PROXIMATE AND NUTRIENT ASSESSMENT OF AQUAPONIC SLUDGE AND INSECT FRASS COMBINATIONS FOR ORGANIC FERTILIZER PRODUCTION

OWOLABI RAMON OLAYINKA

MATRIC NUMBER: 222162

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CERTIFICATION

This is to certify that this research was carried out by OWOLABI, RAMON OLAYINKA with matric number 222162, under my supervision in the Department of Aquaculture and Fisheries Management, University of Ibadan, Ibadan, Nigeria.

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Supervisor **Date**

Dr. O.O. OYEBOLA

B.Sc., M.Sc., Ph.D. (Ibadan)

DEDICATION

I dedicate this work to Almighty Allah, the giver of knowledge who saw me through the journey of this program. I also dedicate it to my late father, Alhaji Amusa Owolabi whose contribution to this journey is unmatched. May your soul continue to rest in peace *baba mi owon.*

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ABSTRACT

The INCiTiS-FOOD project created circular food production models for sustainable city food production in African cities. However, the need for the re-use of agro-based urban food production related wastes necessitated an investigation into the chemical, and mineral qualities of the insect production frass, dead flies and aquaponic sludge in the INCITIS-Food's circular city food production model for sustainable utilization.

Samples of waste types including sludge (SoAn), BSF-Based frass (FoAn), and dead BSF flies (FDOAn) were obtained from respective aquaponic digester, wheat offal-based frass of BSF feeding system, and dead BSF flies in a circular aquaponic - BSF production system. These were analyzed for proximate, and mineral content of freshly collected and subsequent daily (24hours) for 7days anaerobic storage condition in replicates. The best-quality two waste sources were obtained at the period of highest nutrient content, then combined at 0%, 25%, 50%, 75%, and 100%. The combinations were assessed for proximate, and mineral content. Proximate and mineral content of the aqeous solution of the best combination were assessed during 7days soaking period to select the best soaking duration (days) for highest mineralization. Data were analyzed for differences through descriptive statistics and ANOVA at $p<0.05$.

The study reveals the dynamic nature of nutrient composition in organic waste materials during anaerobic storage, highlighting the potential of Aquaponic sludge, black soldier fly frass, and dead BSF flies as valuable resources for plant nutrition. Results indicate that Crude protein was lowest in BSF-Frass (14.99±0.30), highest in BSF flies (51.92±0.23). crude ash was lowest (5.17±0.06) in deadflies, highest (12.53±0.32) in sludge. Then, Nitrogen(N) was lowest in frass (2385±7.071), highest in deadflies (12015±21.213). Potassium(K) was lowest in frass (1935±7.071), highest in deadflies

(2295±35.355). Phosphorus(P) ranges from the lowest in frass (1800±14.142) to the highest in deadflies (1975±21.213).

It can therefore be inferred from the results that even the treatment with the least nutritional composition can be used for organic fertilizers, although careful management is required due to high nutrient concentrations and imbalance N:P:K ratios which has been observed to improve after the frass/sludge combinations have been evaluated. Further research is recommended to optimize application methods. This study underscores the feasibility of utilizing organic waste materials for sustainable agriculture and resource recovery, contributing to a circular economy and promoting environmental sustainability.

Keywords: Aquaponic Sludge, Black Soldier Fly Frass, Dead Flies, Circular economy, Sustainable agriculture.

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CHAPTER ONE

INTRODUCTION

1.1 Background

Food production is required if human beings are to live a long and secure life (Gamage *et al.,* 2023). Human survival is hinged on sustainable production of crops, animals, and fish in agriculture, aquaculture, and their integrations. Agriculture is a human activity, encompassing both crop, and animal production, at the same time, aquaculture is the breeding, growing, and harvesting of fish and other aquatic plants, also known as farming in water.

Aquaculture is an environmental source of food and commercial products that help to improve healthier habitats and are used to reconstruct the population of endangered aquatic species. Technology has increased the growth of fish in coastal marine waters and open oceans due to the increased demand for seafood (US Department of Commerce, National Oceanic and Atmospheric Administration, 2022). Aquaculture production is outstanding and its uses continue to unfold, particularly in aquaponics and integrated multi-trophic aquaculture, both of which integrate fish farming and aquatic plant farming.

Aquaculture is the farming of aquatic organisms including fish, molluscs, crustaceans and aquatic plants; implying some form of intervention in the rearing process to enhance production, such as regular stocking, feeding, protection from predators, etc. Fish farming also implies individual or corporate ownership of the stock being cultivated (Food and Agriculture Organization, 2011). However, aquaculture is one of the industries most directly affected by climate change and some forms of aquaculture have negative impacts on the environment through nutrient pollution or disease transfer to wild populations (FAO, 2019).

Also, modern agricultural practices affect the environment in terms of nutrient cycle, soil erosion, carbon sequestration, and many other ecological impacts. Meanwhile, organic farming is an influential practice to minimize ecological impact for sustainable agriculture development. Usage of more organic matter in agricultural practices can reduce the adverse effects on the environment by saving its natural cycles on the recovery process. Such an integrated farming approach may enhance the food quality, and may largely exclude the usage of chemical fertilizers, pesticides, growth hormones, and feed additives of livestock activities.

Organic farming is one of the fastest-growing sectors in agriculture, contributing 1% of the world's agricultural area; a farming system that uses fertilizers of organic origin such as compost manure, green manure, and bone meal and emphasizes techniques such as crop rotation and companion planting (Seufert *etal*., 2017).

Organic farming is practiced in 187 countries, with at least 3.1 million farmers operating 72.3 million hectares of farmland organically (Willer *et al.,* 2021). Organic food and drink sales in 2019 totaled more than 106 billion euros worldwide, showing the high interest of contemporary people getting used to healthy and environment-friendly eating habits: being health conscious. Organic farming is practiced in 187 countries, with at least 3.1 million farmers operating 72.3 million hectares of farmland organically (Willer *et al.,* 2021).

Organic farming mirrors the sustainability concepts of Global Agriculture (Gamage *et al.*, 2023). However, there is a need for a combination of organic farming and other new technologies making new trends toward sustainable farming systems, enhancement of agricultural productivity, and quality of life of many farmers in an environmentally friendly way. It reduces carbon emissions, improves soil health, and reloads natural ecosystems for cleaner water and air, all while avoiding hazardous pesticide residues (Gamage *et al.,* 2023).

The primary distinction between organic and conventional farming is that conventional farming depends on chemical involvement to combat pests and weeds, as well as to supply plant nutrients. In the meantime, the availability of organic food production is often challenged by low productivity and the need for nutrient addition through organic fertilization. A combination of organic farming and technologies of soiless farming and organic fertilizer production would reduce the limitations and challenges of organic farming, and boost healthy food production and food security.

One of the trending techniques that fits into integration with organic production is the aquaponic system of fish production and insect farming.

Aquaponics is a unique farming method that combines aquaculture, the practice of raising fish, with hydroponics, the method of growing plants in a soilless environment. In an aquaponics system, fish and plants are cultivated together in a symbiotic environment where they mutually benefit from each other’s presence. The fish produce waste, which is converted by beneficial bacteria into nutrients that plants can absorb. In turn, the plants filter and purify the water, creating a healthy environment for the fish. This closed-loop system is highly efficient, using significantly less water than traditional farming methods and eliminating the need for chemical fertilizers (Gogreenaquaponics, 2024).

Aquaponic reduces the release of aquaculture liquid waste effluents into the environment by channeling liquid waste from fish production units into vegetable production. However, the systems still leave solid wastes to be discharged into the environment. In this case, the environmental footprint is reduced but not abolished. Finding proper use for this solid waste from aquaponic in crop production has been a good idea, but would require knowledge of its chemical and mineral content and the dynamics of these in storage time and possible combinations with other waste sources in achieving nutrient balance for crop growth.

Insect farming, also known as mini livestock or microstock, is being integrated as a cost-effective replacement for fish meal in aquaculture and aquaponic systems. Insects can be farmed for their products, such as silk, honey, lac, or insect tea, or for direct use as food, feed, dye, and other purposes (Dobermann*et al.*, 2017). Certain fly larvae can substitute fish meal due to their similar amino acid composition, and formulations can enhance unsaturated fatty acids. Insects serve as feed for various animals, including reptiles, fish, mammals, and birds (Sánchez-Muros,2014). However, insect farming generates organic waste, such as frass and dead flies, which contribute to the ecological footprint. These wastes, combined with aquaponic sludge, have potential for organic fertilizer production. Understanding the chemical and nutrient composition of such combinations is essential for effective use (Rumpold,2013).

1.2 Problem statement

Synthetic fertilizers harm the environment due to high nitrogen and phosphorus levels, leading to phosphorus runoff that causes algae blooms and devastates aquatic life (Schill, 2024). While they do not directly kill soil bacteria, synthetic fertilizers stimulate microbes to consume more organic matter than plants can replenish, depleting soil nutrients over time (Schill, 2024). Overreliance on synthetic fertilizers has reduced research into improving organic alternatives, making synthetic options more effective for yield but detrimental to long-term soil health (Schill, 2024). Agriculture, heavily dependent on inorganic fertilizers, contributes about 20% of global greenhouse gas emissions, making soil fertility management crucial (Schill, 2024). Excessive use of synthetic fertilizers alters soil biological activity, reduces organic matter, and negatively impacts earthworms and other essential decomposers (Schill, 2024). Runoff from these fertilizers contaminates water bodies, leading to eutrophication, harming aquatic species, and contributing to acid rain through ammonia emissions (Schill, 2024). Heavy metals from continuous synthetic fertilizer use accumulate in soil and crops, reducing food nutritional quality and increasing health risks from nitrates, particularly in children (Agramondis, 2023). Aquaculture, a key solution for global food security, generates wastewater rich in pollutants, including heavy metals and biological contaminants, requiring improved treatment methods for sustainable management (Liu et al., 2024). While recirculating aquaculture systems and other treatments exist, their efficiency in removing pollutants needs enhancement to achieve zero-waste discharge (Liu et al., 2024). A shift toward sustainable practices in fertilization and aquaculture wastewater management is necessary to mitigate environmental and health risks while ensuring long-term productivity (Schill, 2024; Liu et al., 2024).

1.3 Justification

The proximate and nutrient assessment of aquaponic sludge and insect frass combinations for organic fertilizer production is essential to determine their suitability as a sustainable soil amendment. Nutrient profiling ensures the presence of essential macronutrients and micronutrients needed for plant growth. The organic matter content in the combination plays a crucial role in improving soil structure, microbial activity, and nutrient retention. Waste valorization through this assessment promotes circular economy practices by reducing environmental pollution and repurposing organic waste into useful agricultural inputs. Additionally, assessing the combination’s decomposition rate and potential nutrient leaching minimizes the risk of water contamination and soil degradation. Optimizing the nutrient composition aligns with specific crop requirements, improving yield and quality. Lastly, conducting a thorough assessment ensures compliance with agricultural and environmental regulations, supporting the development of sustainable fertilization practices.

1.4 Objectives

1.4.1 Main Objectives

The main objective of this study is to understand the chemical and mineral composition of insect frass and aquaponic sludge, their combination, and stored products for possible use in the production of liquid organic fertilizer.

1.4.2 Specific Objectives

The specific objectives of the study are to:

1. Evaluate the proximate and mineral composition of fresh aquaponic sludge, Insect frass, and dead flies.
2. Investigate the storage time for the best proximate and mineral profile yield in an anaerobically stored Aquaponic sludge, Insect frass, and dead flies.
3. Assess the effects of the inclusion levels of aquaponic sludge and Insect frass or dead flies on proximate and mineral profile of the combinations for the production of organic fertilizer

CHAPTER TWO

LITERATURE REVIEW

2.1 Aquaponics.

Aquaponics is a food production system that couples aquaculture (raising aquatic animals such as fish, crayfish, snails or prawns in tanks) with hydroponics (cultivating plants in water) whereby the nutrient-rich aquaculture water is fed to hydroponically grown plants (Rakocy and James, 2023).

Plants are grown in hydroponics systems, with their roots immersed in the nutrient-rich effluent water. This enables them to filter out the ammonia that is toxic to the aquatic animals, or its metabolites. After the water has passed through the hydroponic subsystem, it is cleaned and oxygenated, and can return to the aquaculture vessels (Ibrahim, *et al.*, 2023).

The size, complexity, and types of foods grown in an aquaponic system can vary as much as any system found in either distinct farming discipline (Rakocy *et al.*, 2013). The main fish grown in aquaponics are tilapia, koi, goldfish, carp, catfish, barramundi, and different types of ornamental fish. The main plants produced include lettuce, pak choi, kale, basil, mint, watercress, tomatoes, peppers, cucumbers, beans, peas, squash, broccoli, cauliflower, and cabbage (Yavuzcan *et al.*, 2017).

Fish, plants and microbes are three main components of aquaponics, and microbes play the bridge role of converting fish waste to plant nutrients. The three major types of modern aquaponic designs are deep-water or "raft", nutrient film technology, and media-based bed or reciprocating systems (Zou *et al.*, 2016).

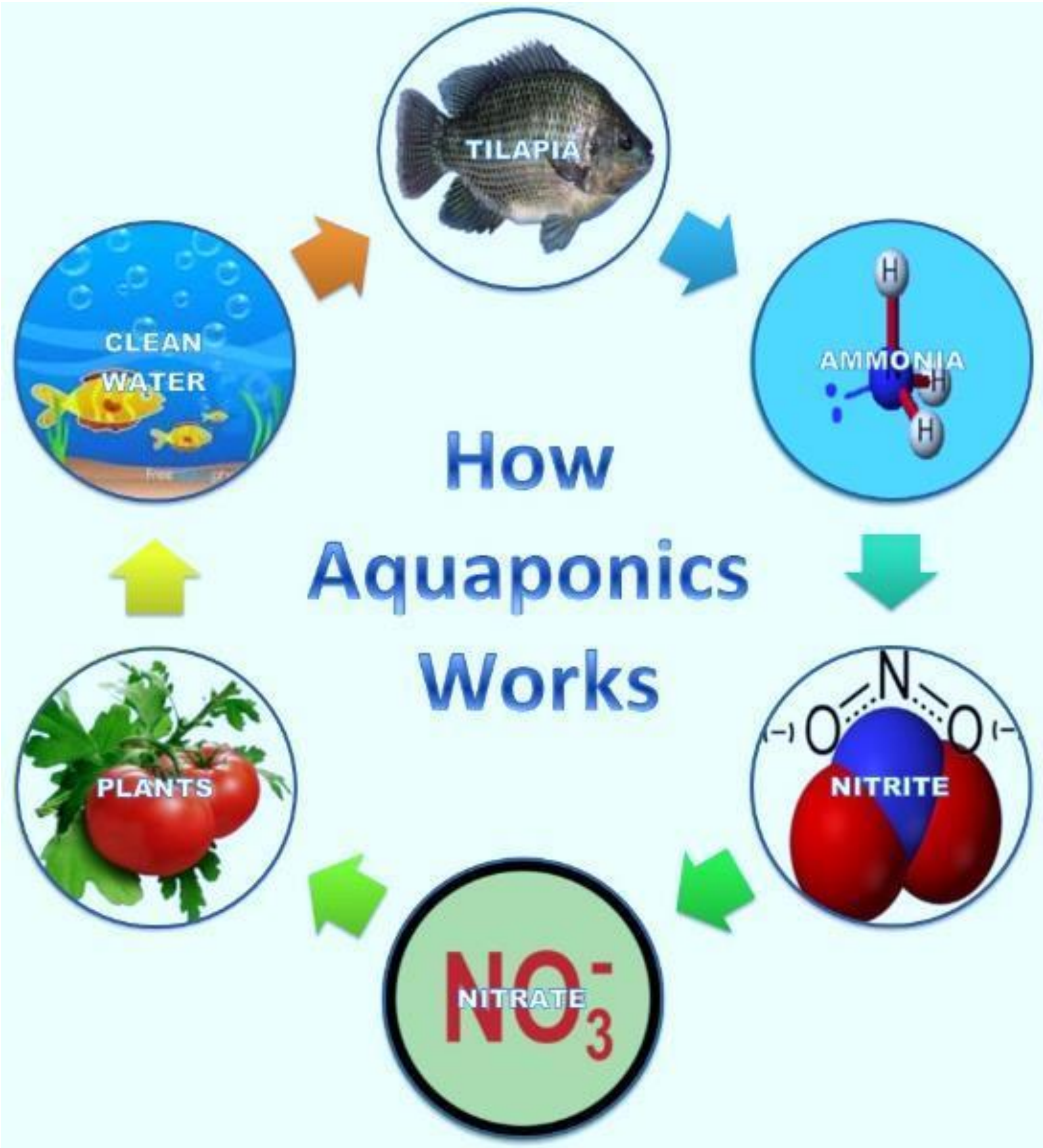

Plate 1: Mechanism of Aquaponic cycle

Source: Dimitrij and Larry (2013).

