ELUCIDATION OF LOCUST AND GRASSHOPPER CONSUMPTION AND PROSPECTS OF REARING AS FOOD AND FEED IN WESTERN KENYA

BY

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DECLARATION

Declaration by the candidate

This thesis is my original work and has not been presented for a degree in any other University. No part of this thesis may be reproduced without the prior written permission of the authors and/or the University of Eldoret

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DEDICATION

I dedicate this work to God Almighty for it is Him who gave me the grace and strength to carry out this study successfully. Lastly, I dedicate this work to all research scientists in edible insects, food nutritionists, policymakers, and stakeholders with a passion for promoting edible insects as alternative protein sources for both human food and animal feed.

ABSTRACT

The increase in demand for the consumption of animal proteins coupled with the growing world population necessitates a re-evaluation of dietary habits. The strategies that can help increase food security include promoting edible insects as protein sources. Edible insects' protein is comparable to or higher than the most commonly consumed animal proteins hence a good alternative protein source. The study's main objective was to determine the knowledge and perceptions of edible grasshoppers and locust consumption in Western Kenya and the prospects of their rearing for food and feed. An experiment was carried out to investigate the growth performance of rearing locusts under laboratory and greenhouse conditions on sorghum, wheat and green gram plant diets. The growth performance of kales using decomposed locust frass was also determined. The data was analyzed using SPSS version 20 and STATGRAPHICS Centurion XVI. Of 901 respondents, 91.6% were knowledgeable about grasshopper consumption, while 8.4% had no idea. *Cyrtacanthacris tatarica* was most identified as edible (58.6%) while *Ruspolia differens* was least (1.2%) identified. Those who had never bought the insect were significantly different from those who had ever bought it (χ^2 = 92.2, d.f.=1, p<0.0001). Respondents willing to rear were 50.1% which was significantly different from those who were not willing (χ^2 = 13.4, d.f.=2, p=0.0012). The growth performance of desert locusts raised on different diets showed a significant difference in their growth (p<0.05). Nymphs raised on wheat in the laboratory had the highest total weight at week eight (2.48 ±0.33 g), while those raised on sorghum had the least (1.42±0.06 g). The percentage survival rate was high in nymphs raised on wheat both at the greenhouse (96.56%) and laboratory (90.31%), but lowest in nymphs raised on sorghum (76.41%). The nymphs raised on sorghum in the laboratory took the longest time (54.29) days to complete their development while nymphs raised on wheat took the shortest time in the laboratory (37.49) days and greenhouse (36.56) days. Desert locusts raised on a green gram diet had high amounts of protein (48.14±0.6), fat (36.08±0.2), and crude fiber (12.89±0.6) compared to desert locusts raised on other diets. The growth of kales planted with decomposed locust frass was comparable to kales planted with chicken manure in terms of the height of the plant, number of leaves and chlorophyll content. The growth performance of kales planted in plain soil performed poorly. The results show that the respondents of western Kenya were more knowledgeable about grasshopper and locust consumption and were willing to rear them for food and feed. Desert locusts can be reared under greenhouse conditions on a small scale and wheat and green gram plant diets can be used as feed substrate. Furthermore, locust frass has the potential to be used as an organic manure.

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LIST OF ABBREVIATIONS AND ACRONYMS

ANOVA	Analysis of Variance
AOAC	Association of Official Analytical Chemists
BSF	Black Soldier Fly
BSSF	Black Soldier Fly Frass
EAA	Essential Amino Acids
FAO	Food and Agricultural Organization
IBF	Insect-Based Feeds
ICIPE	International Centre of Insect Physiology and Ecology
ILIPA	Improving Livelihood by Increasing Livestock Production in Africa
KMFRI	Kenya Marine and Fisheries Research Institute
KNBS	Kenya National Bureau of Statistics
MUFA	Monounsaturated Fatty Acids
NACOSTI	National Commission for Science, Technology and Innovation.
RH	Relative Humidity
RH	Relative Humidity
SFA	Saturated Fatty acids
UN	United Nations
UNDESA	United Nations Department of Economics and Social Affairs

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CHAPTER ONE

INTRODUCTION

1.1 Background

The current world population is expected to increase from 7.6 billion to 9.8 billion by 2050 (UN, 2019), while that of Africa is expected to double to 2.2 billion from 1.1 billion by 2050 (UNDESA, 2017). Therefore, the demand and production of food and feed especially in terms of protein from existing agroecosystems will also increase. There will be greater pressure on agricultural land for livestock production for proteins (Van Huis & Oonincx, 2017; FAO 2019), fish supply, and an increased need for nutrients (FAO, 2015; Gasco *et al.*, 2019). Meat from conventionally raised livestock, which is mostly consumed by humans, accounts for 15 % of the amount of energy required in the human diet (Ordoñez-Araque *et al*., 2022). However, agricultural land required for animal grazing as well as the production of fodder for livestock is approximately 80 percent of the total land area thus exerting a lot of pressure on already shrinking agricultural land (Van Huis & Oonincx, 2017). There is also competition for grains by both humans and livestock since harvested grains from agricultural land are consumed by both (Nyakeri *et al*., 2017), thus leading to a decrease in food supply and thus food insecurity.

The increasing demand for animal protein coupled with the growing world population and the destruction of natural resources necessitates a rapid reevaluation of dietary habits, especially those associated with the consumption of meat or animal protein. Researchers have therefore proposed several innovative strategies that can help increase food and feed security, and strategies include promoting edible insects as an alternative sustainable high quality protein source for human consumption as well as livestock feed (Van Huis & Oonincx, 2017; FAO, 2021; Veldkamp *et al*., 2022).

Traditionally edible insects, especially in the tropics, have historically performed an important task in satisfying human dietary needs (Holloran *et al*., 2018; Oonincx & Finke, 2021; FAO 2021). Most edible insects are rich in protein, minerals, fats and vitamins, which is as good as vertebrate meat (Ebenebe *et al*., 2020; Egonyu *et al*., 2021; FAO, 2021; Veldkamp *et al*., 2022) hence a favourable alternative protein source for the human diet (Hlongwane *et al*., 2020).

However, insect consumption has decreased in many communities worldwide (Rumpold *et al*., 2014). For example, in developing countries, worldwide integration has led to the development of Western dietary patterns, which has contributed to the loss of food diversity and traditional habits of entomophagy. Western culture considers entomophagy to be filthy, disgusting, or even unsafe (Looy *et al*., 2014). This habit and lifestyle have spread to developing countries including Kenya where the communities that consume insects view entomophagy with disgust. This traditional custom is slowly disappearing since it is now considered primitive by some populations (Dunkel *et al*., 2014). Another reason for the decrease of entomophagy especially in Kenya could be the unavailability of edible insect protein. Most edible insects consumed are collected from the wild and hence not available throughout the year, they are seasonal (Van Huis, 2015; Van Huis & Oonincx, 2017; Arena *et al*., 2020). At the same time, insects harvested from the wild could be contaminated with toxic pesticides used in agricultural farms which poses a danger to human health (Aman *et al*., 2016; Jongema, 2017) and hence not safe for consumption. Loss of insect habitat due to natural events such as floods, climate fluctuations, earthquakes, and volcanic eruptions coupled with human activities of converting the insects' habitats into croplands and settlements has also contributed to the decline in insects and affected negatively their populations. Hence, the habitat can no longer support the insect species and in some instances lead to insect species extinction (Bali & Kaleka, 2021; Seni, 2022). This has also affected negatively the culture of entomophagy leading to a decline in insect consumption due to their unavailability.

However, in the recent past, interest has increased in the use of insects as a sustainable source of protein and a way to address malnutrition, especially in developing countries (Clarkson *et al*., 2018). The rising nutritional gap in the human diet and livestock feeds can therefore be filled by the rearing of insects for proteins (Egonyu *et al.*, 2021). Unlike conventional livestock production, raising edible insects for both food and feed has several advantages, such as emitting low levels of greenhouse gases and ammonia compared to large livestock farming (Van Huis & Oonincx, 2017; Sogari *et al*., 2019; Kowalska, 2019; FAO 2021). Rearing insects also require a small space where they can breed and reproduce (Megido *et al*., 2016; Doberman *et al*., 2017; Sogari *et al*., 2019; Kowalska, 2019). Some insect species can be successfully grown on organic by-products and thus converted into high-value protein products (Van Huis & Oonincx, 2017; Henchion *et* al., 2017; Sogari *et al.*, 2019). Insects also have high reproductive potential and high growth rates compared to livestock, and therefore take less time to mature (Kowalska, 2019; FAO, 2021). In addition, the feed conversion efficiency of insects is very high, which means that the insect conversion into biomass is very efficient (Van Huis & Oonincx, 2017). Another advantage of edible insect protein is that nearly 100% of the larvae and 80% of the adults of most edible insects are consumed hence there is minimal wastage (Amadi & Kabari, 2016; Henchion *et al*., 2017).

