal feed.

Livestock such as poultry require mineral elements such as phosphorus, calcium, magnesium and zinc to facilitate metabolic functions. They aid growth and development, immune function, reproductive performance and various enzymatic activities. Phosphorus concentration of HF and BSF prepupae meal did not vary significantly within the two substrates used but differed significantly across different substrates whereby HF and BSF prepupae fed on CD had similar amount of phosphorus but higher concentration than those fed on DSE. These results suggested that CD and DSE contain different levels of phosphorus element. This implies that livestock farmers should manage both substrates sustainably and recycle them into larval biomass and frass that could be used for soil enrichment that improves vegetable and crop production hence improved food security

The phosphorus content of the HF prepupae meal was comparable to that seen when rearing HF prepupae on cattle manure, but it was higher than that found in soya meal and lower than that found in fishmeal (Hussein *et al.*, 2017), just as it was for the BSF prepupae fed on chicken manure (Shumo *et al.*, 2019). Previous studies on broiler production indicate that proper skeletal system development should have a balanced concentration of phosphorus and calcium in the ratio of 2:1 (Matuszewski *et al.*, 2020). Thus, BSF is a better alternative than HF prepupae meal.

Black soldier fly prepupae meals contained more calcium than HF prepupae due to the presence of exoskeleton in the BSF prepupae meal. In both BSF and HF prepupae meal the concentration of calcium was lower than soymeal and fish meal (Hussein *et al.*, 2017). Levels of other mineral elements assessed (magnesium and zinc) in BSF and HF prepupae recorded a lower but well balanced than it is in soybean meal and fishmeal. Although the results of mineral concentration show insignificant trends, HF prepupae meal is more likely to be used as feed because it contains more protein, low fibre, fat content and balanced mineral concentration hence the need for a follow-up experiment in fish, pigs, and poultry.

CHAPTER SIX: CONCLUSION AND RECOMMENDATION

6.1: Conclusion

Black soldier fly larvae had higher mean larval weight, prepupal yield than HFL. High prepupae weight of BSFL indicates that it can meet required quantities of feed much faster than HFL, although both larvae can be reared in the same farm for use as animal feed.

Housefly larvae reared on DSE and CD performed better in terms of biomass reduction rate, biomass reduction index than BSFL. This renders HFL an alternative agent of biodegrading DSE and CD, reduce accumulation of such wastes on the farms and produce valuable organic fertilizer

House fly prepupae reared on DSE had the highest crude protein (60.1%) content compared to BSF prepupae. However, both BSF and HF prepupae could be used as an alternative source of protein in the same farm interchangeably in case of unprecedented occurrence for sustainable feed production and formulation for improved food security.

6.2: Recommendations

1. Dairy shed effluent should be adopted as a viable substrate for mass rearing of HF based on its superior growth performance, nutritive value and quality of prepupae fed on this substrate as it is locally availability.
2. House fly larvae and BSFL should also be adopted as alternative source of feed interchangeably since one could insure the other in terms of sustainable feed production and supply.

6.3 Recommendations for further studies are required to determine the:

- a) A comparative study on growth performance and nutritive performance of poultry and fish reared on HF and BSF based feeds

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Appendix 1

Mean (\pm SE) percentage of dry matter, crude protein, crude fiber, Ash, Nitrogen-free extract and ether extract in cow dung and dairy shed effluent. The

Nutrient content	cow dung	Dairy shed effluent	p -value
Dry matter	98.5 \pm 0.11 ^a	98.3 \pm 0.16 ^a	\geq 0.05
Crude protein	12.47 \pm 0.13 ^a	14.2 \pm 0.09 ^b	\leq 0.05
Crude fiber	38.60 \pm 0.08 ^a	26.8 \pm 0.15 ^b	\leq 0.05
Ether extra	3.30 \pm 0.09 ^a	1.9 \pm 0.06 ^b	\leq 0.05
Ash	19.70 \pm 0.1 ^a	18.1 \pm 0.05 ^b	\leq 0.05
Nitrogen-free extract	25.9 \pm 0.04 ^a	39.0 \pm 0.06 ^b	\leq 0.05

Mean (\pm SE) percentage values with different superscript letter (s) in the same row are significantly different at $P \leq 0.05$.

Appendix 2



JARAMOGI OGINGA ODINGA UNIVERSITY OF SCIENCE & TECHNOLOGY
BOARD OF POSTGRADUATE STUDIES
Office of the Director

Tel. 057-2501804
Email: bps@jooust.ac.ke

P.O. BOX 210 - 40601
BONDO

Our Ref: A451/4084/2020

Date: 23rd February 2022

TO WHOM IT MAY CONCERN

RE: BENJAMIN MUTHAMA KILONZI - A451/4084/2020

The above person is a bonafide postgraduate student of Jaramogi Oginga Odinga University of Science and Technology in the School of Agricultural and Food Sciences pursuing Master of Science in Food Security and Sustainable Agriculture. He has been authorized by the University to undertake research on the topic: *“Assessing Bioconversion Efficiency of Black Soldier Fly and Housefly Larvae in Managing Dairy Shed Effluent for use as Feed”*.

Any assistance accorded him shall be appreciated.

Thank you.

Prof. Dennis Ochuodho
DIRECTOR, BOARD OF POSTGRADUATE STUDIES

Appendix 3



**JARAMOGI OGINGA ODINGA
UNIVERSITY OF SCIENCE AND TECHNOLOGY**

**DIVISION OF RESEARCH, INNOVATION AND OUTREACH
JOOUST-ETHICS REVIEW OFFICE**

Tel. 057-2501804

Email: erc@jooust.ac.ke

Website: www.jooust.ac.ke

P.O. BOX 210 - 40601

BONDO

OUR REF: JOOUST/DVC-RIO/ERC/E4

16th June, 2022

Benjamin Muthama Kilonzi

A451/4084/2020

JOOUST

Dear Mr. Kilonzi,

**RE: APPROVAL TO CONDUCT RESEARCH TITLED "ASSESSING BIOCONVERSION
EFFICIENCY OF BLACK SOLDIER FLY AND HOUSEFLY LARVAE IN MANAGING
DAIRY SHED EFFLUENT FOR USE AS FEED"**

This is to inform you that JOOUST ERC has reviewed and approved your above research proposal. Your application approval number is ERC 17/06/22-16. The approval period is from 16th June, 2022 – 15th June, 2023.

This approval is subject to compliance with the following requirements:

- i. Only approved documents including (informed consents, study instruments, MTA) will be used.
- ii. All changes including (amendments, deviations and violations) are submitted for review and approval by JOOUST IERC.
- iii. Death and life threatening problems and serious adverse events or unexpected adverse events whether related or unrelated to the study must be reported to NACOSTI IERC within 72 hours of notification.
- iv. Any changes, anticipated or otherwise that may increase the risks of affected safety or welfare of study participants and others or affect the integrity of the research must be reported to NACOSTI IERC within 72 hours.
- v. Clearance for export of biological specimens must be obtained from relevant institutions.
- vi. Submission of a request for renewal of approval at least 60 days prior to expiry of the approval period. Attach a comprehensive progress report to support the renewal.
- vii. Submission of an executive summary report within 90 days upon completion of the study to JOOUST IERC.

Prior to commencing your study, you will be expected to obtain a research permit from National Commission for Science, Technology and Innovation (NACOSTI) <https://oris.nacosti.go.ke> and also obtain other clearances needed.

Yours sincerely,

Prof. Francis Anga'wa

Chairman, JOOUST ERC

Copy to: Deputy Vice-Chancellor, RIO Director, BPS Dean, SAFS