Plate 2: A commercial aquaponics system.

Source: Ryan Riffis from Urbana, USA - Growing Power, Milwaukee.

An electric pump moves nutrient-rich water from the fish tank through a solids filter to remove particles the plants above cannot absorb. The water then provides nutrients for the plants and is cleansed before returning to the fish tank below.

Plate 3: A Deep Water Culture hydroponics system.

Source: Bryghtknyght (2010).

Plate 4: Plant placed into a nutrient rich water channel in a nutrient film technique system.

Source: Ryan Somma (2010).

Plate 5: Filtered water from the hydroponics system drains into a catfish tank

Source: Ryan Somma (2009).

Status of Aquaponics in Nigeria

Nigeria as a sub-saharan state has been faced with different challenges in terms of water and food availability.

There is therefore the need to develop an intensive system of aquaponics which could at the same time address the challenges of water scarcity in aquaculture and again provide an addition source of food from plant materials cultured through hydroponics which is the bases of modern aquacultural system of farming termed AQUAPONICS.

Oladimeji *et al*. (2020a) and Dauda *et al.* (2019) describe the system of aquaponics as efficient enough to support plants growth and waste management. According to Ajibade and Oyeniyi (2018), high cost of investment, technical know-how, government policies are the main constraints to the development of aquaponics in Nigeria. More so, it is clear and logical that in situation like Africa, the population significantly lack expertise.

Foods from aquaponics are easily marketed because they are healthier than most other foods including those from field crops hence, there is need to develop a model of intervention to simplify the production of aquaponic system to benefit more people (Mcuhunu *et al.*, 2017).

Oladimeji *et al.* (2020b) gave substantial evidence to support the claim that the aquaponics system is more efficient in the production of African catfish and pumpkin compared to other production systems in terms of input cost for optimum performance. Growing fish and pumpkin in the aquaponics system is much cheaper than conventional means of growing them separately in Nigeria.

Based on the assumption of Ajibade and Oyeniyi, (2018) aquaponics in Nigeria and other sub-saharan states is poorly developed with little of knowledge added to it. There is information on the commercial scale quaponics production in Nigeria at the moment.

However in 2024, the University of Ibadan INtegrated and Circular Technologies for Sustainable city region FOOD systems in Africa (INCiTiS-FOOD) living laboratory reported to have achieved important harvest at the aquaponic unit of the laboratory, successfully growing *Solanum macrocarpon* (Efo Igbagba), *Solanum lycopersicum* (Tomatoes) and *Capsicum annuum* (Bell pepper) with stable and good yields.

The harvest reflected the effectiveness of three different systems - The Nutrient Film Technique, Deep Water Culture and Gravel bed- in supporting plant growth. This progress shows that solutions developed in the living laboratories of INCiTiS-FOOD network provides good options for growing food sustainably in Nigeria even in the major cities.

2.1.1 Components of aquaponics

Aquaponics consists of two main parts, with the aquaculture part for raising aquatic animals and the hydroponics part for growing plants. Although consisting primarily of these two parts, aquaponics systems are usually grouped into several components or subsystems depending on the type of system. Depending on the sophistication and cost of the aquaponics system, the units for solids removal, biofiltration, and/or the hydroponics subsystem may be combined into one unit or subsystem (Rakocy *et al.,2013*).

The components are as follows:

1. **Rearing tank**: The tanks for raising and feeding the fish.
2. **Hydroponic subsystem**: The portion of the system where plants are grown by absorbing excess nutrients from the water.
3. **Water pump:** Used to circulate water.
4. **Settling basin (optional):** A unit, also known as a clarifier, for catching uneaten food and detached biofilms, and for settling out fine particulates.
5. **Biofilter (optional):** A place where the nitrificationbacteria can grow and convert ammonia into nitrates, which are usable by the plants.
6. **Sump (optional):** Certain systems use a sump. The sump is equipped with a pump or pump inlet that circulates the treated culture water back to the rearing tanks.

(Rakocy *et al.*, 2013).

Live components

Aquaponic systems rely on a symbiotic relationship between three main live components: plants, fish (or other aquatic animals), and bacteria. Some systems also include additional live components like worms.

Plants: Plants are the primary producers in an aquaponic system, converting sunlight, carbon dioxide, and nutrients into **biomass**.A wide variety of plants can be grown in aquaponic systems, including **leafy green vegetables**, **herbs**, **fruits**, and **vegetables**.

Plants help to purify the water by removing excess nutrients and waste products. Since plants at different growth stages require different amounts of minerals and nutrients, plant harvesting is staggered with seedlings growing at the same time as mature plants. This ensures stable nutrient content in the water because of continuous symbiotic cleansing of toxins from the water (Rakocy *et al.,* 2013)

Fish (or other aquatic creatures): Fish and other aquatic animals are the primary consumers in an aquaponic system, providing a source of protein and nutrients for the plants.A variety of fish species can be used in aquaponic systems, including tilapia, goldfish, catfish and koi.

Fish help to fertilize the plants by producing 'waste' that is rich in nutrients

Bacteria: Bacteria play a crucial role in aquaponic systems, converting ammonia from fish waste into nitrate, a nutrient that can be used by plants. Beneficial bacteria, such as Nitrosomonas and Nitrobacter, are essential for maintaining a healthy and balanced ecosystem. They help to purify the water by removing excess ammonia and other waste products (Baganz *et al.*, 2021).

Algae: While often regarded as a nuisance in traditional aquaculture, **algae** can be a beneficial component in certain aquaponic designs. In systems such as Integrated Aqua-Vegeculture System, algae are intentionally cultivated in the surface layer of the biofilter. In these systems, algae act as a nutrient sink, absorbing excess nutrients, which helps maintain optimal water quality and reduces the risk of nutrient imbalances (Gross, 2024). However, not all aquaponic systems utilize algae in this way; in other types of systems, algae in the fish tank are considered a nuisance that needs to be controlled.

Algae can release substances that can be harmful to fish, other microorganisms, and plants. For example, blue-green algae, also known as cyanobacteria, can produce toxins that directly threaten the health of fish, and their physical presence can damage the gills of fish (Yavuzcan *et al.*,2017).

2.1.2 Nutrient cycling and biofilters in Aquaponics

Aquatic effluents, resulting from uneaten feed or raising animals like fish, accumulate in water due to the closed-system recirculation of most aquaculture systems. The effluent-rich water becomes toxic to the aquatic animal in high concentrations but this contains nutrients essential for plant growth (Rakocy *et al.*, 2013).

Typically, after a system has stabilized ammonia levels range from 0.25 to .50 ppm; nitrite levels range from 0.0 to 0.25 ppm, and nitrate levels range from 5 to 150 ppm (Deer *et al.,* 2021). During system startup, systems take several weeks to begin the nitrification process(Deer *et al.,* 2021). As a result, spikes may occur in the levels of ammonia (up to 6.0 ppm) and nitrite (up to 15 ppm) as the nitrosomonas and nitrobacter bacteria have yet to establish populations within the system.

Nitrate levels peak later in the startup phase as the system completes nitrogen cycles and maintains a healthy biofilter and these bacteria grow into a mature colony (Sallenave, 2022). With nitrate levels peaking later in the startup phase. In the nitrification process ammonia is oxidized into nitrite, which releases hydrogen ions into the water.

Over time, the water's pH will slowly drop, non-sodium bases such as potassium hydroxide or calcium hydroxide can be used to neutralize the water's pH if insufficient quantities are naturally present in the water to provide a buffer against acidification. In addition, selected minerals or nutrients such as iron can be added in addition to the fish waste that serves as the main source of nutrients to plants (Rakocy *et al.,* 2013.

2.1.3 Operation in Aquaponics

The five main inputs to the system are water, oxygen, light, feed given to the aquatic animals, and electricity to pump, filter, and oxygenate the water. Spawn or fry may be added to replace grown fish that are taken out from the system to retain a stable system.

In terms of outputs, an aquaponics system may continually yield plants such as vegetables grown in hydroponics, and edible aquatic species raised in an aquaculture. Typical build ratios are .5 to 1 square foot of grow space for every 1 U.S. gal (3.8 L) of aquaculture water in the system. 1 U.S. gal (3.8 L) of water can support between .5 lb

(0.23 kg) and 1 lb (0.45 kg) of fish stock depending on aeration and filtration (Rogosa, 2013).

Feed source

As in most aquaculture based systems, stock feed often consists of fish meal derived from lower-value species. Ongoing depletion of wild fish stocks makes this practice unsustainable. Organic fish feeds may prove to be a viable alternative that relieves this concern.

Other alternatives include growing duckweed with an aquaponics system that feeds the same fish grown on the system (Rogosa, 2013). Excess worms grown from vermiculture composting, using prepared kitchen scraps (Amadori, 2011) as well as growing black soldier fly larvae to feed to the fish using composting grub growers

Plant nutrients

Healthy plant growth relies on diverse organic compounds in the root environment, produced by microbial decomposition. These include vitamins, hormones, and enzymes, essential for growth, yield, flavor, and pathogen resistance. Organic matter like humic acid helps make micronutrients available. While inorganic nutrients are vital, plants need organic metabolites for optimal development (Rakocy *et al.,* 2013).

Water usage

Aquaponic systems are designed to recirculate and reuse water efficiently, rather than discharging or exchanging it under normal operation. This system relies on the interaction between animals and plants to maintain a stable aquatic environment with minimal fluctuations in nutrient and oxygen levels.

Plants absorb dissolved nutrients from the circulating water, which reduces the need for water discharge and minimizes the water exchange rate(Rakocy *et al.,* 2013). Some authors have reported 90% less water usage through aquaponics compared to conventional commercial fish and crop production systems (Okomoda, 2023).

Water is added to the system only to replace losses due to plant absorption and transpiration, evaporation, overflow from rainfall, and removal of solid wastes.

Consequently, aquaponics uses about 2% of the water required by conventional irrigation methods for the same vegetable production (Hygnstrom, 2014). This efficiency allows for the cultivation of crops and fish in areas with limited water or fertile land.

Aquaponic systems can also mimic controlled wetland conditions, making them useful for biofiltration and treating household sewage (Hygnstrom, 2014). The nutrient-rich overflow water can be collected in catchment tanks and reused to boost the growth of soil-planted crops or pumped back into the aquaponic system to maintain water levels (Ashish, 2023).

In traditional aquaculture, regular water exchange is essential, unlike in aquaponics. Producing 1 kg of beef typically demands 5,000 to 20,000 liters of water. Semi-intensive and extensive conventional aquaculture requires 2,500 to 375,000 liters for the same amount of fish. In contrast, recirculating aquaculture systems (RAS) are highly efficient, recycling 95% to 99% of water and using under 100 liters per kilogram of fish (Goddek *et al.,* 2015).

Fish stocking

In order for aquaponic systems to be financially successful and make a profit whilst also covering its operating expenses, the hydroponic plant components and fish rearing components need to almost constantly be at maximum production capacity (Rakocy *et al.*, 2013). To keep the bio-mass of fish in the system at its maximum (without limiting fish growth), there are three main stocking method that can help maintain this maximum.

Sequential rearing: Multiple age groups of fish share a rearing tank, and when an age group reaches market size they are selectively harvested and replaced with the same amount of fingerlings (Rakocy *et al.*, 2013). Downsides to this method include stressing out the entire pool of fish during each harvest, missing fish resulting in a waste of food/space, and the difficulty of keeping accurate records with frequent harvests (Rakocy *et al.*, 2013).

Stock splitting: Large quantities of fingerlings are stocked at once and then split into two groups once the tank hits maximum capacity, which is easier to record and eliminates fish being "forgotten". A stress-free way of doing this operation is via "swimways" that connect various rearing tanks and a series of hatches/moving screens/pumps that move the fish around (Rakocy *et al.,* 2013).

Multiple rearing units: Such systems usually have 2–4 tanks that share a filtration system, and when the largest tank is harvested, the other fish groups are moved up into a bigger tank whilst a new batch is started in the smallest tank (Rakocy *et al.,* 2013). It is also common for there to be several rearing tanks yet no ways to move fish between them, which eliminates the labor of moving fish and allows each tank to be undisturbed during harvesting, even if the space usage is inefficient when the fish are fingerlings (Rakocy *et al.,* 2013).

Ideally the bio-mass of fish in the rearing tanks doesn't exceed 0.5 lbs/gallon, in order to reduce stress from crowding, efficiently feed the fish, and promote healthy growth (Rakocy *et al.,* 2013).

Disease and pest management

The most effective organic pesticide is Neem oil, but only in small quantities to minimize spill over fish's water. Commercialization of aquaponics is often stalled by bottlenecks in pest and disease management. The use of chemical control methods is highly complicated for all systems. While insecticides and herbicides are replaceable by well- established commercial biocontrol measures, fungicides and nematicides are still relevant in aquaponics. Monitoring and cultural control are the first approaches to contain pest population. Biological controls, in general, are adaptable to a larger extent. Non- chemical prophylactic measures are highly proficient for pest and disease prevention in all designs (Gross, 2024).

Plants grown in aquaponic systems might have higher resistance to diseases compared to those grown in traditional hydroponic systems. This environment supports a diverse range of microorganisms, some of which may help protect plant roots from pathogens (Rakocy *et al.,* 2013).

Automation, monitoring, and control

Today's technology has greatly improved aquaponic systems. With the use of advanced sensors and IoT devices, these systems can now run with a lot of automation. This makes it possible to closely manage important factors like nutrient levels, water usage, and lighting. Automating these processes not only makes aquaponics more efficient but can also lead to better crop yields and smarter use of resources (Ibrahim, 2024).

Many have tried to create automatic control and monitoring systems and some of these demonstrated a level of success. For instance, researchers were able to introduce automation in a small scale aquaponic system to achieve a cost-effective and sustainable farming system (Benoît, 2018). Commercial development of automation technologies has also emerged. For instance, a company has developed a system capable of automating the repetitive tasks of farming and features a machine learning algorithm that can automatically detect and eliminate diseased or underdeveloped plants (Simon and Matt, 2018). A 3.75-acre aquaponics facility that claims to be the first indoor salmon farm in the United States also includes an automated technology. The aquaponic machine has made notable strides in the documenting and gathering of information regarding aquaponics (Brown, 2017).

Economic viability

Aquaponics offers a diverse and stable polyculture system that allows farmers to grow vegetables and raise fish at the same time. By having two sources of profit, farmers can continue to earn money even if the market for either fish or plants goes through a low cycle (Blidariu *et al.*, 2011).

The flexibility of an aquaponic system allows it to grow a large variety of crops including ordinary vegetables, herbs, flowers and aquatic plants to cater to a broad spectrum of consumers (Blidariu*et al.*, 2011). Some profitable plants for aquaponic systems include chinese cabbage, lettuce, basil, roses, tomatoes, okra, cantaloupe and bell peppers (Diver and Steve, 2006).

For environmentally conscious consumers, aquaponic products are appealing because they are organic and pesticide-free, and the systems have a relatively small environmental footprint. Aquaponic systems are also economically efficient due to their low water usage, effective nutrient cycling, and minimal land requirements. These systems can be established in areas with poor soil quality or contaminated water and require only a small amount of water. Additionally, aquaponic systems are typically free from weeds, pests, and soil-borne diseases, which allows for the consistent and rapid production of high-quality crops (Blidariu *et al.*, 2011).

Research concerning aquaponics has focused mainly on technical facets, with a limited number of studies addressing its economic viability, particularly in commercial contexts. While aquaponics is generally deemed profitable and sustainable, the calculation of costs and the comparison of systems are rendered complex due to diverse site conditions, climatic variations, and fluctuating market prices. Energy expenses constitute a significant factor and exhibit considerable variation across countries, thereby complicating assessments of profitability. Some researchers propose that aquaponics achieves financial equilibrium after a span of two years, whereas others contend that profitability should be gauged on a per square meter basis (Rharrhour *et al.*, 2022).

The existing body of research pertaining to aquaponic systems and their economic sustainability remains considerably less extensive when compared with that of conventional hydroponic systems. Based on the research currently available, the economic viability of aquaponic enterprises must be evaluated on an individual basis. Numerous variables—including system design, seasonal climatic conditions, and local energy or land costs—play a pivotal role in determining the profitability of aquaponic ventures (Richard, 2015).

Additional research shows the support that aquaponic systems can use 14% less fertilizer than hydroponic systems (AlShrouf, 2017). Despite this reduction, a grower should determine if the cost of maintaining aquaculture is cheaper than the use of extra fertilizer in hydroponics.

Other non-system-based barriers to the economic success of aquaponic systems could include that these systems require a high degree of knowledge in multiple disciplines, a lack of financing opportunities for aquaponics, and the fact that the general public doesn't understand what aquaponics is (Goddek *et al.*, 2015).