Apart from the insects being used as food for human proteins, they are also a good protein source that could be included in animal feeds since they have been found to have unique properties of nutrients that are equivalent to fish meal and soybean (KMFRI, 2021), and this may help to bring a solution to increasing fishmeal demands in aquaculture and livestock feeds. The amount of crude protein in insects for example has been reported to be between 34% to 74% on a dry matter basis depending on the species of insect and the stage of growth (Gasco *et al.,* 2020). This is comparable to fishmeal and soybean which have a crude protein content of 51% and 49% respectively (Vernooij & Veldkamp, 2019). The other nutritional value of the insects also includes essential amino acids (EAA), Vitamins such as vitamin B12, and minerals (Gasco *et al.,* 2020). Besides, the chitin and fatty acids present in insects are useful bioactive compounds that promote animal growth as well as help in counteracting any antimicrobial resistance (Veldkamp *et al*., 2022). These unique properties, therefore, show that they are a suitable substitute for the commonly used fishmeal and soy in feed production.

The main challenge in promoting insects as a preference protein source for both feed and food is the lack of awareness and unsustainable production systems that ensure food and feed safety (Selaledi *et al*., 2021). Therefore, to produce edible insects sustainably, there should be an enhancement of guaranteed quantity production through small-scale farming which is going to lead to an increase in consumer acceptance.

Grasshoppers and locusts (Orthoptera: Acrididae), historically have been associated with insect pests that destroy crops across the world (Cheseto *et al.,* 2015; Clarkson *et al*., 2018). However, these insects have been used historically as human food in some continents of Asia, Africa and Southern America (Kietzka *et al.,* 2021). They are rich in nutrients such as fiber, proteins, fats and minerals (Mariod *et al*., 2017; Clarkson *et* *al.,* 2018), which is comparable to that of conventional proteins such as eggs, meat, fish, and soybeans (Ssepuuya *et al.,* 2018). Apart from their nutritional composition, locusts have phytosterols which when ingested are metabolized into derivatives that provide good health benefits to humans since they are an important source of energy to the human body (Kietzka *et al*., 2021). They also have great potential to contribute to livelihood and employment opportunities as farmers rearing the insect can sell the surplus harvested and earn an income.

The western region of Kenya is traditionally known for entomophagy, and hence obtaining insights into the current knowledge relating to the consumption patterns of grasshoppers and locusts is very important, especially to encourage entomophagy in the current times of globalization. The knowledge obtained will be used for future decisions related to entomophagy. It is also imperative that the traditional community practicing entomophagy is also enriched by local knowledge about edible insect species, ways of collection or harvesting, and preparation or cooking methods (Riggi *et al*., 2016) hence it was important to find out this information from the respondents as well as their perception towards edible grasshoppers/locusts to document this knowledge. The current study, therefore, sought to document this traditional knowledge to restore and promote entomophagy so that this new information can be passed on, especially to new consumers (Manditsera *et al.,* 2018) as well as used for future decisions related to entomophagy and insect domestication.

Locusts and grasshoppers have recently been viewed as having great potential to be reared under controlled conditions for food and feed (Mariod *et al*., 2017; Ssepuuya *et al*., 2018). This is because, they have high reproductive potential and their numbers can increase 10 to 16 folds between each generation (Clarkson *et al.,* 2018), they have a shorter life cycle since they attain maturity stage between 4-8 weeks depending on the rearing conditions and hence high biomass production (Gosh *et a*l., 2014; Clarkson *et al.,* 2018). Besides insect rearing is environmentally safe since less water and land are required and lower greenhouse gases are emitted (Kelemu *et al.,* 2015; Van Huis & Oonincx, 2017).

To have enough grasshoppers/locusts for food and feed, the ability to mass rear them is an important factor. This will ensure that insects are available throughout and are produced in a relatively safe environment free from contamination that is most likely to be encountered in the wild or open fields. It is therefore important to understand the conditions that enhance their success in growth and development under controlled conditions (Niassy *et al*., 2016). Locusts are phytophagous and therefore the type of feed/plants given to them will affect their rate of growth and nutrient composition and hence good tissue formation and energy requirement for the insect (Niassy *et al*., 2016; Ssepuuya *et al*., 2018). Apart from feed, the chemical composition of insects is also influenced by factors such as stage of development, sex, temperature, and humidity (Paul *et al.,* 2016). The optimum conditions for rearing locusts must therefore be considered for successful mass rearing of the insect. Unfortunately, the performance, growth and nutritional composition of desert locusts reared under laboratory and greenhouse conditions on some of the locally available crops are scanty, which poses a constraint on the development of sustainable small-scale rearing as an alternative protein for food and feed. The current study was conducted to determine the possibilities of rearing locusts on locally available plants to increase the protein source in the diet of the inhabitants of western Kenya.

The production of insects as a source of protein is expected to increase, and therefore small-scale producers must look at the context of zero waste and contribute to the circular economy by investing in all parts of insects, including their frass which can be used as fertilizer, especially by insect farmers. Despite intensive research on the use of insects as food and feed, sufficient information is not available on insect frass biofertilizers. However, several studies have been conducted using black soldier fly's frass as organic fertilizers in different crops and cropping systems (Quillam *et al.,* 2019; Beesigamukama *et al.,* 2020; Anyega *et al.,* 2021; Agustiyani *et al.,* 2021). Use of decomposed insect frass as an organic fertilizer has not been utilized in the past. Therefore, introducing a new organic fertilizer such as frass in any farming system requires more investigation on how crops will respond to the new fertilizer. Decomposed locust frass has not been documented as being used in any cropping system, hence their performance in the cropping system is not known.

The main objective for the current research was to investigate the current knowledge on the consumption of edible grasshoppers and locusts in Western Kenya, and to promote the consumption of these insects through small scale rearing especially under greenhouse conditions. It was also important to investigate the effects of desert locust frass on the growth of kales and their nutritional quality in comparison with chicken manure and artificial fertilizer. The study also investigated the best feed plants to be used in rearing the grasshopper and locust that could give higher protein content.

1.2 Problem statement

The whole world, and especially developing countries, is witnessing a rapid demand for food products, especially animal proteins, but how to meet the growing demand remains an open and important question. An alternative protein to the most commonly consumed vertebrate is required in order to meet the demand of the rising world population. This alternative protein should be safe and accessible to the population. The most commonly consumed vertebrate proteins such as beef, pork, chicken eggs and fish are becoming expensive and unreachable especially to lower anad most middle income population and consumers. As a result of not having balanced diet due to lack of proteins, malnourishement especially in childred, and the old creeps in the population. The companies that produce animal feeds are also facing similar challenges because the protein ingredient used in feed production is also becoming scarce and expensive. This has led to lower quality feeds which eventually affect negatively the growth of animals that feed on them. There is therefore a need to come up with an alternative problem that can solve these problems. This study hence proposes edible insects to be used as an alternative protein to meet the rising protein demand for both human food and animal feed. The proposed insect is therefore grasshoppers and locusts. However, the current knowledge on the consumption of grasshoppers and locusts in western Kenya as an important traditional practice has not been documented. At the same time, knowledge on the methods of rearing grasshoppers and locusts on a small scale for food and feed has not been richly investigated in Kenya. Suitable feed substrates to be used in rearing these insects for food and feed that can produce an insect of high protein value at the same time a larger insect of high quality and quantity has not been fully investigated. The use of desert locust frass as an organic fertilizer in the growth of vegetables has not been documented. The present study therefore sought to fill these gaps and to come up with solutions

1.3 Justification

Edible insects as food and feed have received much attention as a result of rising animal protein prices, food shortages and human population growth (Ayensu *et al*., 2019; FAO 2021; Selaledi *et al*., 2021). The most commonly consumed conventional protein for the human diet is expensive and sometimes not readily available (Selaledi *et al*., 2021). Edible insects can therefore fill this gap, which can be a good alternative protein that can meet the daily goal of alternative dietic protein (FAO 2021; Selaledi *et al*., 2021). Besides, the protein content of most edible insects is comparable to that of other animal-based proteins (Raheem *et al.,* 2018; Nowakowaski *et al*., 2021; Veldkamp *et al*., 2022). Grasshoppers and locusts are edible insects consumed in the Western region of Kenya (Munke *et al.,* 2016). Traditionally, the communities that consume insects are believed to have very rich knowledge of the specific edible species, availability, methods of harvesting, and preparation/cooking methods of the insects suitable for consumption (Hlongwane *et al*., 2020; Omemo *et al*., 2021). There was therefore a need for the current study to document the traditional knowledge of the edible grasshoppers and locusts in the western region of Kenya to promote entomophagy and the information to be availed to new consumers. The collected information from the study is also expected to help future decision-making concerning entomophagy and hence encourage the culture of edible insect consumption among the population.

To encourage grasshopper and locust consumption as an alternative protein source, there is a need to produce enough insects that can be available to consumers. Grasshoppers and locusts have been reared in the laboratory successfully mostly for experimental studies (Egonyu *et al.,* 2021; Meena *et al*., 2021). For laboratory experiment, the insectary room where the insects are being raised need to be kept warm through heating up the room using light bulbs. At the same time, optimum humidity must be established for bettwr growth and development. However, this is quite costly for small scale production especially the amount of electricity bill one is likely to encounter. An alternative is therefore rearing them under greenhouse conditions, since only a nylon paper will be required to enlose the rearing house. And this is relatively less costly compared to the laboratory rearing. The study therefore investigated the rearing of the desert locust under greenhouse conditions in order to establish their growth performance and compared with those reared under laboratory conditions.

The findings from this study, therefore, are intended to provide innovative, cheap, and sustainable locust-rearing methods that will eventually lead to sustainable insect protein for both food and animal feed and hence contribute to food and domestic animal feed security.

1.4 Objectives

1.4.1 Broad objective

To contribute to food and nutrition security by strengthening the role of grasshopper and locusts in western Kenya's local diets while enhancing sustainability through small-scale insect farming.

1.4.2 Specific objectives

1. To determine the current knowledge, and practice of edible grasshoppers and locusts' consumption as protein sources for food and feed in western Kenya.
2. To establish the influence of sorghum, wheat and green gram seedlings on the growth performance of the desert locusts raised under laboratory and greenhouse conditions.
3. To determine the nutrient content of desert locusts reared on sorghum, wheat and green gram seedlings.
4. To establish the growth performance of kales grown using decomposed desert locust frass and chicken manure.

1.5 Hypothesis

The study was guided by the following null hypotheses.

$H0_1$: The inhabitants of the western region of Kenya do not know the edible species of grasshoppers and locusts and insect consumption is not part of their culture.

HO_2: There is no difference in the growth and development of desert locusts' nymphs when raised on sorghum, wheat and green gram seedlings diet.

HO_3: There is no difference in the nutrient composition of desert locusts' meal when locust nymphs are raised on sorghum, wheat and green gram seedlings diet

$H0_4$: There is no difference in the growth performance of kale plants grown using decomposed locust frass and chicken manure.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

Edible insect proteins are good alternative sources of protein that could be utilized as food as well as feed. This chapter looks at the culture of entomophagy around the globe and especially in Africa, the most commonly consumed insects and their benefits in terms of nutrients and medicinal. The methods of harvesting grasshoppers and locusts and various methods of cooking to increase palatability are also discussed. The challenges of insect consumption and how these challenges can be overcome are well elaborated in this chapter. The chapter also looks at insect farming and the rearing of locusts under controlled conditions.

2.2 Entomophagy

Entomophagy is the culture and practice of eating edible insects by humans (Dobberman *et al*., 2017; Raheem *et al*., 2018). However, this culture depends on the availability of insects, the ability to collect them, whether they are wild or raised as mini-livestock, and the beliefs and traditions of the people who eat them. (Ayieko & Millicent, 2010).

Eating edible insects has been a traditional practice in many countries around the world since time immemorial (Mlček *et al*., 2021; Ordoñez-Araque *et al.*, 2022). Many native communities especially in Australia, Africa, Asia, and Latin America practiced entomophagy as their traditional heritage and have consumed a number of insect species as their traditional foods over the centuries (Kinyuru *et al*., 2013; Makkar *et al*., 2014). Locusts, for example, were prepared for royal banquets in the Middle East as early as the eighth century BC (Bodenheimer, 1951). However, this traditional practice of consumption of edible insects especially in Africa has been decreasing, and this could be associated with how Western countries view insects with a lot of phobia and disgust (Looy *et al.,* 2014; Abdullahi *et al.,* 2021).

The number of edible insects worldwide is still under investigation; however, researchers have attempted to identify most of these edible insects around the world. According to the literature search done by Mitsuhashi (2016), there are more than 2,100 edible insect species known worldwide while Van Huis (2020) identified 2000 edible insect species. It is also reported that over two (2) billion people in the world are consuming edible insects (Papastavropoulou *et al.,* 2021). Insect species that are commonly consumed throughout the world belong to the orders; Coleoptera (beetles) at 31%, Lepidoptera (caterpillars) at 18%, Hymenoptera (bees, wasps, ants) at 14%, Orthoptera (crickets, locusts, and grasshoppers) at 13%, Hemiptera (scale insects and true bugs) at 10%, Isoptera (termites) at 3%, Odonata (dragonflies) 3%, Diptera (flies) 2% and others 6% (Van Huis, 2015; Dobberman *et al.,* 2017; Jongema, 2017). The majority of the edible insects consumed are terrestrial 88% while 12% are aquatic (Papastavropoulou *et al.,* 2021). These insects are normally consumed in various stages, for instance, both adult and immature larvae of the beetles are eaten, lepidopterans are mostly consumed as caterpillars (larvae stage), hymenopterans are mostly consumed in their larval or pupae stages, while Orthopterans, Homoptera, and Isoptera are consumed in their mature stages (Anankware *et al*., 2016).

The accurate total sum of edible species of insects consumed in Africa is still under investigation. However, scientists have tried to record their findings in several areas of the continent. For example, Ramos-Elorduy *et al*. (2012) in their findings recorded 524 edible insect species in 34 African countries while Van Huis *et al*., (2013) reported 246 edible insect species in 27 African countries. A study by ICIPE identified about 470 edible insect species in African communities (Munke *et al*., 2016). Hlongwane et al., (2020) recorded a total of 212 species of edible insects in Africa that are consumed in various parts of Africa. The most commonly eaten insect species in Africa include nine orders, namely Lepidoptera 44%, Orthoptera 23%, Coleoptera 15%, Isoptera 12%, Hemiptera 4% and the rest of the order Hymenoptera, Diptera and Mantodea less than 1%. Among African countries and regions, the Central region of Africa is the most important biodiversity hotspot in Africa, with 256 species of edible insects (Munke *et al*., 2016). In Nigeria, 22 edible insect species from six different orders have been recorded with potential for consumption while Ghana has 9 edible insect species identified (Anakware *et al.,* 2016). Eastern Africa has recorded a total of 100 edible insect species, while 8 species have been recorded from Northern Africa, and 17 species recorded in Kenya (Van Huis, 2015).

The palm weevil, *Rynchophorus phoenicis* is one of the most commonly consumed edible insect species in Africa and is eaten at the larval stage. It is considered a delicacy in Benin, the Democratic Republic of Congo, Cameroon, and also throughout West Africa. The palm trees which have fallen often become the breeding sites for palm weevils (Matandirotya *et al*., 2022). Lepidopteran caterpillars are mostly consumed at their larval stages too. The Mopane caterpillar is commonly consumed in the South African region. Over 9.5 billion Mopane caterpillars are harvested in South Africa alone amounting to US$ 85 Million (Raheem *et al.,* 2018). Apart from the Mopane caterpillar, other species of caterpillars are also eaten in Africa though to a lesser extent. In the Republic of Congo, Zambia, and Zimbabwe, 38 different species of edible caterpillars have been recorded. In Burkina Faso, the mostly eaten insect is the Shea tree caterpillar (*Cirina butyrospermi*) (Anvo *et al*., 2017).

Winged termites are largely consumed across many Sub-Saharan countries. They are eaten as snacks or side dishes with or after the wings have been removed and the insect has been fried or dried and roasted (FAO, 2013; Kelemu *et al*., 2016).

Many species of locusts and grasshoppers are a common food source in many parts of Sub-Saharan Africa and 126 species have been identified in Africa (Van Huis, 2022). In Tanzania, the Bahaya community considers grasshoppers a delicacy, and, in Uganda, where they are commonly known as 'nsenene' and are traditionally collected by women and children. In Kenya around the Lake Victorian region, grasshoppers and locusts form part of the food culture with the youth engaging in hunting the species (Kelemu *et al*., 2016).