One of the limitations of aquaponics development is the lack of commercially viable financial feasibility, considering that private companies do not share their studies with the public (Rharrhour *et al.,* 2022).

2.1.4 Aquaponic sludge and wastewater treatment

In aquaponics, the wastewater charged with solids (i.e. the sludge) is a valuable source of nutrients, and appropriate treatments need to be carried out. The treatment goals differ from conventional wastewater treatment because in aquaponics solids and water conservation is of interest (Delaide *et al.,* 2019). Moreover, regardless of the wastewater treatment applied, its aim should be to reduce solids and at the same time mineralise its nutrients. In other words, the aim is to obtain a solid-free effluent but rich in solubilised nutrients (i.e. anions and cations) that can be reinserted into the water loop in a coupled setup or directly into the hydroponic grow beds in a decoupled setup. Fish sludge solids are mainly composed of degradable organic matter so that the solid reduction can be called organic reduction. Indeed, the complex organic molecules (e.g. proteins, lipids, carbohydrates, etc.) are principally composed of carbon and will be successively reduced to lower molecular weight compounds until the ultimate gaseous forms of CO2 and CH4 (in the case of anaerobic fermentation). During this degradation process, the macronutrients (i.e. N, P, K, Ca, Mg and S) and micronutrients (i.e. Fe, Mn, Zn, Cu, B and Mo) that were bound to the organic molecules are released into the water in their ionic forms (Delaide *et al.,* 2019). This phenomenon is called nutrient leaching or nutrient mineralisation. It can be assumed that when high organic reduction is achieved, high nutrient mineralisation would also be achieved.

On the one hand, sludge contains a proportion of undissolved minerals, and on the other hand, some macro- and micronutrients are released during the mineralisation process. These can quickly precipitate together and form insoluble minerals. The state between ions and precipitated minerals of most of the macro- and micronutrients is pH dependent. The most well-known minerals that precipitate in bioreactors are calcium phosphate, calcium sulphate, calcium carbonate, pyrite and struvite. Delaide *et al.,(*2019) reported that Ca and P are released in anaerobic reactor when the pH dropped under 6. They showed that the release corresponded exactly to the mineralisation of calcium phosphate. Delaide *et al.,* (2019) also observed the solubilisation of P, Ca and other macronutrients in upflow anaerobic sludge blanket reactor (UASB) that turned acidic. Jung and Lovitt (2011) reported a 90% nutrient mobilisation of aquaculture-derived sludge at a very low pH value of 4. I4. In this condition, all the macro- and micronutrients were solubilised. There is thus an antagonism between organic reduction and nutrient mineralisation. Indeed, organic reduction is maximal when the microorganisms are active for degrading the organic compounds, and this happens at pH in a range of 6–8. Because nutrient leaching occurs at pH below 6, for optimal organic reduction and nutrient mineralisation, the most effective would be to divide the process in two steps, i.e. an organic reduction step at pH close to neutral and a nutrient leaching step under acidic conditions (Delaide *et al.,* 2019).

They may also lead to higher oxygen consumption, the production of toxins, eutrophication, and the blockage of plumbing and equipment (Fu *et al.*, 2018). Fine particles may also get into gills of fish or coat on roots of plants, threatening their survival. Solid waste management is essential for aquaponics. At present, only nutrient in liquid effluent is recovered in aquaponics while fish sludge is concentrated by mechanical filtration unit and then removed from the system as waste (Khiari *et al.*, 2019). According to Cerozi and Fitzsimmons (2017), daily sludge discharged accounts for 5–20 % of the total volume of recirculating aquaculture system. The discarded sludge can be further treated by land field application, composting, or anaerobic digestion. Field application comes with high transportation cost due to the high water content of sludge (≥99.76%) (Strauch *et al.*, 2018), incalculable loss of nutrients and severe environmental pollution.

2.1.5 Aquaponic sludge composting

Composting has been accepted as a promising method of stabilizing solid waste. It converts sludge into humic substances with a significant reduction in volume and the stabilized end product can serve as solid fertilizer and soil conditioner. The shortcomings are long processing period and air pollution due to emission of ammonia and pollutant VOCs (Volatile Organic Compounds).Anaerobic digestion decomposes organic matters by anaerobic bacteria to generate methane as biogas energy resource and nutrients like ammonium and phosphate in liquid phase could be reused. Remaining digested sludge can also be used as fertilizer. It is limited by production of offensive odours, low by-products yield, high process variability, and decreased nutrients availability (Khiari *et al.,* 2019).The management of fish sludge remains an issue regarding on the nutrient recovery and enhancement of the efficiency in aquaponics. A new way of fish sludge management in aquaponics is recovering nutrients from fish sludge and reintroducing them into the system as liquid fertilizer. The potential of nutrient recovery in fish sludge, technologies for collection of fish sludge, and the nutrient mineralization are reviewed. A modified biological aerated filter is also proposed for both the filtration and the nutrient conversion of fish sludge.

Potential of nutrient recovery from fish sludge in aquaponics as a closed loop of food production system, aquaponics is desired to fulfil zero discharge, eliminate negative environmental impact and enhance system sustainability. A great potential is to recover the nutrients of fish sludge into soluable form via mineralization and then reintroduce the obtained nutrient solution as recirculating water to provide liquid fertilizers for hydroponic plants (Goddek *et al.,* 2019). Aquaponic sludge contains large amounts of water, nutrients and energy, which should not be regarded as merely waste.

According to Fu et al. (2018), 17 %, 3 %, and 62 % of residual feed and fish faeces are protein, fat and carbohydrates (based on dry matter). Most macronutrients and micronutrients that are essential for the plant can be obtained from aquaponic solid waste. Cripps and Bergheim (2000) mentioned that the sludge solids contain 7–32 % of the total nitrogen and 30–84 % of the total phosphorus of the wastewater. Goddek *et al.,* (2019) noticed that among macronutrient, 6 % of the nitrogen, 18 % of the phosphorus, 6 % of the potassium, 16 % of the calcium, 89 % of the magnesium are contained in the sludge; while for micronutrients,24 % of the iron, 86 % of the manganese, 47 % of the zinc, and 22 % of the copper were measured (based on dry matter). Phosphorus is more present in sludge (Delaide *et al.,* 2017). Micronutrients like Cu, Zn and Mn are also mainly concentrated in solids (Strauch *et al.,* 2018). More than 99% of N, P, Fe, Mn, Zn, Se, Co and Cr, 95–98% of K, 69–87% of Ca, 67–85% of Mg, 69–86% of S, 95–98% Mo, and 90–96% Cu are derived from fish feed based on dry matter (Strauch *et al.,* 2018).Nutrient recovery from fish sludge can also alleviate the problem of plant nutrient deficiency faced by aquaponics and save the cost of additional purchase of plant nutrients.

According to the definition of aquaponics by European Union Aquaponics Hub, no less than half of the nutrition that hydroponics needs should be provided by aquaculture tank.

The existing system is far from meeting this requirement. Most nutrients provided by the aquaculture effluent are insufficient compared with those in the nutrient solutions used by independent hydroponic systems (N: 70–164 mg/L, P: 5–40 mg/L, K: 120–280 mg/L, Ca: 80–140mg/L, Mg: 40–60 mg/L, S: 60–130 mg/L, Fe: 2.0–6.0 mg/L, Mn: 0.4–1.0 mg/L, B: 0.2–1.0 mg/L, Cu: 0.01–0.1mg/L, Zn: 0.04–0.08 mg/L, Mo: 0.01–0.4 mg/L). Therefore, the hydroponic products in aquaponics are restricted to leafy vegetables rather than fruit crops (Nozzi *et al.*, 2018). Aquaculture effluent is generally deficient in phosphorus, potassium, calcium and micronutrients, especially iron, molybdenum and manganese(Delaide *et al.*, 2017). If the nutrients obtained via fish sludge mineralization were added into aquaculture effluent, the concentrations of total nutrients available for plants would be effectively increased, and the deficiency of specific nutrients could be eliminated (Montanhini and Ostrensky, 2015).

2.1.6 Aquaponic Sludge removal technology

Collecting fish sludge effectively has a great significance to the recovery of nutrients. At present, the solid removal methods adopted by aquaponics are mainly those used in the recirculating aquaculture system (RAS) which include sedimentation, sieve separation, medium filtration and foam separation. Sedimentation works on the basis of the gravity of particles and the centrifugal force generated by the water flow rotation or the centripetal force generated by the secondary retention. Settling basins, tube or plate separators, centrifugal separators, and swirl separators are commonly used devices (Rakocy, 2012). Sedimentation requires lower energy consumption and operating cost but is time-consuming and manpower-consuming for it is bulky. Sieve separation traps solids by a sieve with a certain aperture base on the particle size and removes solids by back washing. Drum filters are the most frequently used equipment. For suspended solids with particle size between 60-100 microns, the removal rate of rotary drum filters can reach 68–94 % when the inlet concentration is higher than 50 mg/L (Cheng *et al.*, 2014). But the cost of drum filter is high, and the secondary crushing of large particles may be caused in the process, which reduces the efficiency (Cheng *et al.*, 2014).

Media filtration intercepts the suspended solids by the media such as quartz sand, ceramsite, anthracite, and polystyrene materials due to the pores formed. Sand and gravel hydroponic substrates are good alternative for solid waste removal as they intercept solids when aquaculture effluent flow through hydroponic bed and simultaneously decompose organic matters of the solid remained in the unit (Rakocy,2012). Bed tillage or periodic media replacement is required from system water in case of the clogging of the media (Rakocy, 2012). Foam separation is a technique using the interface properties of surfactants and the bubbles generated to absorb the solids. Foam separation needs less energy and has good performance on removing particles less than 10 microns or 50-90 microns, but can be limited by low concentration of organic matter and electrolytes (Shan *et al.,* 2013).The particle size and density of solid are two parameters in consideration of suitable separation technology for fish sludge. In the recirculating aquaculture system, the particle size distribution range of solid particles is relatively wide, from 3 to 300 microns, most of which are less than 20 microns, accounting for more than 47%of the total weight of particles. Particles size over 100 microns are settleable solids, which are suitable for gravity sedimentation or using hydrocyclone; size under 100 microns are unsettleable solid sand some of them may be further dispersed into fine particles with particle size smaller than 30 microns under the action of aquatic organisms and water power (Fu *et al.*, 2018). Solids with particle size less than 60microns are suitable for mechanical filtration or physico-chemical methods (Zhang *et al.,* 2008).Combining the collection of fish sludge with the conversion of solid nutrients in a single equipment in aquaponics has been proposed by Zhang *et al.* (2020) and may be a trend. All the sludge collected in the filter can be further mineralized into soluble nutrients by activities of microorganisms, which can reduce nutrient loss to a higher degree and is highly-efficient in nutrient utilization.

2.1.7 The nutrient mineralization of fish sludge

Fish sludge can be mineralized into soluble and bio-available nutrients that hydroponic plants can uptake either in anaerobic reactors or aerobic reactors with degradation by microorganisms (Delaide *et al.,* 2018).Anaerobic digestion has been regarded as a promising way to stabilize and reduce solid waste along with methane production. In recent years, it also has been evaluated with nutrient recovery. The anaerobic digestion produces less residual sludge than aerobic process (Gichana *et al.,* 2018). It consumes less energy due to zero aeration and can produce biogas to recover energy, which brings economic benefits. Continuously stirred tank reactor (CSTR), up flow anaerobic sludge blanket (UASB) reactor and membrane bioreactor are common reactors of anaerobic digestion (Mirzoyan *et al.*, 2010). Goddek *et al.* (2018)investigated the mineralization performance of fish sludge from RAS in sequential UASB-EGSB reactors and recovered

26–71 % P, K, Ca, and Mg (based on dry matter) in the minimally acidic reactor. Delaide *et al.*(2018) found that among 2–35.8 % of phosphorus, calcium, magnesium and boron and among 5.7–21.9 % of copper, zinc and manganese (based on dry matter) were mineralized in anaerobic reactor for nutrient recycling in aquaponics. Anaerobic digestion faces some drawbacks, including long reaction period and strict requirements of conditions such as pH, temperature, salinity, mineral composition, carbon/nitrogen ratio (C/N),volatile fatty acids (VFAs) content and hydraulic retention time (HRT) (Mirzoyan *et al.*, 2010). According to Strauch *et al.* (2018), TOC (Total Organic Carbon) in aquaculture sludge (366–416 g/kg·dm) is 36–42 % lower than that of typical matrix, and C/N is 1.1–3.8 times lower than the recommended value of anaerobic digestion. This reveals that it is necessary to adjust composition of the fish sludge before anaerobic digestion in order to ensure digestion performance, i.e., supplementing acids, carbon sources and bacterial suspension (Monsees *et al.*, 2017).

Aerobic conversion of fish sludge decomposes organic matters and releases a variety of minerals, including all the macronutrients and micronutrients that plants need via activities of a variety of heterotrophic microorganisms (Khiari *et al.*, 2019). Aerobic conversion has the advantage in dynamics compared with anaerobic reaction, especially in terms of TSS (Total Suspended Solid) and COD (Chemical Oxygen Demand)removal (Delaide *et al.*, 2018).The production of VFAs, anaerobic secondary metabolites and other toxins to plants can also be avoided. At this point, aerobic conversion is more environmental friendly and safe due to the reduction in odour, greenhouse gas emissions and pathogens. Aerobic conversion shows higher nutrients capture abilities and less nutrient loss.

Monsees *et al*. (2017) found that the concentration of nitrate in the aerobic reactors was reduced by 16 % compared to 97 % in the unaerated treatment. Aerobic digestion also increased the concentration of P and K by 30 % and 31 % within 14 d of incubation, while those under anaerobic treatment only had minor increase (Monsees et al., 2017). Delaide et al. (2018) also concluded better mineralization performances of P (54.25 %), Ca (64.95 %), Mg (57.49 %), B (62.98 %), Cu (21.79 %), Zn (24.60 %), Mg (13.18 %), Na (55.98 %) (based on dry matter) in aerobic reactors.

Rakocy *et al*. (2007) showed concentrations of six of thirteen nutrients required by plant exceeded standard hydroponic values after aerobic mineralization of 29 d. The disadvantage of aerobic digestion is the high energy consumption due to continuous aeration, the management complexity and capital costs of the system. The growth rate of microorganisms under aerobic conditions is much faster than that under anaerobic conditions, thus a considerable amount of new biomass may be produced and accumulated in the reactor, which is not conducive to the reduction of solids (Delaide *et al.*, 2018). In general, aerobic digestion may also be a promising approach for nutrient recovery from fish sludge in aquaponics (Monsees *et al.*, 2017).

2.2 Black Soldier Fly (BSF)

Hermetia illucens, is a common and widespread fly of the family Stratiomyidae. Since the late 20th century, *H. illucens* has increasingly been gaining attention because of its usefulness for recycling organic waste and generating animal feed (Tomberlin and van Huis, 2020).

2.2.1 Distribution of Black Soldier Fly

This species is native to the Neotropical realm, but in recent decades has spread across all continents, becoming virtually cosmopolitan (Marshal *et al.*, 2015). It is present in parts of North America and Europe, including the Iberian Peninsula, southern France, Italy, Croatia, Malta, the Canary Islands, and Switzerland, and on the Black Sea coast of Russia in Krasnodar (Gladun, 2019). It can also be found in the Afrotropical realm, the Australasian realm, the east Palaearctic realm, the Nearctic realm, North Africa, Southern Africa, and the Indomalayan realm.

2.2.2 Description of Black Soldier Fly

The adults of *H. illucens* measure about 16 millimetres ($^{5}/_{8}$ in) long (Savonen and Carol, 2005). These medium-sized flies have a predominantly black body, with metallic reflections ranging from blue to green on the thorax and sometimes with a reddish end of the abdomen. The second abdominal tergite has translucent areas, from which the Latin specific epithet derives. The head is wide, with very developed eyes. The antennae are about twice the length of the head. The legs are black with whitish tarsi. The wings are membranous; at rest, they are folded horizontally on the abdomen and overlapped (Savonen and Carol, 2005).