In more than 26 countries in Africa, five species of locusts are commonly consumed and traded, that is, the migratory locust, the brown locust, the desert locust, the red locust, and the Sahelian locust (Egonyu *et al.*, 2021). The consumption of locusts as human food dates back very many years. The Old Testament, for example, describes Orthopterans as one of the acceptable insect foods for consumption, it advocates for the consumption of grasshoppers of any kind, locusts of any kind, and cricket of any kind (Leviticus 11:22; Evans *et al*., 2015). The New Testament also depicts locusts as being a delicacy as documented when people like John the Baptist ate them while ministering in the wilderness (Mathew 3:4; Evans *et al*., 2015).

The consumption of edible insects in Africa has therefore been predominant in the past because Africa is a tropical continent and most edible insects here are larger, often occur clumped and therefore facilitating easy harvesting when in season. However, the availability of edible insects throughout the world is seasonal since they depend on their host plants' availability for their survival (Arena *et al.*, 2020). Environmental factors can also influence insect availability. For example, the temperature influences insects' fecundity, reproduction, and survival such that unfavourable temperatures will negatively impact the insects' survival and reproduction, hence leading to a low population of insects for consumption (Khaliq *et al*., 2014).

The most commonly eaten insects in this region include termites, black ants, crickets, long-horned grasshoppers, and locusts as indicated by studies done by Ayieko *et al*. (2012), Kinyuru *et al*. (2013) and Kelemu *et al*. (2016). A survey conducted by ICIPE on edible insects in Kenya included honey bees, and moths, in addition to the aforementioned list (Munke *et al*., 2016). Most research on edible insects in the Western region of Kenya has focused mostly on the consumption, nutritional analysis, availability, acceptance, value addition, and commercialization of termites and crickets (Waswa *et al.*, 2016, Pambo *et al.*, 2018; Anyuor *et al.*, 2022). More studies have also been done on long-horned grasshoppers, especially their nutritional composition (Kinyuru *et al*., 2013). Socio-economic factors that affect entomophagy in Busia Kenya have also been studied (Omemo *et al*., 2021).

Given the estimated number of consumed edible species in the area and the nutritional composition of these insects, there is still a lack of up-to-date information on the knowledge culture and consumption of edible grasshoppers and locust species. As such, there is a need for more research in this area. The availability of data from this research findings will be fundamental in the recommendation on the commonly consumed and acceptable grasshopper and locust species for consumption and even rearing as mini-livestock.

2.3 Benefits of edible insects

2.3.1 Nutritional Value of Edible Insects

Edible insects can be a great alternative protein food source especially now as the world population is increasing and leading to a lot of pressure on agricultural land for settlement especially in developing countries. Findings from researchers on the nutritional content of edible insects show that insects are rich in digestible proteins, vitamins, minerals, and fats which are comparable to that of red and white vertebrate meat and hence suitable for human consumption (Chakravorty *et al*., 2014; Makkar *et al*., 2014; Alemu *et al*., 2017, Hlongwane *et al.,* 2020). However, the nutritional content of edible insects may not be generalized and this is because every insect's nutritional content varies with the species, developmental stage, habitat, diet or feed the insect consumes (Rumpold & Schluter, 2015; Veldkamp & Bosch, 2015; Kowalska, 2019) and environmental conditions, such as humidity and temperature (Sánchez-Muros *et al*., 2014; Ghosh *et al*., 2017). The type of method used in the nutrient analysis may also bring variation in the nutrient content of insects (Rumpold & Schluter, 2015).

The amount of protein in insects is one of the reasons why edible insects are considered a viable alternative to commonly used vertebrate proteins. The crude protein content of most edible insect species ranges between 20% to 70% (Ordoñez-Araque, *et al*., 2022), which varies between species, the stage of development of the insects (larvae, pupa, or adult), and the type of food the insect consumed during its development period.

Therefore, insect protein can help improve the nutritional quality of malnourished children, especially when used as an alternative to animal protein (Matandirotya *et al*., 2022).

Fat, also known as lipid, is important for health and is the second most important nutrient in edible insects (Rumpold & Schluter, 2015). Taste is very important because it increases the palatability of food by absorbing and retaining the taste and increasing the palatability of food in human consumption (Idowu *et al*., 2019). It also plays an important role in the structural and biological functions of cells and helps transport fat-soluble vitamins and nutrients (Siulapwa *et al.*, 2014). Similarly, fats help in the synthesis of hormones, cellular membranes, structural elements in cells, and protect vital organs (Bophimai & Siri, 2010). The crude fat content in insects varies between 10% to 50% on a dry basis, however, most research analyses show that female insects have higher fat content than males (Ordoñez-Araque, *et al*., 2022). The fat content in some of the acridids has been analyzed, for instance, the long-horned grasshopper has a crude fat content of between 46.2% to 48.2% (Kinyuru *et al.,* 2012), while migratory locusts' fat content was found to range between 18.9% to 20.3% (Mohamed, 2015). Edible insects' fatty acid profile also consists mainly of monounsaturated fatty acids (MUFAs) and saturated fatty acids (SFA) which can range from 30% and above (Ordoñez-Araque, *et al*., 2022). Desert locusts' oils are richer in omega-3 and omega-6 polyunsaturated fatty acids that are essential for heart disease prevention. The oils contain flavonoids and vitamin E. Besides, the phytosterols component present in locusts prevents the absorption of cholesterol by lowering their levels in the body and thereby protecting the body from cardiovascular attacks (Egonyu *et al.*, 2021).

Insects also contain another important aspect of nutrients known as minerals. Minerals play important metabolic and physiological roles in living systems. As cofactors for antioxidant enzymes, copper, zinc, manganese and iron enhance the immune system (Kinyuru & Ndung'u, 2020; Nyangena *et al.,* 2020). Edible insects such as termites, grasshoppers, mealworms and crickets are rich in manganese, magnesium, zinc, calcium, phosphorus, copper and iron (Kim *et al*., 2019). The concentration of these minerals may however vary depending on the insect species and its developmental stage. The iron content of locusts (*Locusta Migratoria*) for example, has been found to range from 8 to 20 mg/100g of dry weight (Ordoñez-Araque, *et al*., 2022) and this is comparable with that of beef which has a content of 6 mg per 100 g of dry weight (Van Huis *et al*., 2013). The other minerals in edible insects are; Phosphorus in the range of 121.0 mg/100g to 140.9 mg/100g, Calcium in the range of 24.5 mg/100g to 27.4 mg/100g, and Potassium in the range of 259.7 mg/100g to 370.6 mg/100g on a dry weight basis (Kinyuru *et al.,* 2012). Nonetheless, insects have a higher content of micronutrients such as manganese, copper, calcium and zinc when compared to the content of most commonly consumed vertebrate meat regardless of the order or species of the insect (Ordoñez-Araque, *et al*., 2022).

Vitamins that play a major role in stimulating metabolic processes and strengthening the immune system are also found in many edible insects (FAO, 2013). Thiamine (Vitamin B1) is present in most edible insects in the ranges of 0.1mg to 4 mg per 100g of dry matter. The principal role of thiamine is to metabolize carbohydrates into energy and it also acts as a coenzyme. Riboflavin (Vitamin B2) is also present in the range of 0.11 mg to 8.9 mg per 100g (FAO, 2013). The long-horned grasshopper (*Ruspolia differens*), has α- tocopherol (vitamin) in the range of 161 mg/100g to 170mg/100g (Kinyuru *et al.,* 2012). Desert and migratory locusts also contain vitamins A, D, and

E which are either absent or found in trace amounts in pork, beef, mutton, and bacon (Egonyu *et al.*, 2021). For instance, Migratory locust contains 10-20 μg/100 g of vitamin B12, which is 5–10-fold its levels in pork, beef, mutton, and bacon (Egonyu *et al.*, 2021).

Insects' main fiber is found in chitin (Ordoñez-Araque, *et al*., 2022). Some insect's fiber content has been estimated. For example, African migratory locust crude fiber content has been estimated at 27%, and the Jamaican field cricket at 8% (Ordoñez-Araque, *et al*., 2022).

The deficiencies of micronutrients especially in pregnant women, preschool children, and the old and vulnerable sick population in society can therefore be prevented by including edible insects in their diet since insects contain most nutrients required for their growth and development (Van Huis *et al*., 2013). For example, in Kenya, complementary foods based on edible termites have been developed and evaluated to combat child malnutrition (Munke *et al*., 2016). In Kenya, insects are recognized as part of a traditional protein-rich food culture by the Kenya National Guidelines on Nutrition and HIV/AIDS. The organization believe that insects can meet the protein needs of the most vulnerable in society, for example, they have recommended that food security in HIV-affected households can be addressed by advancing traditional foods such as termites in their diet (Munke *et al*., 2016).

In addition to the nutritional importance of edible insects in the human diet, another advantage of consuming insects is that they are less likely to cause the risks to human health (zoonotic infection) that are known in other farm animals such as swine and avian influenza, mainly due to their taxonomic distance from humans (Van Huis, 2013).

The information on the nutritional composition of edible insects and their importance to human health therefore gives the confidence to avail this information, especially to new consumers and other stakeholders in the food industry to encourage entomophagy.

2.3.2 Medicinal benefits of edible insects

Insects or chemicals extracted from insects have been used as medicine in ancient cultures for thousands of years to treat various ailments and injuries. The use of insects as medicine is known as entomotherapy and close to 1000 insect species have been reported to have medicinal value (Choudhary *et al*., 2022). Phytophagous insects consume many plants and some of the plants consumed are medicinal and contain compounds that can cure diseases (Matandirotya *et al.*, 2022). Some insects are believed to have active substances or ingredients which have a variety of biofunctional activities useful in the treatment of various ailments (Aguilar-Toalá *et al.*, 2022). In Chinese culture, insects are incorporated as part of herbal medicine in their traditional treatment.

The medicinal benefits of insects have therefore been identified in various parts of the world. The venom from bees is used to treat diseases such as arthritis, skin diseases rheumatism, and tumours in many Asian communities (Bairagi, 2019). Apart from the bee venom, the royal jelly of bees is also used in cosmetics as a lip balm to prevent the cracking of lips and dryness and also to smooth hard cracking skin, especially on the soles of the feet (Chung *et al.*, 2001). In India, the honey bee is used in the treatment of cough, fever, and stomach pain (Choudhary *et al.*, 2022).

Termites, especially in Asian communities, are used to treat various ailments, for example, *Macrotermes annandalei* is believed to have many immunostimulating effects that prevent unwanted overactivation of the immune system upon exposure to either pathogens or xenobiotics (Chen *et al.,* 2009). *Macrokeratomes exiguous* are also used in the treatment of asthma, bronchitis, influenza, flu, and whooping cough (Bairagi, 2019). Silkworm *Bombyx mori* powder is considered by Koreans to have an ingredient that lowers blood glucose (Belluco *et al*., 2013) and the same is also believed by the Indians to treat pneumonia (Choudhary *et al*., 2022).

Maggot therapy was used to treat unhealthy skin and soft tissue wounds in both humans and animals. The live disinfected maggot was introduced into the affected wound to clean out the dead tissue in the wound by killing the bacteria (Bairagi, 2019). This therapy helped speed up the healing process of the infected wound and at the same time prevented infection (Choudhary *et al.,* 2022).

Venom from ants especially in Chinese medicine was used in various treatments. For example, *Polyrachisla mellidens* was used in the treatment of weak vision whereby the ant eggs were mixed with white flour to treat the eye while the leg that was paralyzed was also treated by putting ants into canvas bags and placing them around the leg to stimulate quick healing (Bairagi, 2019). In Mexico, the army ant is used in the treatment of open wounds whereby the ant is introduced to the wound by holding its mandibles up to the wound edges for the ant to bite and hold the wound together thereby helping in stitching hence faster healing of the wound. Besides, the saliva from the ant is also believed to have some antibiotic properties that are used to fight infections in the wound area that were caused by bacteria by making it difficult for the bacteria to grow and multiply (Ramos-Elorduy *et al.,* 1988).

Many people look at cockroaches as indicators of dirt and poor hygiene. However, they also have medicinal value. For example, in China, the domesticated cockroach, *Periplaneta americana* has been traditionally used by the Chinese people to treat children's fever and dilation of the stomach (Chung *et al.*, 2001).

In African culture, the grasshopper was dried and burned to ashes and then mixed with water to form a paste, which was then applied to the patient's forehead to relieve severe headaches (Srivastava *et al*., 2009). In Zimbabwe, the toad grasshoppers are roasted and given to children who wet their beds to eat for treatment to stop them from bed wetting (Van Huis, 2022). In Mexican culture, it has been reported that crushed hind legs from *Sphenarium spp*, *Taenipoda spp,* and *Melanoplus spp* of grasshoppers are diluted and drunk as a diuretic and treatment for some intestinal disorders. *Zonocerus elegans* grasshopper in Cameroon is used to treat diseases such as burns, malaria, spleen pain, and tuberculosis, while the same grasshopper species is said to cure common eye problems such as redness and itching in countries like Nigeria and Tanzania (Van Huis, 2022). Locusts have medicinal value as they are also believed to treat post-childbirth anaemia, asthma, and chronic cough among Asian communities (Bairagi, 2019). *Schistocerca species* are also consumed as a dietary supplement to cure nutritional deficiencies, especially in undernourished children (Aman *et al*., 2016). Desert locusts also contain major sterols such as stigmasterol, campesterol, and β-sitosterol that help in opposing high cardiovascular and blood pressure diseases in humans. In addition, the hydrolysates contained in baked or cooked desert locusts can multiply human skin fibroblasts when consumed, and this is critical in integrating elements of the skin's extracellular matrix hence helping to lower the manifestation of ageing (Egonyu *et al.*, 2021).

Insects such as yellow mealworm, wax moth, and silk moth have been shown to have Angiotensin-converting enzyme (ACE) which researchers believe could play a role in reducing high blood pressure (Van Huis, 2020).

Edible insects if incorporated in animal feeds also have some health benefits to the animal consuming them. The chitin and fatty acids present in insects are useful bioactive compounds that promote animal growth as well as help in counteracting any antimicrobial resistance (Nowakowski *et al*., 2021, Veldkamp *et al*., 2022). Gasco *et al*., (2018b), in their studies, found that antimicrobial peptides present in insect-based foods improved the gastrointestinal health of chickens and pigs and hence improved their ability to digest nutrients from their feeds. The incorporation of mealworm larvae protein in broiler chicken feeds was also found to effectively help reduce *E. coli* and *Salmonella infections* in broiler chicken (Nowakowski *et al*., 2021).

Therefore, besides insects being rich in nutritional composition, their medicinal value is also important in both the human diet and animal feed diet. Hence insect protein consumption has more benefits compared to commonly consumed vertebrate protein.

2.4 Utilization of Edible Grasshoppers and Locusts

2.4.1 Harvesting of grasshoppers and locusts

Most edible insects are collected from the wild, especially by the communities that consume them. The women and children in rural areas are the ones who harvest edible insects. The methods of harvesting grasshoppers and locusts vary throughout the world. In Mexico, the Chapulines grasshoppers (*Sphenarium purpurascens*) are mostly found in alfalfa fields and the local communities harvest them by manually handpicking them from the fields in the early morning hours when they are inactive (Fombong *et al*., 2021). In Nepal, harvesting of grasshoppers is done through chasing by making loud noises using utensils, and smoke or through net capture (Van Huis, 2021).

In Uganda and Tanzania, when the long-horned grasshoppers *(Ruspolia species*) are in season, large-scale harvesting is done by use of light traps at night (Mmari *et al.,* 2017). This method of light trapping involves container traps that are made of empty oil drums which are topped by vertical iron sheets. The long-horned grasshoppers are then harvested at night time whereby bright light is used to lure the insects to the sight and fresh grass is burned to produce smoke. The smoke makes insects dizzy and hence crush themselves into the iron sheets and straight away fall into the drums, and eventually picked up by the harvesters (Makkar *et al*., 2022).

In Madagascar, when in season, grasshoppers and locusts are harvested by pulling big sheets over the vegetation or collected at night using torch light when the insects are resting on shrubs or trees. In Cameroon, grasshoppers are mostly found resting on banana leaves thus harvested by shaking them from the leaves very early in the morning when they are still inactive. In West Niger when in season, grasshoppers are hand-picked very early in the morning or late evening from their habitat (Van Huis, 2021). According to Egonyu *et al*., (2021), the current techniques used in harvesting locust swarms include hand collection, sweeping with brooms, using light traps at night, using large sweep nets and immature stages (hopers) harvested by driving them into long deep trenches. Most regions of the world including the western region of Kenya still collect edible insects such as grasshoppers and locusts from the wild. However, wild harvesting is not sustainable since these insects are seasonal (Van Huis *et al*., 2021).

Knowledge of the different methods of harvesting grasshoppers and locusts from the wild practised in various regions of the world is therefore essential in enabling consumers and those interested in edible insects but do not know how to harvest them to easily access the insects whenever they are in season.

2.4.2 Processing of Grasshoppers and Locusts for Consumption

It is paramount to understand the various methods used in preparing grasshoppers and grasshoppers before consumption to promote their palatability, especially for new consumers. The methods of preparing and processing edible insects for human consumption are influenced by the tradition and culture of the communities that practice entomophagy. After the acridids have been harvested, they can be processed and consumed by first removing the appendages, that is, legs and wings. Generally, grasshoppers and locusts can be consumed as fried, roasted, sun-dried, or smoked on naked fire, or ground into powder or paste form or its protein extracted (Aman *et al.*, 2016, Egonyu *et al*., 2021; Hlongwane *et al.*, 2021). The processed insect makes it more palatable and therefore increases its acceptability.