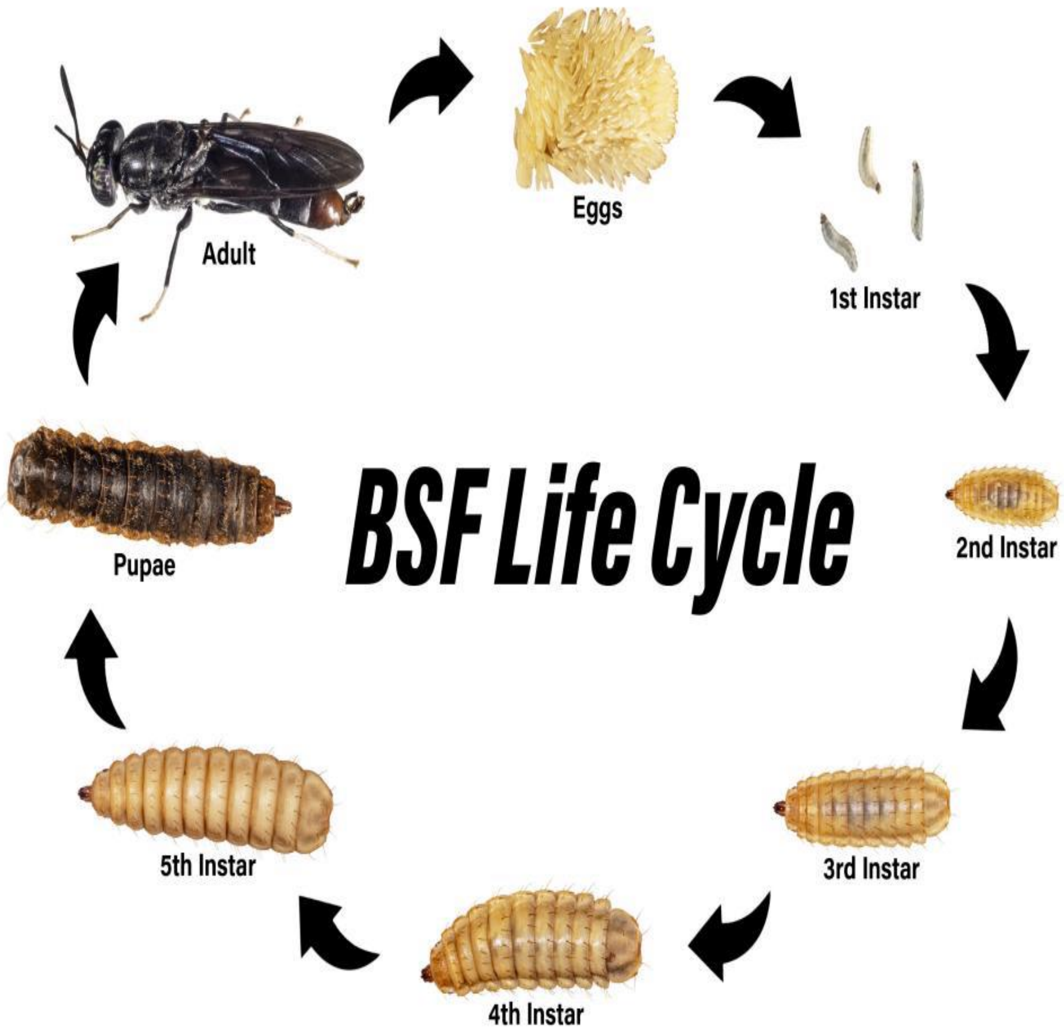

Figure 1: The complete life cycle of a Black Soldier Fly (BSF).

Source: Terrell and Ingwell (2022).

Plate 6: Adult of *Hermetia illucens* - Black Soldier Fly (BSF).

Source: Hectonicus (2012).

H. *illucens* is a mimic fly, very close in size, color, and appearance to the organ pipe mud dauber wasp and its relatives. The mimicry of this particular kind of wasp is especially enhanced by the fly's elongated and wasp-like antennae, pale hind tarsi, and the presence of two small, transparent "windows" in the basal abdominal segments that make the fly appear to have a narrow "wasp waist" (Tomberlin *et al.,* 2002). Black soldier fly larvae can be differentiated from blowfly or housefly larvae by a thin gray-black stripe on their posterior ends.

2.2.3 Lifecycle of Black Soldier Fly

An adult female lays approximately 200 to 600 eggs at a time (Tomberlin *et al.*,2002). These eggs are typically deposited in crevices or on surfaces above or adjacent to decaying matter such as manure or compost, and hatch in about 4 days (Sheppard *et al.*, 2002). Freshly emerged larvae are 1.0 millimetre (0.04 in) long, being able to reach a length of 25 millimetres (1 in) and weight of 0.10 to 0.22 grams (1.5 to 3.4 gr) by the end of larval stage (Tomberlin *et al.*, 2002). The larvae are able to feed on a wide variety of organic matter,(Kuppusamy *et al.,* 2020; Spranghers *et al.*, 2017; Lalander *et al.,* 2019) adapting to diets with different nutrient content (Lalander *et al.*, 2019). The larval stage lasts from 18 to 36 days, depending on the food substrate provided to the larvae (Bruno *et al.,* 2018) of which the post-feeding (prepupal) stage lasts around 7 days (Holmes et al., 2013). The length of larval stage can be delayed by months due to low temperature or lack of food. The pupal stage lasts from 1 to 2 weeks (Holmes et al., 2013). Adults can live typically 47 to 73 days when provided with water and food, such as sugar in captivity or nectar in the wild, or survive for about 8 to 10 days on fat reserves gathered during larval stage when water is provided. (Bertinetti *et al*., 2019)

Plate 7: Black soldier fly larvae

Source: Terraristik *et al.* (2011).

2.2.4 Human relevance and use of Black Soldier Fly

Neither larvae nor adults are considered to be agricultural pests or disease vectors. Black soldier fly larvae play a role similar to that of redworms as essential decomposers in breaking down organic substrates and returning nutrients to the soil. The larvae have voracious appetites and can be used for composting household food scraps and agricultural waste products.

Additionally, black soldier fly larvae are an alternative source of protein for aquaculture, animal feed, and pet food (Rumpold and Schlüter, 2013).

Black Soldier Fly (BSF) as decomposers/in composting

Black soldier fly larvae (BSFL) are used to compost waste or convert the waste into animal feed. Waste streams include fresh manure and food wastes of both animal and vegetable origin. Fly larvae are among the most efficient animals at converting biomass into feed (Banis, 2019).

When the larvae have completed their larval development through six instars (Barros, 2019) they enter a stage called the "prepupa" wherein they cease to eat, and tend to migrate toward cool, dark, and dry substrates to pupate (Barros, 2019). This prepupal migration instinct is used by grub composting bins to self-harvest the maturelarvae. These containers have ramps or holes on the sides to allow the prepupae to climb out of the composter and drop into a collection area.

Black soldier fly larvae are beneficial for use as composters in the following ways:

- Their large size relative to houseflies and blowflies allows BSFL to prevent houseflies and blowflies from laying eggs in decaying matter by consuming larvae of other species. This means compost systems inhabited by BSFL may be a more human-friendly way to handle food waste when compared to those inhabited by houseflies and blowflies which typically produce a much worse smell (Banis, 2018).
- They are not a pest to humans. Unlike houseflies, adult black soldier flies have greatly reduced sponging mouthparts, meaning they can only consume liquids such as flower nectar, although they typically do not eat at all. Unlike houseflies, which regurgitate food along with digestive enzymes, adult black soldier flies therefore do not spread pathogens or diseases (Cranshaw *et al.*, 2017).

- They are not attracted to human habitation or foods (Banis, 2018). As a detritivore and coprovore, the egg-bearing females are only attracted to rotting food or manure.
- Black soldier flies do not fly around as much as houseflies. They have less expendable energy due to their limited ability to consume food as adults. They are very easy to catch and relocate when they get inside a house, as they do not avoid being picked up, they are sanitary, and they neither bite nor sting. Their only defense seems to be hiding. When using a wet grub bin that collects or kills all the pupae, the black soldier fly population is easy to reduce by killing the pupae/prepupae in the collection container, before they become adult flies. They may be killed by freezing, drying, manually feeding to domestic animals, putting the collection container in a chicken coop for automatic feeding, or feeding to wild birds with a mouse/pest-proof feeder (Erikson *et al.*, 2004).
- Significant reductions of *E. coli* 0157:H7 and *Salmonella enterica* were measured in hen manure after larvae were added to the manure (Erikson *et al.,* 2004).
- They quickly reclaim would-be pollutants: Nine organic chemicals were greatly reduced or eliminated from manure in 24 hours, making them a potential tool for bioremediation (Erikson *et al.*, 2004).
- They quickly reduce the volume and weight of waste: larval colonies breaks apart their food, churn it, and create heat, increasing compost evaporation. Significant amounts of waste are also converted to carbon dioxide respired by the grubs and symbiotic/mutualistic microorganisms. The use of BSFL in a compost system typically reduces the volume of compost by around 50%.

Aside from protein production, fly larvae also produce frass. Fly larval frass is a granulated and odorless residue that can be used as organic fertilizer directly (Lohri *et al.*, 2017) or through conversion by earthworms (Cappellozza *et al.,* 2019).

Black Soldier Fly (BSF) as feed

Black soldier fly larvae are used as feed for pets and livestock animals. The harvested pupae and prepupae are eaten by poultry, fish, pigs, lizards, turtles, and even dogs (Lei *et al.,* 2019). The insect is one of the few insect species approved to be used as feed in aquaculture in the EU (European Union, 2017).

At the pupal stage, black soldier flies are at their nutritional peak. They can be stored at room temperature for several weeks, and their longest shelf life is achieved at 10 to 16 °C (50 to 60 °F) (Chia *et al.*, 2018)

Black Soldier Fly (BSF) as human food

In 2013, Austrian designer Katharina Unger invented a table-top insect-breeding farm called "Farm 432" in which people can produce edible fly larvae at home (Andrews, 2013). It is a multi-chambered plastic machine that looks like a kitchen appliance and can produce 500 grams (1.1 lb) of larvae or two meals in a week.

The taste of the larvae is said to be very distinctive. According to Unger, "when you cook them, they smell a bit like cooked potatoes. The consistency is a bit harder on the outside and like soft meat on the inside. The taste is nutty and a bit meaty (Andrews, 2013).

Black Soldier Fly Larvae (BSFL) for producing grease

BSFL can be used to produce grease, which is usable in the pharmaceutical industry (e.g. in cosmetics, surfactants for shower gel), thereby replacing other vegetable oils such as palm oil. It can also be used in fodder (Debode *et al*., 2016).

Black Soldier Fly Larvae (BSFL) for producing chitin

BSFL can be used to produce chitin. Chitin is used in shipping as an agent against biofouling. It is also used in water purification. Chitin also has potential as a soil amendment, to improve soil fertility and plant resilience (Debode *et al.*, 2016).

Black Soldier Fly Larvae (BSFL) for producing organic plant fertilizer

Material left over after the larval waste decomposition process (frass) consists of larval faeces, shed larval exoskeletons, and undigested material. Frass is one of the main products from commercial black soldier fly rearing (Schmittet al., 2020). The chemical profile of the frass varies with the substrate on which the larvae feed, but in general, it is considered a versatile organic plant fertilizer due to a favorable ratio of three major plant nutrients: nitrogen, phosphorus, and potassium (Gärttling, 2022). BSFL frass is commonly applied by direct mixing with soil and considered a long-term fertilizer with slow nutrient release (Gärttling, 2022). Plant trials have also found short-term fertilizing effects comparable to fast-acting, synthetic fertilizers (Kebli *et al*., 2017). In addition to its nutrient contribution, BSFL frass can carry further components that are beneficial for soil fertility and soil health, such as chitin (Beesigamukama *et al*., 2020) from the shed exoskeletons of the larvae. Finally, the use of BSFL frass as a fertilizer can effectively alter the soil microbial community composition, which plays a crucial role for soil fertility (Song *et al.,* 2020).

Debate is going on whether the frass from BSFL rearing can be used as a fertilizer in a fresh state or has to undergo further composting before its application. Some assume that further composting would lead to the reduction of potential phytotoxic properties (Song*et al.,* 2020). In the European Union, insect frass has to be treated for one hour at 70 °C (158 °F) before commercialization for safety reasons, the same as other animal manure products(the International Platform of Insects for Food and Feed, 2021).

Black Soldier Fly Larvae (BSFL) in bioremediation

Recent research in the field of entomoremediation shows the potential of this insect for purification of biomass contaminated with heavy metals (Bulak, 2018). Larvae of *H. illucens* were used in a bioremediation experiment, in which they consumed up to 49% of dry weight corn leaves polluted with cadmium or zinc, for 36 days (Bulak, 2018). Artificially polluted corn leaves were used a model plant material comparable to plant biomass polluted as a result of phytoextraction. The 49% loss of polluted dry weight material is a better result than in the case of composting alone, which is one of the standard proposed pretreatments for biomass polluted after phytoextraction. The type of heavy metal did not affect the degree of consumption in this experiment. Cadmium mostly accumulates in the puparium, while zinc accumulates in the adult fly (Bulak, 2018).

Potential source of plastic-degrading enzymes and bacteria and biodiesel production

It has been stated that *H. illucens* larval gut microbiota represents an optimal ecological niche for isolating enzymes and microbial strains with optimized plastic-degrading ability (De Filippis *et al*., 2023). It could be a feasible feedstock for biodiesel production (Mohan,et al., 2023).

2.2.4 Culturing of Black Soldier Fly

Larval colonies

The main difficulty in farming black soldier fly larvae (BSFL) comes when obtaining larvae or eggs to start or replenish the colony. This is usually done by enticing the soldier flies to lay eggs in small holes over a grub bin. Adult flies lay clusters of eggs in the edges of corrugated cardboard or corrugated plastic. In some regions, starting or maintaining adequate larvae colonies is possible from wild black soldier flies, but pest species such as houseflies and blowflies are also drawn to many of the foods used to attract soldier flies, such as fermented chicken feed.

In tropical or subtropical climates, black soldier fly adults might breed year-round, but in other climates, a greenhouse may be needed to obtain eggs in the cooler periods. Black soldier fly larvae are quite hardy and can handle more acidic conditions and higher temperatures than redworms. Larvae can survive cold winters, particularly with large numbers of larvae, insulation, or compost heat (generated by the microorganisms in the grub bin or compost pile). Heat stimulates the larvae to crawl off, pupate, and hatch, and a great deal of light and heat seem to be required for breeding. Many small-scale BSFL farmers start their larval colonies from eggs deposited by wild soldier flies.

Space and shape

Newly emerged soldier flies perform the beginning of their mating ritual in flight. The male grabs onto the female, and then grasps the female's ovipositor with his genitals. They mate while stationary and connected (Jetter, 2010).

Heat

Adults typically mated and oviposited at temperatures of 24 to 40 °C (75 to 104 °F) or more. Around 99.6% of oviposition in the field occurred at 27.5 to 37.5 °C (81.5 to 99.5 °F) (Zhang *et al*., 2010).

Light

Quartz-iodine lamps have been successfully used to stimulate mating of adults (Zhang et al. 2010). In particular, mating success of reared black soldier fly can be dramatically increased by exposing the adults to light that is particularly rich in wavelengths near 440 and/or 540 nm and has an irradiance that is an appreciable fraction of the intensity of full sunlight (Schneider, 2020). In tropical conditions, morning direct sunlight is optimal for emergence, mating, and egg laying, with indirect sunlight often preferred before and after mating (Schneider, 2020).

Humidity

Humidity at 70% is considered optimal for all stages of their lifecycle (Holmes, 2010). Substrate was found to be unnecessary for pupation, but substrate is thought to act as a regulator for humidity, which prevents desiccation. A 93% emergence rate was observed when humidity was held at 70%(Holmes, 2012).

Wild birds and free-range poultry can consume insects in the adult, larval and pupal forms naturally (Sánchez-Muros,2014). Grasshoppers and moths, as well as houseflies, have been used as feed supplements for poultry (Rumpold, 2013). Apart from Organic food and drink sales in 2019 totaled more than 106 billion euros worldwide, showing the high interest of contemporary people getting used to healthy and environment-friendly eating habits: being health conscious. More than 75% of the world's agricultural production is produced through certified organic farming. It is one of the most prolific and cost-effective agrarian systems in the world.

According to the United Nations, the global population is expected to add another two billion people to almost ten billion by 2050. Earth’s population is rapidly expanding, and the need for more resources comes with that expansion - food production is expected to increase by 70% to meet the demands of the booming population.

Today, more than one billion people depend on farming for income. The earth’s population has become a concern, and the possibility of producing that much food with limited natural resources is increasingly concerning. Sustainable agriculture provides a solution for this increasing concern.

2.3. Organic farming in Nigeria

Nigeria, the seventh most populous country in the world, is plagued by livelihood challenges such as poverty and food insecurity, which are more pervasive among farming households and rural communities.

In Nigeria, organic farming (OF) is still in its infancy, hence there is need for its popularization and policy. The major aim of organic farming is for the production of safe, highly nutritious food and long term sustainability of the environment. Researchers have discovered that chemical fertilizers and other agro-chemicals used in conventional agriculture destroy the environment by altering the natural balance of the ecosystem and in many cases affect food quality with the intake of minerals such as lead or excess copper by crops which are dangerous for human consumption.

The practice of organic agriculture (OA) in Nigeria has undergone expansion due, among other things, to consumer interest in food safety issues. Organic Farming (OF) is a holistic production management system that promotes and enhances agro-ecosystem health, including biodiversity, biological cycles, and soil biological activity.