In Mexico, the Chapulines grasshoppers are cleaned and then toasted in a little oil with garlic, salt, and lemon. In Asian countries especially Japan, harvested grasshoppers are prepared by boiling or frying and then sun-dried before consumption, and also the grasshoppers are cooked in soy sauce and sugar to enrich the flavour. In Thailand, the grasshoppers are first prepared by deep frying and later used as a cracker ingredient and also, they are fermented to make a cooking sauce (FAO, 2013). The Khoisan of Southern Africa consumed locusts and grasshoppers after roasting them on grills while, the Nambikwara people of Brazil ate locusts almost daily by toasting them over charcoal and then eaten, or mixed with fruit juice or added to cassava flour to make bread (Kietzka *et al*., 2021). Fats can also be extracted from insects and used for the preparation of other food products such as in bakeries (Egonyu *et al*., 2021).

In Kenya, particularly the western region, the grasshoppers are mostly consumed after smoking or burning them in hot coal. However, termites which are the most commonly consumed insect in this region are consumed in processed form where its ingredient is used in fortifying children's porridge (Kinyuru *et al.,* 2013). Edible insects in western Kenya have also been used as ingredients in the production of meat loaf, muffins and sausages (Ayieko *et al.,* 2010) as well as in wheat buns production (Pambo *et al.,* 2016).

Recently people have started to embrace entomophagy since this old culture of insect consumption has started to decrease. The population that still consume edible insects mainly eat them as entire insect either cooked or raw, others consume them when it has been prepared in non-recognizable form, and still they can be eaten in extract form (Liceaga, 2022).

Apart from consuming the whole insect, there is also value addition of the insect product, for example, insect protein can be applied in bakery and cereal-based products such as bread, pasta, cookies, and tortillas. Insects such as cockroach (*Nauphoeta cinerea*) and house crickets have recently been processed into powder and their protein is used in enriching wheat flour for baking and bread loaves, these food products are nutritionally rich and acceptable to those that have consumed the product (Liceaga, 2022).

Current research and reports show that some firms are working to extract and process insect proteins into adaptable food elements, such as textured insect proteins that can be used to replace dairy products and eggs in baking and food processing. Processed insect proteins which are used in beverages are also being produced (Shockley *et al.,* 2018). There has also been documentation on the efforts in the production of insect protein supplements, energy bars based on insect powder, and beverages enriched with insect proteins (Liceaga, 2022).

Value addition of insect products and knowledge of different methods of preparation are therefore ways in which that can encourage entomophagy, especially to new consumers.

2.5 Insect Farming

Most insects, especially in the tropics, are collected from the wild which is not sustainable for human food and livestock feed since most insects are seasonal (Van Huis, 2015; Van Huis & Oonincx, 2017; Arena *et al.*, 2020). Harvesting from the wild is not also safe because there is the risk of contamination due to the use of agricultural pesticides in farms which leads to the contamination of plants that insects consume (Aman *et al*., 2016; Jongema, 2017). Wild harvesting could also lead to overexploitation of the natural environment and thus interfere with the ecosystem balance (Van Huis, 2015; Abdullahi *et al*., 2021).

Farming of edible insects as mini-livestock for alternative protein sources is therefore expected to ensure the availability and continuous production of insects in quantity and quality throughout the seasons (Babarinde *et al.*, 2020), especially as the demand for protein increases with the human population. However, for successful rearing or mass production of insects, it is important to understand the insects' biology and ecology and the factors that enhance their growth and development (Sánchez-Muros *et al*., 2014).

Although still in its infancy, insect farming is rapidly growing and expanding agribusiness in many countries around the world (Tanga *et al.,* 2021). Rearing insects for food and feed is therefore a current and exciting topic, which is also very challenging. Therefore, a significant amount of research is needed to answer some questions, such as those related to rearing and cost-effective production. Several countries around the world have farmed and commercialized insects for both human consumption and animal feed production. These insects include the mopane caterpillar (*Imbrasia belina*), house cricket (*Acheta domestica* L.), mealworm (*Tenebrio molitor* L.), mealworm (*Alphitobius diaperinus Panzer*), superworm (*Zophobas morio Fabricius*), African weevil (*Rhynchoporus phoenicis*), the domesticated silkworm (Bombyx mori L.) and the cockroach (*Blaptica dubia Serville*) (Ordoñez-Araque *et al.,* 2022). There are also others such as the black fly (*Hermetia illucens*) and the house fly (*Musca domestica*) (Veldkamp & Bosch, 2015; Chaala *et al*., 2018; FAO, 2019). These insects have been successfully reared because their life cycle process can be monitored in a confined environment (Sanchez-Moros *et al*., 2014).

There have been success stories of insect farming in some Asian countries. In Thailand for example, insect farming plays an important role, with more than 20,000 farms producing 7,500 metric tons of edible insects per year, mainly for human consumption and markets. The most cultivated insects are the native cricket (*Gryllus bimaculatus*) and the house cricket (*Acheta domesticus*), with more than 20,000 registered farmers participating in the business (Gine *et al*., 2021). This enterprise in Thailand provides significant income and entertainment opportunities for tens of thousands of Thai people involved in the cultivation, processing, transportation and marketing of insects (Durst & Hanboonsong, 2015; Guine *et al*., 2021). In Cambodia, crickets (Teleogryllus testaceus) are mass-produced as a sustainable, cost-effective and high-quality alternative protein source to traditional livestock (Megido *et al*., 2016). In South Africa, the AgriProtein project produces common housefly protein on a large scale for animal feed production while Enviroflight (USA) produces Black soldier flies also for animal feed production (FAO, 2013).

In Kenya, edible insect farming is receiving a lot of attention from various stakeholders. Currently, the International Centre for Insect Physiology (ICIPE), government institutions, and academic institutions are involved in research initiatives such as ILIPA and GREiNSECT aims to generate scientific evidence for small, medium and large-scale insect production to develop the commercial potential for food and animal feed (Bruitrago *et al.*, 2021).

The Flying Food Project in Kenya and Uganda have played a big role in supporting the expansion of small-scale insect farms in both countries (Barennes *et al*., 2015; Holloran *et al*., 2015). ICIPE in Kenya has trained more than 1,000 farmers on the production of black soldier fly larvae to enrich animal feeds by selling harvested insects to feed millers (Buitrago *et al.*, 2021). Jaramogi Oginga Odinga University of Science and Technology in Kenya has successfully reared the crickets for food and currently are involved in the training of small-scale farmers around the region who have benefited from the innovation (Oyaro *et al*., 2022).

Grasshoppers and locusts (acridids) are other candidates that could be reared as mini-livestock for food and even feed for livestock since people are already familiar with them and some people consume them. The success in rearing these acridids to produce both quality and quantity could increase the availability of edible insects and hence encourage and promote entomophagy, especially in Kenya. Better methods are needed to enable large-scale production and processing as a small-scale commodity to make locust and locust production an alternative protein source for food and feed (Makkar *et al*., 2014) since harvesting in the wild is not sustainable as most insects are seasonal. Crickets and BSF have so far been successfully reared in both Kenya and Uganda, but rearing technologies for other insects such as grasshoppers, locusts, flatworms, mealworms and African fruit beetles are still in various stages of optimization in the laboratory (Tanga *et al.,* 2021).

2.6 Enhancing Entomophagy

2.6.1 Challenges of Edible Insect Consumption

The culture of entomophagy has been facing numerous challenges, especially among the communities that used to practice entomophagy. One of the challenges is the cultural shift in the long traditional culture of eating insects in many parts of the world from a long tradition of hunting and gathering in the wild to a more sedentary agricultural way of life, which has resulted in the perception of insects as pests and a threat to crops (Van Huis *et al*., 2013). European countries associate insects with disease transmission, filth, and crop destruction and this often triggers a reaction of fear and phobias among the people even in communities that traditionally consumed insects (Looy *et al*., 2014; Abdullahi *et al.,* 2021). Globalization has also contributed to changes in people's habits and lifestyles especially eating habits, hence making many people view insects with a lot of disgust and consider those consuming them as primitive (Dunkel *et al.,* 2014). The disgust factor has a lot of power in people's everyday life and this makes them not try new foods such as insects. The feeling of disgust towards entomophagy in the Western world has contributed to the general misconception that entomophagy in the developing world is caused by starvation and is merely a survival mechanism (Abdulahi *et al.*, 2021). This feeling of disgust is no different in the Kenyan population that once considered edible insects as a delicacy.