Organic farming, therefore, is a sustainable agricultural approach that holds great potential for effectively contributing to local food security, the health of citizens, increased family health, and environmental standards (Ogungbaro and Olaiya, 2024).

Organic farming is being promoted by some domestic non-governmental organisations as a means of addressing the problem of poverty and food insecurity among farming households and rural communities in the country. Promoters consider organic farming to be well-suited to smallholder farmers' socio-economic conditions in Nigeria, and that it can help improve their livelihood conditions through increased agricultural productivity and farm income.

However, the adoption of the technology by smallholder farmers has been underwhelming due to a mix of factors, which include institutional considerations, farmers' livelihood assets and vulnerability context, their livelihood activities, and gender-related variables shaped adoption Decision-making (Adebiyi *et al.*, 2019).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study Area

The experiment was conducted at the Aquaponic and insectary laboratories of INtegrated and Circular Technologies for Sustainable city region FOOD systems in Africa (INCiTiS-FOOD) project, Department of Aquaculture and Fisheries Management, University of Ibadan, Ibadan, Nigeria. The culture water was obtained from the well and borehole of the Department of Aquaculture and Fisheries Management. The laboratory analyses were done in the laboratories of the Department of Animal Science of the same university.

The INCiTiS-FOOD is an European Union funded project which combines 23 partners with multidisciplinary competencies and experiences from Europe and Africa in sectors of academia, industry, research, communication and other various fileds. The project has eight(8) living laboratories in Africa, with two in Nigeira which are located in Lagos and the University of Ibadan. The project develops food and agricultural technologies that can be practiced in urban cities as well as rural farming settlements. The project provides systems that are circular and focuses on zero wastes, and suggests technologies and practices that would lead to sustainability of food production either commercially or at small and medium scales.

3.2 Aquaponic Setup

The Aquaponic Setup is composed of two 1metre x 1metre x 1metre tanks (Tanks A and B) with stagnant renewal water exchange system, two other tanks with the same size, but with a recirculating water exchange system, a concreted sump tank, three hydroponic grow beds (Nutrient Film Technique, Deep water Culture and Gravel bed).

Clarias gariepinus (African catfish) is the fish being raised in the four tanks and the fish are fed with skretting feed for a period of six months before they are harvested. The three grow beds were growing different species of plants, ranging from *Solanum macrocarpus* (Vegetable Leafy garden eggs), *Solanum lycopersicum* (Tomato plants), *Capsicum annuum* (Chili and bell pepper) with all the plants grown on the beds at the same time.

The two tanks running on recirculating system are both fixed with a waste harvester which harvests wastes from the tanks and deposit it with water into a radial flow tank. The radial flow tank further separates the liquid waste from the solid wastes. The liquid waste is then taken to the filtration chamber where different sizes of sand, stones and gravels traps any remaining solid wastes in the water, then the purely liquid waste is transported to the sump tank. The water stored in the sump tank is then distributed back to the fish tanks and to the grow beds. The water from the grow beds is then directed back to the sump tank. All of these structures are located in a protected screen house which avoids the invasion of pests and other unwanted materials into the laboratory.

The solid wastes (sludge) were harvested from the digester and the radial flow tanks.

Plate 8: INCiTIS Aquaponic Laboratory.

Plate 9: Sump tank of INCiTiS Laboratory

Plate 10: Radial flow tank of INCiTiS Laboratory

Plate 11: The sand filteration chamber of INCiTiS Laboratory

Plate 12: Harvesting of sludge from the Radial flow tank of INCiTiS Laboratory

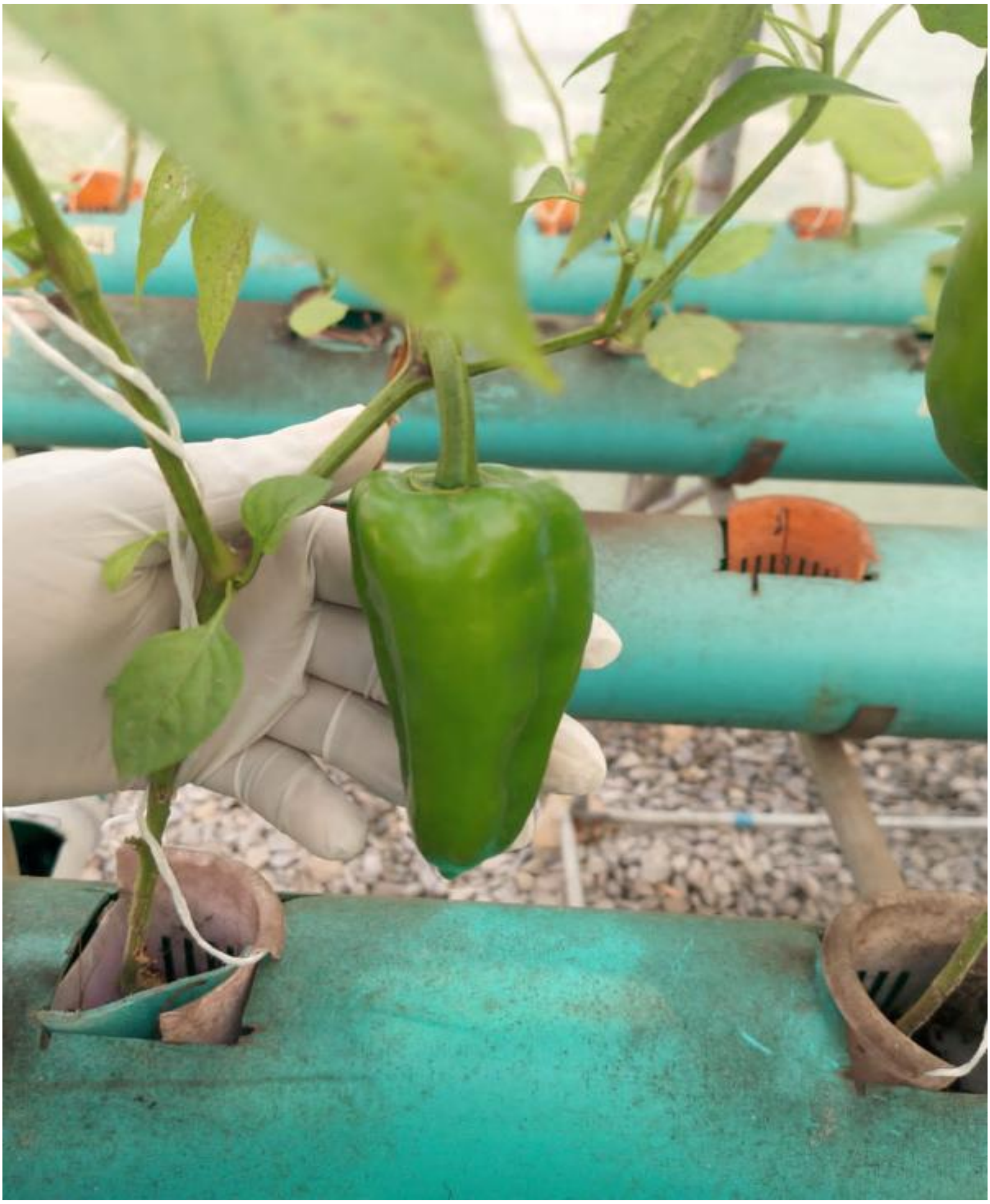

Plate 13: Samples of the Chili and Bell Pepper (*Capsicum annumm*)from the system

Plate 14: Samples of the Tomato fruit (*Solanum lycopasicum)*from the system

3.2.2 Insectary

The insectary is housed in a 10m x 5m screen house, protected from direct insolation with shade-nets. The insectary has three units of love cage, 20 incubation trays of 50 cm x 100cm dimensions and incubation tray shelves. The insectary was used to produce black soldier flies (BSF). Larva of BSF was obtained and stocked in the love-cage that is provided with eggies following standard procedure. The nuptial larva emerges to loving flies which lays eggs in the eggies. The eggs were manually collected by scraping, and incubated on the substrate of waste wheat offal from which the pupae feed and grow. The remains of the feed is collected as frass which was analysed for use in fertiliser production in the current experiment. Similarly, the BSF after laying eggs dies. This also constitutes a waste. The grown insect larvae were harvested and used for feed formulation for aquaponic fish production.

Operationally, the insect culture laboratory houses the love cages for the flies to mate and lay eggs. An attractant (freshly packed poultry dropping) is put in a container covered with net which allows the flies to get attracted to lay eggs in the eggies that is placed on the attractant. The eggs are scraped in a tray that contains substrate (brewery wastes) which the larvae feed on once hatched. The substrates are moistened and mixed with new ones as the old ones are being utilized until the larvae get matured and harvested. The substrate remains, moulted exoskeleton and wastes from the larvae are all the constituents of the frass that is gotten from the system and used for the experiment. After lovemaking, parent flies dies. This makes the flies another waste product that is gotten from the system. The wastes (sludge, frass and dead flies) are all analysed to assess the chemical and proximate composition and to further explore their potentials for organic fertilization.

Plate 15: Black Soldier Fly's love net of INCiTiS Laboratory

Plate 16: Frass sample of Black Soldier fly Larvae reared in INCiTiS Laboratory

Plate 16: Frass sample of Black Soldier fly Larvae reared in INCiTiS Laboratory

3.3 Sample Collection

Samples of aquaponic sludge, frass and dead flies were randomly collected. The aquaponic sludge produced in the digester tank of the simplified aquaponic set up of the INCITIS-FOOD project at the University of Ibadan, Nigeria were collected and utilised. These were considered for organic fertilizer production due to the considered disgusting impact of releasing these to the environment. These solid wastes are the aquaponic sludge used for the current study. The solid wastes (sludge) from the digester tank were collected on daily basis, weighed (g) using an electronic scale and dried. The final weight after drying is measured. Samples of the sludge from the aquaponic unit and samples of dead flies and frass from the insectary were randomly collected and analysed for proximate and mineral contents following standard procedures.

3.4 Determination of proximate and mineral composition of fresh aquaponic sludge, Insect frass, and dead flies.

Aliquot of freshly collected sludge, frass and dead BSF were subjected to standard procedures for proximate and mineral analysis. Specifically, proximate profile of containing moisture content, crude protein, crude ash, ether extract, crude fibre was determined by the methods described in Association of Official Analytical Chemist (AOAC) (2010). Also, the minerals in the samples were analysed using Spectrophotometric and titrimetric methods as applicable in AOAC, (2010).

3.4 Determination of the effect of storage time on proximate and mineral profile in anaerobically stored Aquaponic sludge, Insect frass, and dead flies.

Aqueous samples of the sludge, frass and dead flies were replicated and kept for 7 days under anaerobic conditions inside a covered plastic container. Five (5) grams each of the experimental samples were collected in small sample containers. Each of the sample was soaked with fifty (50) grams of distilled water and rinsed thoroughly. The samples were immediately hermetically covered to ensure that the system has no interaction with the environment and to ensure zero entrance of oxygen into the system. The only replicated sample for each day were only opened and subjected to proximate and mineral content analysis to understand the trend and be able to know the best period to keep the wastes in covered condition for optimum nutrient yield. The Frass, Sludge and Dead fly samples were labelled F0An, S0An and Df0An respectively. The S0An, S1An, S2An, S3An, S4An, S5An, S6An, and S7An taken at 0 hr, 24th hr, 48th hr, 72nd hr, 96th hr, 120th

hr, 144th hr and 168th hr respectively which signifies the period that each of the samples was stored. Analysis of proximate and mineral content followed the described method in section 3.3.

3.5 Determination of the effects of inclusion levels of aquaponic sludge and Insect frass or dead flies on proximate and mineral combinations for the production of organic fertilizer.

This activity was taken with the opinion that some essential mineral for standard organic fertilizer may be inadequate in either sludge, frass and dead flies, a combination of sludge and either of the frass/dead egg was made. The choice of frass or dead flies for the combination was based on proximate and mineral content and ease of dissolution. Although dead flies are rich in protein, the chitinous nature was considered a factor that will hinder dissolution in liquid fertilizer production. Hence, samples of dried sludge were combined with frass at 0, 25, 50, 75, 100 percent in replicates and analysed for proximate and mineral content following the earlier described methods. Specifically, The levels were 100% frass and 0% sludge, 75% frass and 25% sludge, 50% frass and 50% slugde, 25% frass and 75% sludge and 0% frass and 100% sludge. These levels were labelled A, B, C, D and E, respectively. The combination with the optimum proximate and mineral yield will be assessed for the effect of aerobic storage time of 7 days on the proximate and mineral content.

3.6 Statistical Analysis

Data was analysed for descriptive statistics, mean, percentage and standard deviation. Data across treatments were compared using ANOVA and students, T-test with significance taken at $p<0.05$.

CHAPTER FOUR

RESULTS

4.1 Differences in Proximate Quality of the freshly collected (0Hour) and 7 Days Anaerobically Stored Aquaponic sludge (SoAn), BSF-Based frass (FoAn), and dead BSF flies (FDOAn) from INCiTiS-Food Urban Production System.

Table 1 shows the descriptive values of the proximate qualities of the freshly collected sludge, frass and the dead BSF flies. Moisture content was lowest in deadflies (85.58±0.04), highest in Sludge (93.10±0.01). Crude protein was lowest in BSF-Frass (14.99±0.30), highest in BSF flies (51.92±0.23). Crude Fibre was lowest (2.18±0.042) in deadflies, highest in frass (4.74±0.085). The Ether Extract ranged from 0.80±0.11 (sludge) to (0.86±0.04) deadflies while crude ash was lowest (5.17±0.06) in deadflies, highest (12.53±0.32) in sludge.

Table 1: Differences in Proximate Quality of the freshly collected (0Hour) sludge (SoAn), BSF-Based frass (FoAn), and dead BSF flies (FDOAn) from Incitis-Food Urban Production System

Parameters	Sludge (SoAn) mean±SD	BSF-Based frass(FoAn) mean±SD	Dead flies(FDOAn) mean±SD
Moisture content	93.01±0.01	90.19±0.01	85.58±0.04
Crude Protein	31.94±0.28	14.99±0.30	51.92±0.23
Crude Fibre	3.19±0.21	4.74±0.09	2.18±0.04
Ether Extract	0.79±0.11	0.82±0.15	0.86±0.04
Crude Ash	12.53±0.32	11.21±0.13	5.17±0.06

Table 2: Differences in Proximate Quality of the one-Day anaerobically stored (24Hour) sludge (SoAn), BSF-Based frass (FoAn), and dead BSF flies (FDOAn) from Incitis-Food Urban Production System

Parameters	Sludge (SoAn) mean±SD	BSF-Based frass(FoAn) mean±SD	Dead BSF flies(FDOAn) mean±SD
Moisture content	92.79±0.01	89.7±0.01	84.92±0.04
Crude Protein	32.25±0.36	15.63±0.26	52.65±0.24
Crude Fibre	3.12±0.09	4.56±0.14	2.36±0.05
Ether Extract	0.90±0.09	0.78±0.01	0.96±0.14
Crude Ash	12.42±0.08	11.02±0.09	5.075±0.04

Table 3: Differences in Proximate Quality of the two-Day anaerobically stored (48Hour) sludge (SoAn), BSF-Based frass (FoAn), and dead BSF flies (FDOAn) from Incitis-Food Urban Production System.

Parameters	Sludge (SoAn) mean±SD	BSF-Based frass (FoAn) mean±SD	Dead BSF flies(FDOAn) mean±SD
Moisture content	89.99±0.01	89.34±0.02	84.23±0.02
Crude protein	25.53±0.11	16.36±0.17	53.35±0.06
Crude fibre	2.15±0.07	3.99±0.07	1.99±0.05
Ether extract	0.65±0.07	0.75±0.01	0.82±0.09
Crude Ash	7.05±0.08	10.17±0.09	4.66±0.13

Table 4: Differences in Proximate Quality of the three-Day anaerobically stored (72Hour) sludge (SoAn), BSF-Based frass (FoAn), and dead BSF flies (FDOAn) from Incitis-Food Urban Production System.

Parameters	Sludge (SoAn) mean±SD	BSF-Based frass (FoAn) mean±SD	Dead BSF flies (FDOAn) mean±SD
Moisture content	91.74±0.01	89.13±0.03	83.96±0.01
Crude protein	32.75±0.19	17.11±0.17	53.83±0.09
Crude fibre	2.36±0.08	3.82±0.08	1.90±0.04
Ether extract	0.55±0.09	0.60±0.06	0.69±0.09
Crude Ash	8.23±0.18	9.53±0.09	4.37±0.09

Table 5: Differences in Proximate Quality of the four-Day anaerobically stored (96Hour) sludge (SoAn), BSF-Based frass (FoAn), and dead BSF flies (FDOAn) from Incitis-Food Urban Production System.

Parameters	Sludge (SoAn) mean±SD	BSF-Based frass(FoAn) mean±SD	Dead BSF flies(FDOAn mean±SD
Moisture content	91.52±0.03	88.88±0.04	83.39±0.02
Crude protein	32.84±0.14	17.08±0.07	54.68±0.19
Crude fibre	2.72±0.18	3.46±0.07	1.63±0.08
Ether extract	0.29±0.08	0.49±0.06	0.69±0.13
Crude Ash	7.55±0.14	10.79±0.16	3.64±0.04

Table 6: Differences in Proximate Quality of the five-Day anaerobically stored (120Hour) sludge (SoAn), BSF-Based frass (FoAn), and dead BSF flies (FDOAn) from Incitis-Food Urban Production System

Parameters	Sludge (SoAn) mean±SD	BSF-Based frass (FoAn) mean±SD	DeadBSFflies (FDOAn) mean±SD
Moisture conten	91.12±0.02	88.65±0.07	82.89±0.02
Crude protein	34.61±0.33	18.02±0.08	54.84±0.15
Crude fibre	2.19±0.24	3.13±0.21	1.49±0.04
Ether extract	0.29±0.08	0.22±0.06	0.61±0.04
Crude Ash	6.92±0.26	9.91±0.13	0.42±0.04

Table 7: Differences in Proximate Quality of the six-Day anaerobically stored (144Hour) sludge (SoAn), BSF-Based frass (FoAn), and dead BSF flies (FDOAn) from Incitis-Food Urban Production System

Parameters	Sludge (SoAn) mean±SD	BSF-Based frass(FoAn) mean±SD	Dead BSF flies(FDOAn) mean±SD
Moisture content	90.78±0.035	88.26±0.014	82.37±0.021
Crude protein	34.74±0.099	17.85±1.287	55.63±0.092
Crude fibre	1.64±0.028	2.99±0.014	1.44±0.001
Ether extract	0.34±0.028	0.37±0.021	0.61±0.007
Crude Ash	6.42±0.049	8.56±0.028	3.27±0.007

Table 8: Differences in Proximate Quality of the seven-Day anaerobically stored (168Hour) sludge (SoAn), BSF-Based frass (FoAn), and dead BSF flies (FDOAn) from Incitis-Food Urban Production System

Parameters	Sludge(SoAn) mean±SD	BSF-Basedfrass(FoAn) mean±SD	DeadBSFflies(FDOAn) mean±SD
Moisture content	90.40±0.14	88.08±0.04	82.14±0.04
Crude Protein	35.57±0.16	18.94±0.15	56.81±0.16
Crude Fibre	3.40±0.14	5.80±0.42	2.10±0.28
Ether Extract	1.15±0.01	0.75±0.07	1.50±0.14
Crude Ash	10.05±0.21	11.57±0.03	7.94±0.09

4.2 Differences in Mineral Quality of the freshly collected (0Hour) and 7 Days Anaerobically Stored Aquaponic sludge (SoAn), BSF-Based frass (FoAn), and dead BSF flies (FDOAn) from INCiTiS-Food Urban Production System.

Table 9 shows the descriptive values of the proximate qualities of the freshly collected sludge, frass and the dead BSF flies. Sodium(Na) was lowest in Frass (1580±14.142), highest in deadflies (1840±14.142). Nitrogen(N) was lowest in frass (2385±7.071), highest in deadflies (12015±21.213). Potassium(K) was lowest in frass (1935±7.071), highest in deadflies (2295±35.355). Calcium(Ca) was lowest in frass (3900±14.142), highest in deadflies (4390±14.142). Magnesium(Mg) was lowest (1700±28.284), highest in deadflies (1860±14.142). Phosphorus(P) ranges from the lowest in frass (1800±14.142) to the highest in deadflies (1975±21.213). Manganese(Mn) ranges from 3.3±0.141 (frass) to 7±0.141 (deadflies). Zinc (Zn) was lowest in frass (8.5±0.141), highest in deadflies (11.4±0.141). Copper (Cu) ranges from 2.2±0.141 (frass) to 5.25±0.071 (deadflies). Iron(Fe) was lowest in frass (11.55±0.071), highest in deadflies (15.2±0.141).

Table 9: Differences in Minerals Profile of the freshly collected (0Hour) sludge (SoAn), BSF-Based frass (FoAn), and dead BSF flies (FDOAn) from Incitis-Food Urban Production System.

Parameters	Sludge(SoAn) mean±SD	BSF-Basedfrass (FoAn) mean±SD	DeadBSFflies(FDOAn) mean±SD
Sodium(Na)	1655.00±21.21	1580.00±14.14	1840.00±14.14
Nitrogen(N)	3510.00±14.14	2385.00±7.07	12015.00±21.21
Potassium(K)	2125.00±21.21	1935.00±7.07	2295.00±35.36
Calcium(Ca)	4120.00±14.14	3900.00±14.14	4390.00±14.14
Magnesium(Mg)	1800.00±14.14	1700.00±28.28	1860.00±14.14
Phosphorus(P)	1865.00±7.07	1800.00±14.14	1975.00±21.21
Manganese(Mn)	5.65±0.07	3.30±0.14	7.00±0.14
Zinc (Zn)	9.75±0.07	8.50±0.14	11.40±0.14
Copper (Cu)	3.30±0.14	2.20±0.14	5.25±0.07
Iron(Fe)	13.30±0.14	11.55±0.07	15.20±0.14

Table 10: Differences in Minerals Profile of the one-Day anaerobically stored (24Hour) sludge (SoAn), BSF-Based frass (FoAn), and dead BSF flies (FDOAn) from Incitis-Food Urban Production System.

Parameters	Sludge(SoAn) mean±SD	BSF Based frass (FoAn) mean±SD	Dead BSFflies(FDOAn) mean±SD
Sodium (Na)	1595.00±7.07	1465.00±21.21	1755.00±7.07
Nitrogen (N)	3720.00±28.28	2600.00±14.14	12675.00±21.21
Potassium (K)	2190.00±14.14	2065.00±21.21	2410.00±28.28
Calcium (Ca)	4015.00±7.07	3590.00±14.14	4280.00±14.14
Magnesium (Mg)	1690.00±14.14	1600.00±14.14	1755.00±7.07
Phosphorus (P)	1800.00±14.14	1685.00±21.21	1905.00±35.36
Manganese (Mn)	6.60±0.14	4.20±0.14	7.85±0.07
Zinc (Zn)	8.60±0.14	7.70±0.14	10.80±0.14
Copper (Cu)	2.90±0.14	1.55±0.07	4.80±0.14
Iron (Fe)	12.65±0.21	10.75±0.07	14.90±0.28

Table 11: Differences in Minerals Profile of the two-Day anaerobically stored (48Hour) sludge (SoAn), BSF-Based frass (FoAn), and dead BSF flies (FDOAn) from Incitis-Food Urban Production System.

Parameters	Sludge(SoAn) mean±SD	BSF-Based frass (FoAn) mean±SD	Dead BSF flies (FDOAn) mean±SD
Sodium (Na)	1540.00±14.14	1405.00±21.21	1725.00±21.21
Nitrogen (N)	4110.00±14.14	2785.00±21.21	13505.00±21.21
Potassium (K)	2285.00±21.21	2100.00±14.14	2525.00±21.21
Calcium (Ca)	3925.00±21.21	3360.00±14.14	4190.00±14.14
Magnesium (Mg)	1585.00±7.07	1465.00±7.07	1700.00±14.14
Phosphorus (P)	1675.00±7.07	1570.00±14.14	1785.00±21.21
Manganese (Mn)	7.85.00±0.07	5.35±0.07	8.7.00±0.14
Zinc (Zn)	7.60±0.28	7.45±1.48	9.45±0.21
Copper (Cu)	2.30±0.14	1.40±0.14	4.20±0.14
Iron(Fe)	12.30±0.28	10.40±0.14	14.35±0.21

Table 12: Differences in Minerals Profile of the three-Day anaerobically stored (72Hour) sludge (SoAn), BSF-Based frass (FoAn), and dead BSF flies (FDOAn) from Incitis-Food Urban Production System

Parameters	Sludge(SoAn) mean±SD	BSF-Basedfrass(FoAn) mean±SD	DeadBSF flies(FDOAn) mean±SD
Sodium (Na)	1395.00±21.21	1320.00±14.14	1585.00±21.21
Nitrogen (N)	4320.00±28.28	2945.00±21.21	13830.00±14.14
Potassium (K)	2485.00±21.21	2360.00±28.28	2755.00±35.36
Calcium (Ca)	3740.00±14.14	3185.00±21.21	3935.00±21.21
Magnesium (Mg)	1425.00±21.21	1410.00±84.85	1505.00±21.21
Phosphorus (P)	1535.00±21.21	1450.00±28.28	1600.00±28.28
Manganese (Mn)	9.45±0.07	6.55±0.21	10.60±0.28
Zinc (Zn)	6.25±0.07	5.40±0.14	7.60±0.28
Copper (Cu)	1.20±0.14	0.60±0.14	2.65±0.35
Iron (Fe)	10.65±0.21	8.75±0.07	12.70±0.14

Table 13: Differences in Minerals Profile of the four-Day anaerobically stored (96Hour) sludge (SoAn), BSF-Based frass (FoAn), and dead BSF flies (FDOAn) from Incitis-Food Urban Production System.

Parameters	Sludge(SoAn) mean±SD	BSF-Basedfrass(FoAn) mean±SD	DeadBSFflies (FDOAn) mean±SD
Sodium(Na)	1335.00±7.07	1265.00±7.07	1515.00±7.07
Nitrogen(N)	4495.00±21.21	3045.00±21.21	14500.00±14.14
Potassium(K)	2135.00±21.21	1925.00±21.21	2390.00±14.14
Calcium(Ca)	3635.00±21.21	3075.00±7.07	3795.00±7.07
Magnesium(Mg)	1370.00±14.14	1315.00±7.07	1425.00±7.07
Phosphorus(P)	1450.00±14.14	1340.00±14.14	1515.00±7.07
Manganese(Mn)	9.30±0.14	6.15±0.07	9.80±0.14
Zinc (Zn)	5.60±0.14	4.65±0.07	7.35±0.07
Copper (Cu)	0.85±0.07	0.35±0.07	2.50±0.14
Iron(Fe)	10.15±0.21	8.40±0.14	11.75±0.07

Table 14: Differences in Minerals Profile of the five-Day anaerobically stored (120Hour) sludge (SoAn), BSF-Based frass (FoAn), and dead BSF flies (FDOAn) from Incitis-Food Urban Production System

Parameters	Sludge(SoAn) mean±SD	BSF-Basedfrass(FoAn) mean±SD	DeadBSFflies (FDOAn) mean±SD
Sodium(Na)	1300.00±14.14	1220.00±14.14	1490.00±14.14
Nitrogen(N)	4890.00±14.14	3285.00±21.21	15030.00±14.14
Potassium(K)	2055.00±7.07	1885.00±21.21	2315.00±7.07
Calcium(Ca)	3540.00±14.14	3025.00±7.07	3620.00±14.14
Magnesium(Mg)	1320.00±14.14	1250.00±14.14	1375.00±7.07
Phosphorus(P)	1375.00±7.07	1295.00±7.07	1490.00±14.14
Manganese(Mn)	8.55±0.07	5.70±0.14	9.30±0.00
Zinc (Zn)	5.15±0.07	4.25±0.07	6.80±0.00
Copper (Cu)	0.65±0.07	0.15±0.07	2.30±0.14
Iron(Fe)	9.75±0.07	7.70±0.14	11.15±0.07

Table 15: Differences in Minerals Profile of the six-Day anaerobically stored (144Hour) sludge (SoAn), BSF-Based frass (FoAn), and dead BSF flies (FDOAn) from Incitis-Food Urban Production System.

Parameters	Sludge(SoAn) mean±SD	BSF-Based frass (FoAn) mean±SD	DeadBSFflies (FDOAn mean±SD
Sodium(Na)	1250.00±14.14	1175.00±7.07	1375.00±7.07
Nitrogen(N)	5160.00±14.14	3525.00±7.07	15765.00±49.49
Potassium(K)	2015.00±7.07	1820.00±14.14	2270.00±14.14
Calcium(Ca)	3460.00±14.14	2950.00±14.14	3530.00±14.14
Magnesium(Mg	1275.00±7.07	1215.00±7.07	1325.00±7.07
Phosphorus(P)	1350.00±28.28	1250.00±14.14	1430.00±14.14
Manganese(Mn	7.80±0.14	5.15±0.07	8.75±0.07
Zinc (Zn)	4.75±0.07	3.70±0.14	6.35±0.07
Copper (Cu)	0.45±0.07	0.00±0.00	1.75±0.21
Iron(Fe)	9.20±0.14	7.40±0.14	10.50±0.28

Table 16: Differences in Minerals Profile of the seven-Day anaerobically stored (168Hour) sludge (SoAn), BSF-Based frass (FoAn), and dead BSF flies (FDOAn) from Incitis-Food Urban Production System.

Parameters	Sludge (SoAn) mean±SD	BSF-Basedfrass(FoAn) mean±SD	DeadBSFflies(FDOAn mean±SD
Sodium(Na)	1225.00±21.21	1120.00±14.14	132.005±7.07
Nitrogen(N)	5510.00±14.14	3665.00±21.21	16230.00±28.28
Potassium(K)	1930.00±14.14	1770.00±14.14	2160.00±14.14
Calcium(Ca)	339.005±7.07	2890.00±14.14	3420.00±14.14
Magnesium(Mg)	1235.00±7.07	1165.00±7.07	1290.00±14.14
Phosphorus(P)	1300.00±14.14	1220.00±14.14	1375.00±7.07
Manganese(Mn)	7.30±0.14	4.45±0.21	8.15.00±0.07
Zinc (Zn)	4.20±0.14	3.25±0.07	5.7.00±0.14
Copper (Cu)	0.30±0.14	0.00±0.00	1.45.00±0.07
Iron(Fe)	8.40±0.14	6.70±0.14	10.20±0.14

Table 17: Composition in percentage inclusions of frass/sludge compared to standard Nutrient solutions used by independent hydroponic systems.

Nutrient Compostition of a standard synthetic hydroponic fertilizer	100% frass mean±SD	75% frass mean±SD	50% frass mean±SD	25%frass mean±SD	100%Sludge mean±SD
N: 70–164 mg/L,	45,060.00±0.02	50,950.00±0.02	56,280.00±0.01	67,820.00±0.02	75,515.00±0.018
P: 5–40 mg/L,	3,170.00±0.01	3,465.00±0.01	3,500.00±0.01	3,565.00±0.01	3,130.00±0.03
K: 120–280 mg/L,	3,775.00±0.01	5,690.00±0.01	5,940.00±0.01	6,105.00±0.01	2,700.00±0.01
Na:	2,265.00±0.01	2,400.00±0.01	2,475.00±0.01	2,605.00±0.01	2,700.00±0.01
Ca: 80–140mg/L,	2,415.00±0.01	2,635.00±0.01	2,705.00±0.01	2,770.00±0.01	7,380.00±0.01
Mg: 40–60 mg/L,	2,685.00±0.01	2,825.00±0.01	2,875.00±0.01	2,950.00±0.01	2,915.00±0.01
Fe: 2.0–6.0 mg/L,	128.80±0.04	135.94±0.11	138.33±0.06	141.74±0.09	157.00±0.16
Mn:0.4–1.0 mg/L,	29.61±0.09	33.62±0.11	35.03±0.09	36.85±0.09	38.56±0.09
Cu: 0.01–0.1mg/L,	13.16±0.04	14.89±0.09	15.86±0.03	16.78±0.06	18.33±0.09
Zn: 0.04–0.08 mg/L,	56.16±0.06	63.31±0.03	67.49±0.65	72.86±0.05	75.36±0.06

Table 18: Proximate composition in percentage inclusions of frass/sludge.

PARAMETERS	100%FRASS mean±SD	75%FRASS mean±SD	50%FRASS mean±SD	25%FRASS mean±SD	100% SLUDGE mean±SD
Moisture Content	7.77±0.06	9.09±0.04	9.48±0.06	7.31±0.06	6.75±0.05
Crude Protein	28.17±0.11	31.85±0.16	35.18±0.09	42.36±0.16	47.20±0.11
Crude Ash	27.15±0.35	25.89±0.42	26.15±0.09	20.96±0.22	20.15±0.07
Ether Extract	1.05±0.03	1.855±0.05	0.92±0.04	3.58±0.06	0.77±0.05
Crude Fibre	11.6±0.14	10.45±0.21	10.95±0.21	8.60±0.28	7.35±0.21
NFE	35.87±0.16	31.32±0.25	28.28±0.16	25.81±0.06	25.13±0.04

Table 19: Effect of Storage Days on N:P:K Profile of the anaerobically Stored sludge (SoAn), BSF-Based frass (FoAn), and dead BSF flies (FDOAn) from Incitis-Food Urban Production System.