One factor that makes it difficult for Western countries to adopt entomophagy is that edible insects were never considered food before and besides they are not readily available on the market either as processed or semi-processed food products which can make the preparation of food easier (Grabowski *et al.*, 2020). There is also low consumer acceptance of eating edible insects worldwide, including communities that once practised entomophagy due to neophobia, where individuals prefer to eat what they are already familiar with and avoid strange foods such as insects (Barrena & Sanchez, 2012; Verbeke, 2015; Abdullahi *et al.*, 2021). Lack of knowledge about the nutritional benefits of insects both in the West and African regions has led to many potential consumers rejecting insects as well as having negative thoughts about the same (Abdullahi *et al*., 2021). The mainstream media, which includes television, newspapers, magazines, and social media, among others, also portrays insect consumption negatively. This has led to a decrease in insect utilization, leading to malnutrition in communities that rely on insects for nutrition (Hanboonsong *et al*., 2013; Verbeke, 2015).

Modern upbringing style especially in Africa including Kenya has led to a decline in edible insect consumption since there is more adoption and embracing of Western culture and cuisine. At the same time, knowledge of edible insect species and consumption is mostly known by the older generation than the younger generation and even some younger generations consider entomophagy as an old dietary style that is unhealthy (Abdullahi *et al.*, 2021). This habit is not different for Kenya and especially the western region of Kenya.

Some African societies' culture, taboos, and religious beliefs have also resulted in reluctance expressed by some communities toward entomophagy (Kelemu *et al.,* 2016; Abdullahi *et al.,* 2021). For example, in Nigeria, it is prohibited for children to consume queen termites. It is culturally believed that if children are allowed to eat queens, they will value insects more than farming and this can affect crop productivity. Members of the Ire clan of the Yoruba tribe in Nigeria do not eat crickets because the god of iron they worship, Ogun, does not accept animals without blood (Niassy *et al*., 2016). In Zambia among the Bisa people, the consumption of insects is associated with misfortunes such as people becoming insane upon consuming insects (Babarinde *et al*., 2020). In Kenya, particularly western region, the long-horned grasshoppers are not consumed since there is some culture attached to them. The population from this region associated the long-horned grasshopper with good luck once it landed in a homestead. It is therefore taboo to consume this insect (traditional knowledge).

Religion also has a great influence on how people view edible insects. Some missionaries who came to Africa condemned the eating of insects, for example, the consumption of the winged termite was considered a heathen custom by the missionaries (Van Huis *et al.,* 2013). The Legion Maria religious sect in Kenya doesn’t believe in consuming insects because the insect doesn’t have blood, and at the same time, they believe that insects can bring about evil spirits in the family (Babarinde *et al*., 2020).

Insect availability is only seasonal and this factor also hinders their consumption since they are only available during certain periods of the year (Arena *et al.,* 2020). Lack of knowledge of the nutritional qualities of edible insects and different methods of preparation for consumption especially to new consumers is also a barrier (Abdullahi *et al.,* 2021). There is also a lack of insect-rearing knowledge which makes insect consumption to be unsustainable since thy are not available throughout the year. Insect farming in Kenya is through trial-and-error methods making it a challenge, especially to insect consumers.

2.6.2 Methods of increasing acceptance of Entomophagy

Although the negative feelings and perceptions toward entomophagy are strong, this has started to change and the consumption of edible insects is now becoming an acceptable practice in coming years. Similar acceptance was seen in sushi which was introduced and is now widely available and acceptable delicacy almost throughout the world (Van Huis, 2013).

To overcome the barriers to insect consumption, the development, and implementation of appropriate processing strategies by presenting edible insects more attractively and interestingly is required to increase palatability and encourage especially new consumers (Babarinde *et al.,* 2020). This could be done by incorporating insects into familiar foods, for example, by adding extracted and purified insect proteins to food items, such as porridge, bread, muffins, chocolate bars, sausages, meatloaf, and snacks and thus increasing the acceptance of entomophagy especially to new consumers (Van Huis, 2015; Abdullahi *et al*., 2021). Insects can also be dried or fried and processed into powder form to minimize visual associations' hence increasing palatability and thus acceptance (Kim *et al*., 2019). Acceptability can also be enhanced by educating the consumers on the health and environmental benefits of insect consumption to increase the chances of them accepting them (Abdullahi *et al*., 2021). The barrier towards entomophagy can also be broken through public awareness whereby workshops are organized in institutions and at the community level where experts in the field like entomology, nutrition among others can be invited and educate the audience and public at large on the role and contribution of edible insects as a source of nutrients and income. Therefore, increasing the frequencies of exposure to edible insects and experimental tasting for example in workshops and seminars is expected to provide opportunities to learn about edible insects (Kim *et al*., 2019).

Important information especially on how insects can be prepared to achieve the best taste and health benefits should be made known to consumers. This can be done through, for example, the publication of edible insects' recipe books which already some recipes have been published (Kim *et al*., 2019). The published recipe materials, therefore, can be made easily available and accessible to consumers by advertising them on mainstream media and making them easily accessible. Some of the published recipe books are for example, The Insect Cook Book published in the Netherlands and features various insect recipes (Van Huis *et al*., 2013), and the second edition of 'The Eat –a-Bug' Book, (Gordon, 2013) and many more which have already been released.

As recommended by FAO (2010) in their report, learning institutions can be encouraged to develop research and curriculum programs on entomophagy to promote edible insects' protein and invent farming techniques or ways of farming them as mini livestock. The farming techniques on a small scale and at a low cost can hence be trained in local communities thereby increasing the acceptability of edible insects. The curriculum could also include conservation and management issues of such insects. It can include topics on insects like their ecology and biology in an attempt to address the issues of food and feed security.

The information and research work already done and the ones that are still being done on edible insects can also be shared through publications, expert meetings, and awareness of the role of insects through media collaboration, for example, newspapers, Television, magazines, and social media. Finally, consumers should be informed about where they can source the insects and how they can prepare and preserve them for consumption.

2.7 Edible Insects as Alternative proteins source in animal feeds

The demand for animal feed production is expected to increase by 70% by 2050 as livestock production continues to increase (Veldkamp & Bosch, 2015; Sebatta *et al*., 2018). This, therefore, poses a global challenge to animal feed producers to produce enough quality feeds for the increasing demand. Currently, the protein ingredients commonly used in animal feeds are fishmeal, and soybean (Veldkamp & Bosch, 2015; Doberman *et al*., 2017; Van Huis & Oonincx, 2017), however, there has been a decrease in the production of fish throughout the world as a result of over-exploitation of the marine environment and this has subsequently led to an increase in fishmeal prices (Henry *et al*., 2015; Nyakeri *et al*., 2017). Soybean production has also reduced due to challenges of decreased agricultural land for farming as a result of the increasing human population, and climate change (Sebatta *et al*., 2018) and at the same time, there is competition between man and livestock since both consume the soybean (Nyakeri *et al*., 2017). Due to these challenges, the cost of total feed production/input for livestock has increased up to 70% hence making it expensive and unsustainable for livestock farmers (Doberman *et al*., 2017). The higher cost of animal feed production has therefore led to reduced profit margins for smallholder farmers and driven many out of business.

The demand for animal feeds in Africa has been increasing over the years as the population continues to increase. For example, from 2013 to 2017 the demand for animal feed production increased by 30% and the number of mills required to produce animal feeds also doubled, Table 2.1 (Vernooij & Veldkamp, 2019). The total feed production in Kenya alone is about 900,000 million tons per year, with the majority of feed production being 70%, dairy cattle 20%, pigs 5%, other domestic animals 3%, and the remaining 2% is equine and fish (Vernooij & Veldkamp, 2019). Despite these challenges, little has been said about the potential that insects can offer as an alternative protein source for animal feed (FAO, 2013; FAO, 2019). To sustainably meet this demand, feed processing industries will have to look for more innovative ways of producing feeds at an affordable cost without compromising the quality of feeds.

Table 2.1: Total commercial animal feed production in Africa (in %)

Feed production	**2013**	**2014**	**2015**	**2016**	**2017**
Total compound feed	30.97	34.57	36.13	39.5	39.14
Poultry feed	17	21.1	21	20.1	22.35
Cattle feed	10.7	11	8.64	10.9	12.1
Pig feed	0.4	1.1	2.3	2.1	2.2
Number of feed mills	806	1,150	1,210	2,081	2,068

Source: **(**Vernooij & Veldkamp, 2019**)**

In Kenya, aquaculture and poultry production are some of the fastest-growing agribusinesses, however, their sustainability is a major hurdle to their growth due to the high cost of feeds, particularly fish oil, fishmeal and soybean (Doberman *et al*., 2017). To bridge the gap between the scarcity and high cost of fishmeal commonly used in animal feed production, edible insect proteins can be used as an alternative protein source apart from fishmeal. Therefore, their use in animal feed is expected to lower production costs by 25 to 37.5% (Vernooij & Veldkamp, 2019) and they could replace between 25 to 100% of soymeal and fishmeal in animal feed production (Van Huis, 2015).