Storage Time	Sludge(SoAn)	Frass(FoAn)	Dead Flies (FDOAn)
	N:P:K	N:P:K	N:P:K
0Hour	1.9:1:1.1	1.3:1:1.1	6.1:1:1.2
24Hour	2.1:1:1.2	1.5:1:1.2	6.4:1:1.3
48Hour	2.4:1:1.3	1.8:1:1.3	7.3:1:1.4
72Hour	2.8:1:1.6	2.0:1:1.6	8.1:1:1.7
96Hour	3.1:1:1.4	2.2:1:1.4	9.1:1:1.8
120Hour	3.6:1:1.5	2.5:1:1.5	10.1:1:1.9
144Hour	3.8:1:1.5	2.7:1:1.5	10.9:1:1.9
168Hour	3.7:1:1.3	2.6:1:1.3	10.7:1:1.8

Table 20: N:P:K Profile ratio of the Frass/Sludge combinations from Incitis-Food Urban Production System.

Variable	N	P	K	N:P:K Ratio
100% Frass	45060.00	3170.00	3775.00	12:1:1
75% Frass	50950.00	3465.00	5690.00	9:1:1
50% Frass	56280.00	3500.00	5940.00	10:0.6:1
25% Frass	67815.00	3565.00	6105.00	11:1:1
100% Sludge	75515.00	3130.00	2700.00	27:1:1

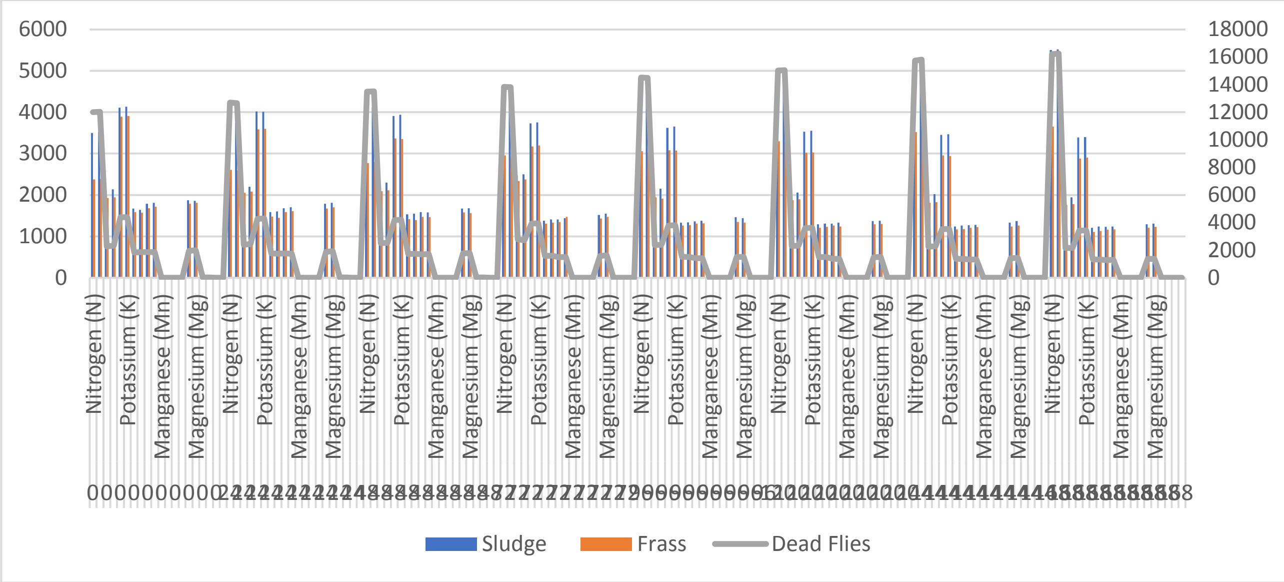

Figure 4.0-1: A graph showing Mineral Nutrient composition in the anaerobically stored Sludge, Frass and Dead Flies.

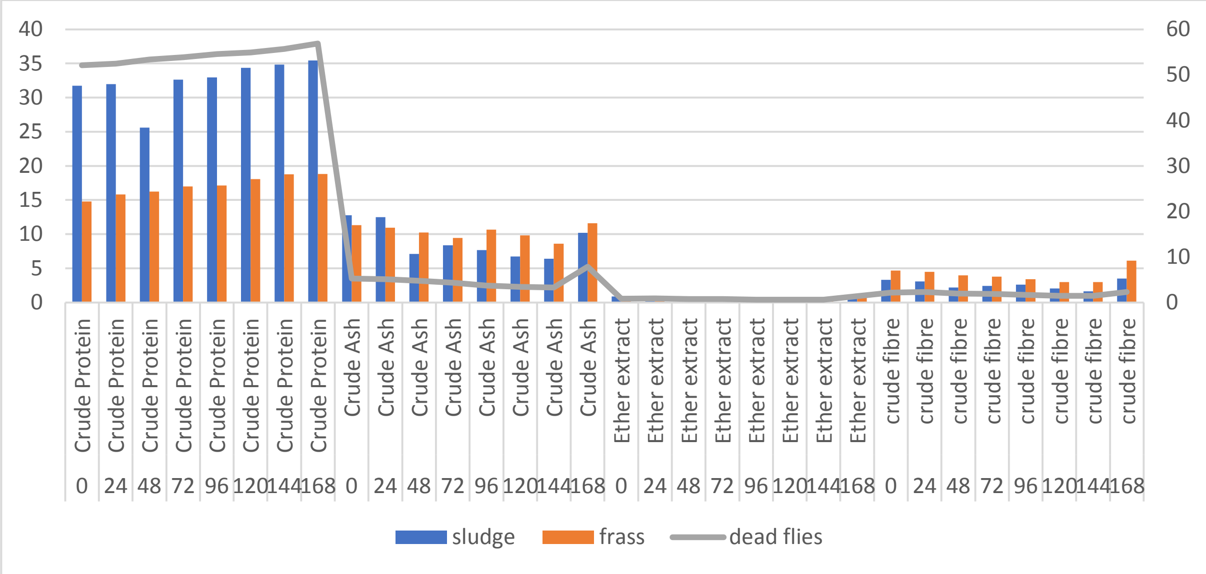

Figure 4.2: A graph showing Proximate Composition in anaerobically stored sludge, frass and dead flies for seven days.

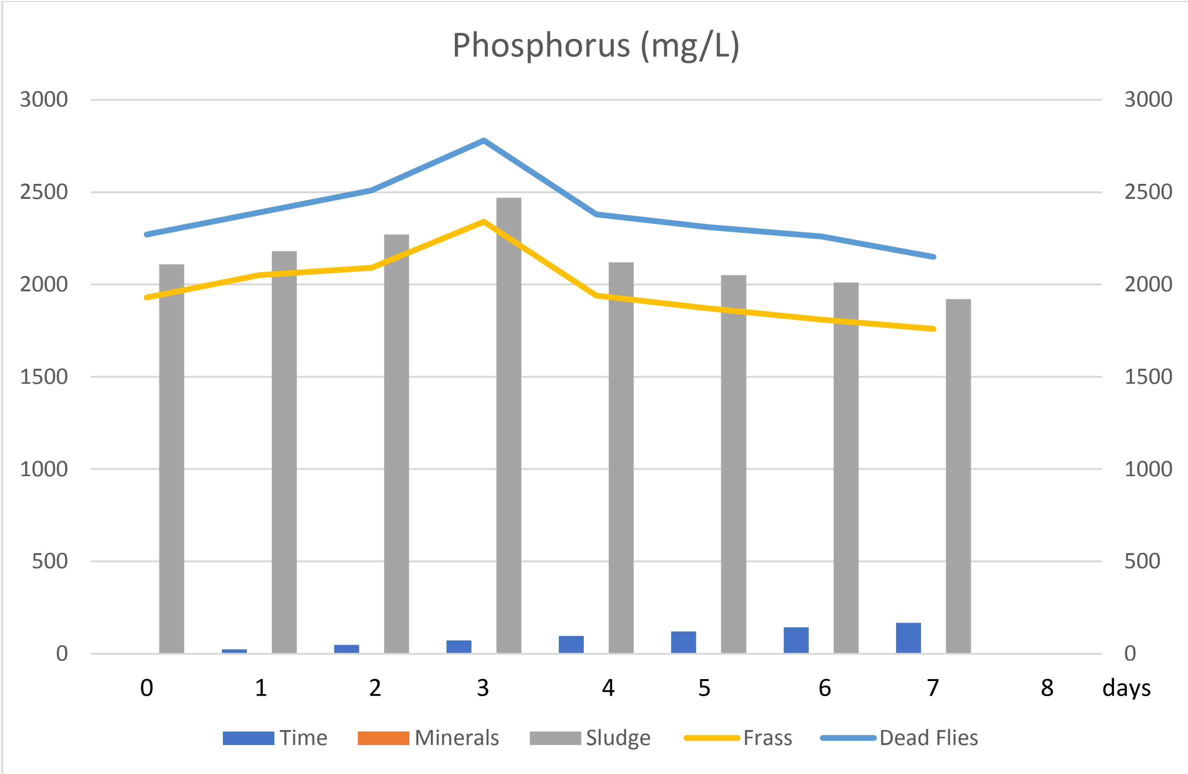

Figure 4.3: A graph showing Phosphorus Composition in anaerobically stored sludge, frass and dead flies for seven days.

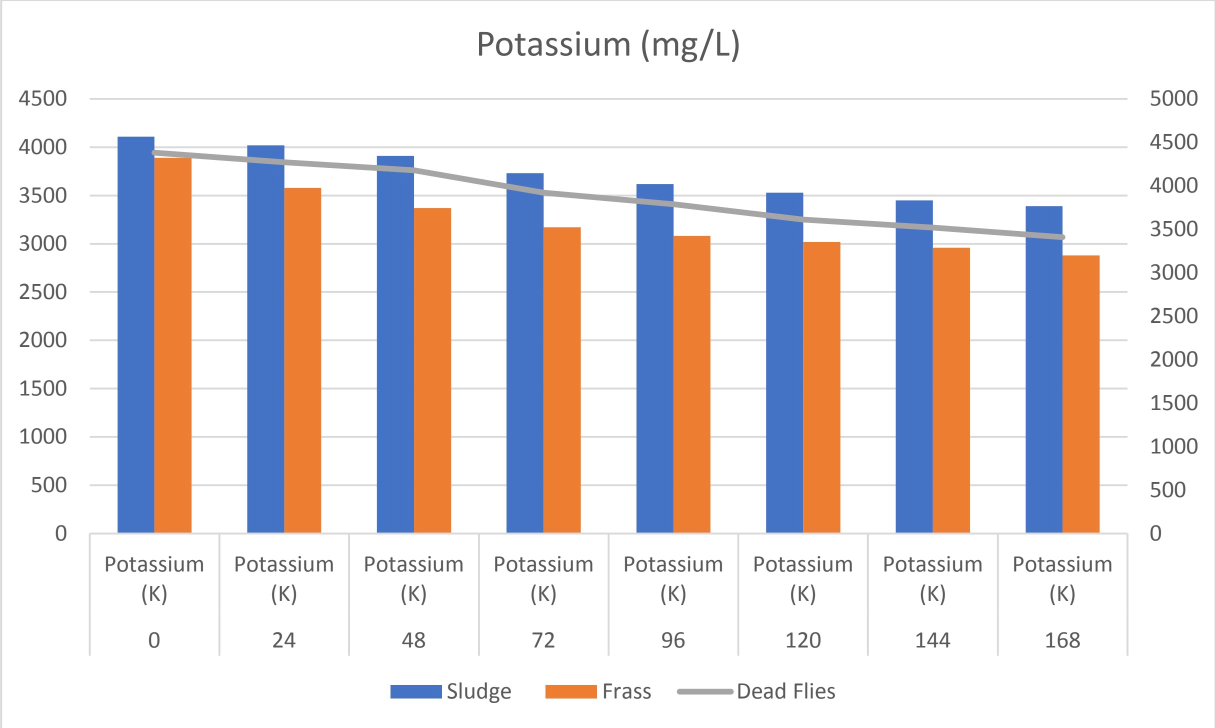

Figure 4.4: A graph showing Potassium Composition in anaerobically stored sludge, frass and dead flies for seven days.

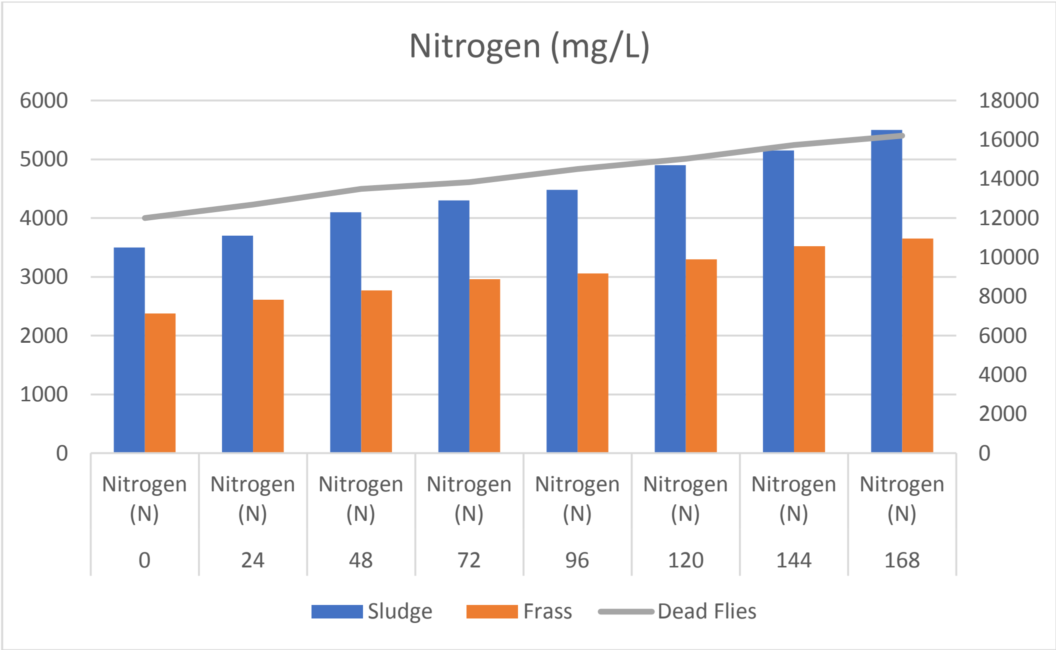

Figure 4.5: A graph showing Nitrogen Composition in anaerobically stored sludge, frass and dead flies for seven days.

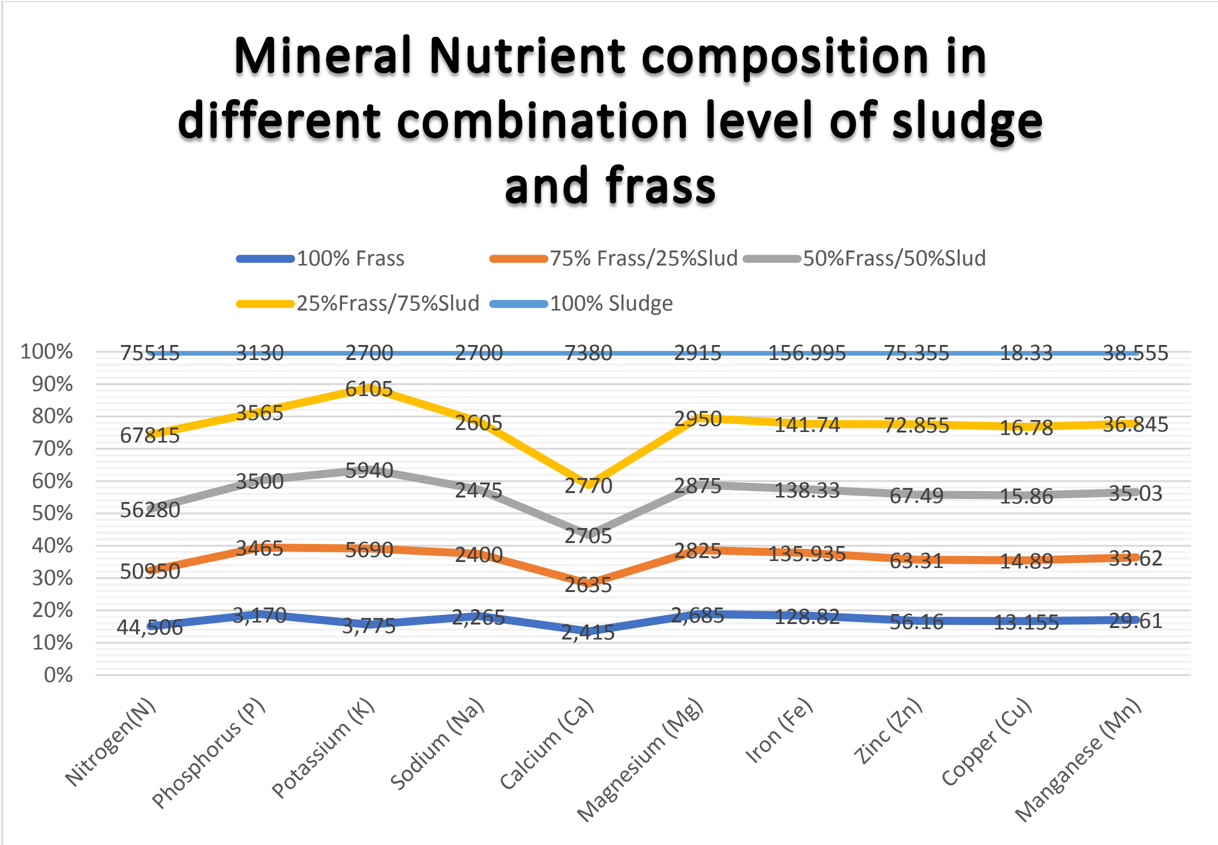

Figure 4.6: A graph showing Mineral Nutrient composition in different combination level of sludge and frass against expanded levels of 10% scale.

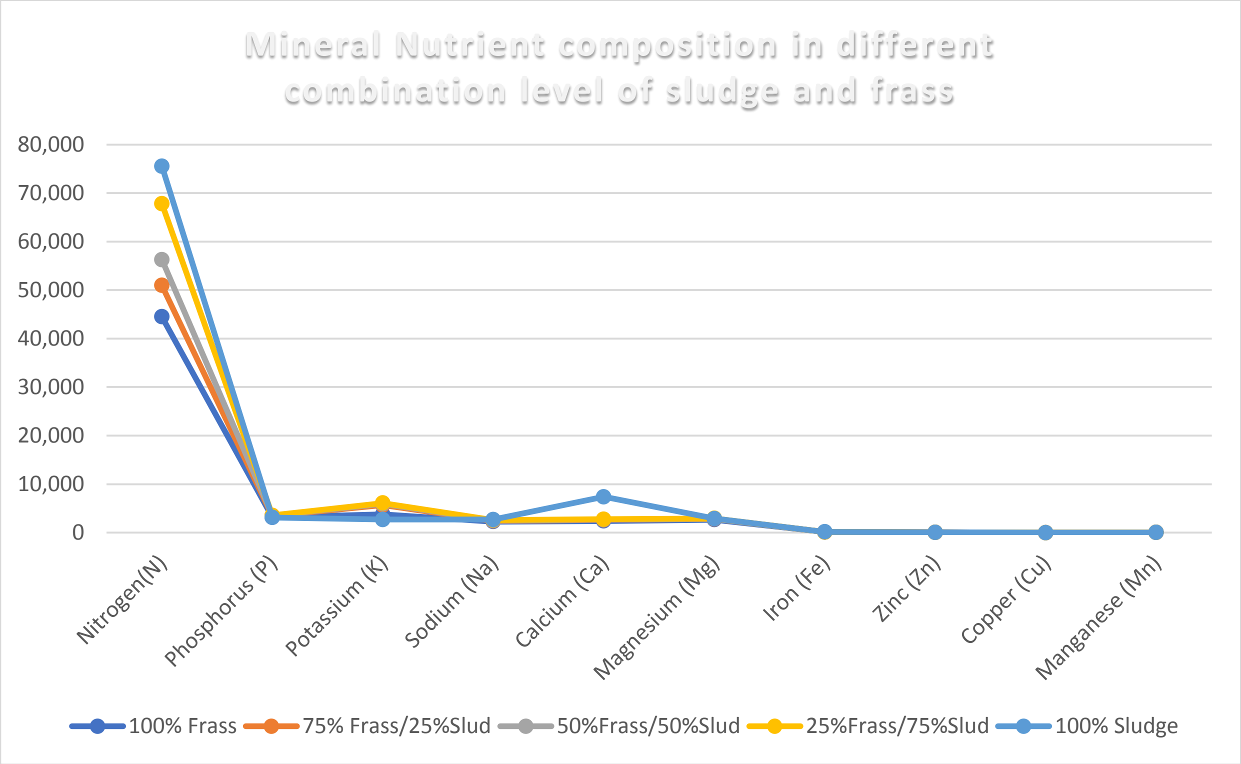

Fig. 4.7. A graph showing Mineral Nutrient composition in different combination level of sludge and frass against the exact amount in each sample.

CHAPTER FIVE

DISCUSSION

5.0. Overall Interpretation

The data reveals valuable insights into the nutritional composition and transformation of organic waste materials (sludge, frass, and dead BSF flies) during anaerobic storage. It also highlights their potential as nutrient sources for hydroponic systems.

5.1. Proximate Analysis

Tables 1-8 examines the proximate composition (moisture, protein, fibre, ether extract, ash) of sludge, frass, and dead BSF flies over a 7-day anaerobic storage period.

They provide insights into how these materials change in nutrient content over time. The trend is as follows.

5.1.1. Moisture Content

All materials exhibit high moisture content, which gradually decreases over time due to anaerobic storage. Sludge consistently has the highest moisture content. The observed decrease in moisture content over time is characteristic of anaerobic digestion. Microorganisms break down organic matter, releasing water as a byproduct.

5.1.2. Crude Protein

Dead BSF flies have the highest crude protein content, followed by sludge, and then frass. Protein levels in dead flies increase with anaerobic storage time. Sludge protein levels are fairly consistent, with a small rise over time. Frass protein levels also rise over time. The high protein content in BSF flies, coupled with its increase during storage, suggests that BSF processing can concentrate protein from waste. This has implications for animal feed production.

5.1.3. Crude Fiber

Frass has the highest crude fibre content. Fibre content generally decreases with storage time. The decrease in fiber content could be attributed to microbial degradation of cellulose and hemicellulose.

5.1.4. Crude Ash

Sludge and Frass have the highest crude ash content. Dead BSF flies have a very low ash content. Ash content decreases with storage time. The reduction in ash content might be due to the volatilization of certain minerals during anaerobic digestion.

5.1.5. Ether Extract

Ether extract levels are relatively low across all materials. The levels vary over time. The fluctuations in ether extract levels likely reflect changes in the lipid composition due to microbial activity.

5.2. Mineral Profile

Tables 9-16 show the mineral content (Na, N, K, Ca, Mg, P, Mn, Zn, Cu, Fe) of the same materials over the same 7-day period. They highlight the availability of essential plant nutrients.

The trend is as follows:

5.2.1. Nitrogen (N)

Dead BSF flies have the highest nitrogen content, followed by sludge, and then frass. Nitrogen levels increase over time for all materials.

5.2.2. Phosphorus (P) and Potassium (K)

All three materials contain significant amounts of phosphorus and potassium. Their levels vary over time.

5.2.3. Calcium (Ca) and Magnesium (Mg)

All three materials are good sources of calcium and magnesium. Their levels vary over time too.

5.2.4. Micronutrients (Mn, Zn, Cu, Fe)

All three materials contain essential micronutrients. Their levels also vary over time. The presence of essential micronutrients further supports the use of these materials for plant nutrition.

5.2.5. Macronutrients (N, P, K)

The high levels of these macronutrients, particularly nitrogen in BSF flies, underscore the potential of these materials as fertilizers. However, the very high values in the frass/sludge mixtures raise concerns about potential toxicity and the need for careful dilution.

5.2.6. Sodium (Na)

The variability in sodium levels warrants attention, as excessive sodium can negatively impact plant growth.

5.3. Frass/Sludge Combinations

Table 17 compares the nutrient content of different frass/sludge mixtures with a standard hydroponic nutrient solution. It's crucial for understanding the potential of these materials as fertilizers.

5.4. Nutrient Concentration

The frass/sludge mixtures have significantly higher nutrient concentrations than the standard hydroponic solution. This indicates that these materials are highly concentrated sources of plant nutrients.

5.5. Nutrient Ratios

The mixtures have imbalanced nutrient ratios, with very high nitrogen levels. This highlights the need for careful dilution and management before application.

5.6. Frass/Sludge Mixtures

Frass/sludge mixtures are highly concentrated nutrient sources, but they require careful management to avoid nutrient imbalances. The presence of essential micronutrients further supports the use of these materials for plant nutrition.

5.7. Statistical Analysis

The provided ANOVA tables and Tukey/Duncan tests analyse the statistical significance of the differences observed in the proximate and mineral analyses. They test the differences between time periods, materials (sludge, frass, flies), and mineral or proximate composition.

The ANOVA tables demonstrate that time and material type significantly affect the proximate and mineral composition of the materials. The interactions between time and mineral or proximate composition are also significant.

Frass/Sludge ANOVA test show that there is a very high statistical significance between the mineral content of the different combinations

Tukey/Duncan tests reveal specific differences between time points and materials. They identify which groups are significantly different from each other.

The ANOVA results confirm that the differences in mineral content between the frass/sludge combinations are statistically significant, indicating that the mixing ratio has a real effect on the final nutrient composition.

5.8. Potential of the wastes as Organic Fertilizers

Sludge, frass, and dead BSF flies have the potential to be used as organic fertilizers due to their rich nutrient content. The imbalanced N:P:K ratios emphasize the need for careful management and potential supplementation with other nutrient sources.

5.9. Time and Material Effects of anaerobic storage

The significant effects of time and material type on proximate and mineral composition highlight the dynamic nature of anaerobic digestion and the distinct characteristics of each material. Anaerobic storage affects the nutrient composition of these materials. Understanding these changes is crucial for optimizing their use.

5.10. Interactions

The significant interactions between time and composition suggest that the changes in nutrient content over time are not uniform across all materials.

5.11. Implications of the experiment and the trend of the study

This study demonstrates the potential of BSF-based bioconversion to transform organic waste into valuable products like protein-rich animal feed and nutrient-rich fertilizers.

5.12. Nutrient Dynamics

It provides insights into the complex nutrient dynamics during anaerobic digestion, which can inform the development of efficient waste management and resource recovery strategies.

5.13. Nutrient Concentration Discrepancies

The most striking observation is the significant difference in nutrient concentrations between the standard hydroponic solution (Nozzi *et al*., 2018) and the frass/sludge mixtures. The frass and sludge mixtures show drastically higher concentrations of all measured elements compared to the standard solution.

5.14. Trend with Frass Percentage

As the percentage of frass in the mixture increases, there's a general trend of increasing nutrient concentrations for most elements (N, P, K, Na, Ca, Mg, Fe, Mn, Cu, Zn). This suggests that frass is a highly concentrated source of these nutrients.

5.15. Sludge Composition

100% sludge displays a unique profile, showing particularly high Calcium levels, and a drop in Potassium.

5.16. Micronutrient toxicity

While micronutrients are essential for plant health, they are required in small amounts, and excessive levels can be toxic especially for sensitive crops.

5.17. Comparison to Standard Hydroponic Solution

The standard hydroponic solution (Nozzi et al., 2018) provides a balanced and controlled nutrient supply within a specific range. The frass and sludge mixtures, in contrast, provide a highly concentrated and potentially imbalanced nutrient supply. The values reported for the frass and sludge mixes are extremely high, compared to normal hydroponic solutions.

5.18. Potential Benefits

Frass and sludge can serve as a potent source of nutrients for hydroponic systems, reducing the need for synthetic fertilizers. The high nutrient content could promote rapid plant growth and high yields.

5.19. Further inferences from the Frass/Sludge combination

5.19.1. High Nitrogen

All the frass/sludge mixtures exhibit a very high proportion of nitrogen compared to phosphorus and potassium. This is especially pronounced in the 100% sludge mixture.

5.19.2. Frass Influence

As the percentage of frass increases, the relative amount of potassium increases, improving the balance slightly.

5.19.3. Sludge Imbalance

The 100% sludge mixture has a much skewed ratio with extremely high nitrogen and low potassium. This could lead to vigorous vegetative growth but may hinder flowering and fruiting.

5.19.4. Comparison with Ideal Ratios

Ideal N:P:K ratios vary depending on the plant's growth stage and specific needs. However, generally, ratios closer to 1:1:1 or 3:1:2 are considered more balanced for overall growth. The ratios observed in the frass/sludge mixtures are far from these ideal ranges.

5.19.5. Implications of the Frass/Sludge combination

Nutrient Management: Using these frass/sludge mixtures directly could lead to nutrient imbalances and potential toxicities especially because of the micronutrients fluctuations. Careful dilution and adjustments with other nutrient sources would be necessary.

5.19.6. Crop-Specific Application

These mixtures might be more suitable for leafy green crops that require higher nitrogen during early growth stages. However, for fruiting or flowering crops, additional phosphorus and potassium would likely be needed.

5.20. Mineral Composition Trends and Interpretation

5.20.1. Nitrogen (N) Trend

N increases **as sludge increases** → 100% sludge has the highest nitrogen.

Also, **N** decreases **as BSF frass increases** → 100% Frass has the lowest nitrogen.

5.20.2. Phosphorus (P) Trend

Phosphorus is highest in BSF frass (FoAn)**,** meaning higher frass content is better for root development**.**

5.20.3. Potassium (K) Trend

Potassium is highest in **sludge** making it crucial for **fruiting and stress resistance**.

5.20.4. Calcium (Ca) & Magnesium (Mg) Trend

Decreases as BSF frass (FoAn) increases**,** meaning that high frass combinations may lack long-term soil fertility support**.**

Increases with higher sludge (SoAn) content**,** improving soil structure and pH buffering capacity**.**

5.20.5. Iron (Fe) and Zinc (Zn) Trend

Iron and Zinc are lower in high-frass combinations, meaning **micronutrient deficiencies may occur** if sludge is too low.

5.21. Suggested Best Combination for Organic Fertilizer Production

Given that sludge is not as available as frass**,** we need a balance between frass availability and soil fertility improvement**.**

5.21.1. Recommended Best Combination:

25% Sludge + 75% BSF Frass

5.21.2. Why is 25% Sludge + 75% BSF Frass the Best?

- **High Nitrogen and Potassium Content** → Essential for plant growth and productivity.
- **Adequate Phosphorus Levels** → Supports root development and flowering.
- **Improves Soil Structure** → Frass provides enough fiber and minerals to balance sludge.
- **Ensures Long-term Fertility** → Sludge adds Calcium, Magnesium, and Iron to sustain soil health.
- **Practicality** → Uses more readily available BSF frass while still benefiting from sludge.

Alternative: If sludge is as available as frass, the 50% Frass - 50% Sludge combination can be used instead to ensure better **mineral balance**.

Summarily, this combination ensures **sustainable soil enrichment**, **balanced nutrient supply**, and **practical implementation** for organic fertilizer production.

CHAPTER SIX

6.1. CONCLUSION

This study analyzed different combinations of Black Soldier Fly (BSF) frass and Aquaponic sludge to determine the best organic fertilizer formulation. The results indicate that sludge is rich in nitrogen (N), calcium (Ca) and potassium (K), essential for plant growth**,** while BSF frass provides important minerals like, magnesium (Mg), iron (Fe), and zinc (Zn), which support soil health**.**

The nutrient trends show that increasing sludge content boosts N, Ca and K**,** but reduces Mg, Fe, and Zn. Conversely**,** higher frass content enhances soil structure and micronutrient levels but lacks sufficient nitrogen, calcium and potassium for plant growth**.** Since sludge is not as readily available as frass, the most suitable combination for organic fertilizer production is 25% sludge and 75% BSF frass**.**

This combination provides:

- ✓ High nitrogen and potassium for plant growth.
- ✓ Sufficient phosphorus for root development.
- ✓ Balanced micronutrients (Ca, Mg, Fe, Zn) to improve soil fertility.
- ✓ Practical application due to the availability of BSF frass.

Thus, a 75% BSF frass + 25% sludge formulation ensures sustainable soil enrichment, crop productivity, and long-term soil health**.**

6.2.RECOMMENDATION

From this study, it is highly recommended:

To adopt the 75% BSF Frass + 25% Sludge ratio for large-scale organic fertilizer production due to its nutrient balance and practicality.

If sludge availability is like that of frass, a 50% Frass - 50% Sludge combination can be used as an alternative to ensure better mineral balance.

Further research should explore the decomposition rate, mineralization when stored aerobically, microbial activity, and field trials of this fertilizer to confirm its effectiveness in different hydroponic systems and/or soil types and crops.

Encourage farmers to integrate BSF frass-based organic fertilizer into sustainable farming systems to reduce reliance on synthetic fertilizers and improve soil health.

By implementing these recommendations, BSF and aquaponic wastes can be efficiently utilized for sustainable agriculture and soil restoration.

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