Naturally, insects are eaten by many animals in the wild including fish, wild birds, as well as free-range poultry domesticated by man (Sanchez-muros *et al*., 2014; Nyakeri *et al*., 2017; Sogari *et al*., 2019; Gasco *et al*., 2020). Free-range chickens and birds pick up larvae and worms from topsoil and in manures and recreational fishing, maggots are used as bait (FAO, 2019; Gasco *et al.,* 2020). Smallholder fish farmers in Africa and Asia use insects in fish feed whereby when in season, they feed these insects directly to fish or sometimes hang lights over fish ponds to attract insects that are later on consumed by the fish (Doberman *et al*., 2017). We can therefore assume that these animals are evolutionarily adapted to eat insects as part of their normal diet, and therefore their inclusion in animal feed will not be anything new.

Several studies have been done on the possibilities of developing and including some insect species as alternative proteins for aquaculture and livestock feeds. A few species have already been recognized around the world which could be potential alternatives and are seen as sustainable raw materials for animal feeds (Sogari *et al.,* 2019). The most predominant and successful insect species that have been supplemented in animal feed production include the black soldier fly (*Hermetia illucens L*.), super worm (*Zophobas morio),* the common house fly (*Musca domestica*), greater wax moth larvae

(*Galleria mellonella L.*), termite (*Macrotermes nigeriensis*), house crickets *(Acheta domesticus),* yellow mealworm *(Tenebrio molitor L.),* and Turkestan cockroaches (*Blatta lateralis*) (Sogari *et al.,* 2019; Gasco *et al*., 2020; Ordoñez-Araque *et al*., 2022). Insects, therefore, have the potential to be incorporated into animal feeds as an alternative to fish meal and soybean meal since their protein content is comparable to that of fishmeal and soybean (Sogari *et al*., 2019; Gasco *et al*., 2020). Besides the utilization of insects as protein, insects also have the advantage of improving the gut health of animals that consume them because, they contain bioactive compounds that have immune-boosting properties such as antimicrobial peptides, lauric acid, and chitin (Sogari *et al.,* 2019).

Several edible insects have been studied as potential proteins in livestock feed with positive results in terms of animal health and performance. For example, fish meat in shrimp and rainbow trout (*Oncorhynchus mykiss*) diets are replaced by 50% larvae of *Tenebrio molitor* (mealworm), and the results of the study indicated no change in moisture, protein or change; rainbow trout fillet raw and cooked with ash content in the brisket. This shows that *Tenebrio molitor* can be a good substitute for fish food (Gasco *et al*., 2019). Similarly, the black soldier flies in animal feed was studied and found that when this feed is completely replaced by dry and crushed Black soldier fly (BSF) larvae meal and fed to chickens, the meal supports the growth of chickens by increasing their weight gain at a rate 96% compared to chickens fed to fish. When catfish meal was partially or completely replaced with BSF larvae meal in place of fishmeal, there was no significant difference in their body length when compared to their usual fishmeal (Makkar *et al*., 2014). In their investigation, Doberman *et al*., (2017) replaced 75% of fishmeal in Nile Tilapia diets with house fly larvae and the results showed that house fly larvae meal had no adverse effects on the growth and performance of Nile Tilapia.

Piglets feeds were partially replaced with BSF larvae protein as an alternative to fishmeal and the results showed that their growth performance was as good as those fed with a fishmeal diet (Makkar *et al*., 2014).

Locusts and grasshoppers are other insect candidates which could be used in animal feeds since they are very nutritious and have high amounts of proteins. Several of them including crickets have been used for raising animals in zoos and pets, however, very little research has investigated them in livestock feeds (Ordoñez-Araque *et al*., 2022). Therefore, partial or total replacement of insect protein in feed is possible where insects could replace 25 to 100 % of soymeal or fishmeal for aquaculture, poultry, livestock, and even pet feed (Makkar *et al.*, 2014).

A survey study was carried out in four counties of Kenya (Kakamega, Uasin Gishu, Kiambu, and Nyeri) on the willingness of poultry and fish farmers to include Insect Based Feeds (IBF) in the fish and poultry diet. The findings showed that farmers were ready and willing to include insects such as houseflies, termites, cockroaches, BSF larvae, grasshoppers, and crickets as alternative protein feed components for poultry and fish production. They were also willing to buy IBF for their livestock (Chia *et al.,* 2020). Similarly, Okello *et al*., (2021) in their studies indicate that farmers in Kenya are willing and ready to accept IBF in animal feeds. However, the main challenge in using IBF is that insects are not readily available in the wild since they are seasonal, and hence getting enough quantity for the production of animal feeds becomes a challenge. The only solution, therefore, is upscaling of insect farming which will provide continuous production in quantity and quality (Babarinde *et al.*, 2020).

2.8 Environmental and economic benefits of rearing edible insects

From an environmental point of view, insect rearing has more benefits than conventional livestock farming. Rearing insects including locusts have a high growth rate and hence mature faster than livestock (Gasco *et al*., 2019), for example; locust life cycle is short and adulthood can be reached at four to eight weeks depending on rearing conditions and their numbers can increase ten to sixteen-fold between each generation (Mariod *et al*., 2017). Insect farming requires less land for rearing hence there is no need to clear additional land for production at the same time, they have the potential to be farmed vertically due to their small size (Tao & Li, 2018; Kowalska, 2019; Sogari *et al.,* 2019, FAO, 2021; Matandirotya *et al*., 2022). Another advantage of rearing insects is that they are cold-blooded and hence besides requiring feed for growth and development, they get warmth and energy from the feeds and thus use low energy and little water in feeding since they obtain moisture from their food (Henry *et al*., 2015; Mariod *et al*., 2017; FAO, 2021). However, when compared to conventional livestock farming, the latter requires more water than insect production since water is necessary for conventional livestock feed production and forage (Tao & Li, 2018; Matandirotya *et al*., 2022).

Insects are also environmentally friendly since they emit fewer greenhouse gases and ammonia compared to livestock (Gasco *et al.*, 2020, FAO, 2021). Manure produced from livestock farming also releases ammonia which may acidify the land while at the same time, manure may contaminate the surface and groundwater during heavy rains and water runoff (Tao & Li, 2018). The edible live weight of most insects is close to 100% for larvae and around 80% for the adult species (Amadi & Kabari, 2016; Henchion *et al.*, 2017) and therefore there is minimal wastage. For example, 80% of crickets' bodies are edible as compared to 55% of chickens and pigs while the edible body weight for beef is 40% (Tao & Li, 2018; FAO, 2021).

Mass rearing of edible insects is also less costly compared to other traditional livestock since little capital is required in the initial establishment of the rearing unit (Clarkson *et al*., 2018). In addition, insects have a very high feed conversion efficiency, which means they are efficient in converting feed into biomass (Sánchez-Muros *et al*., 2014; Van Huis & Oonincx, 2017). For example, 10 kg of feed is required to produce 1 kg of beef, while 5 kg is required for pork however crickets (*Achesta domestica*) require only 1.7 kg to produce the same weight (Collavo *et al.,* 2005). Some insect species can also be grown successfully on organic side streams thus converting organic side streams into high-value protein products (Van Huis & Oonincx, 2017; Henchion *et al.,* 2017; Sogari *et al.,* 2019).
Insect farming also has economic benefits in that rearing and harvesting edible insects offer great opportunities to vulnerable members of society such as women and youth, because, the excess harvested insects can be sold along the supply chain, where both farmers, collectors/harvesters, wholesalers and retailers benefit from the trade (Papastavropoulou *et al*., 2021; Guine *et al*., 2021; Matandirotya *et al*., 2022).

The frass produced from insects has also been found to be a good source of organic fertilizer that enriches the soil for the cultivation of horticultural crops hence increasing crop productivity. For example, several experiments have been conducted using BSFF and the findings have shown that crops planted using BSFF had performed better in terms of plant growth in height, yield, and chlorophyll content which was comparable to other organic fertilizers like chicken manure (Beesigamukama *et al.,* 2020; Anyega *et al.,* 2021; Agustiyani *et al.,* 2021).

2.9 Rearing of the desert locust and grasshoppers

Insect rearing involves raising the insects in captivity whereby they are isolated from their natural populations, their living conditions, and their food quality and diet are monitored.

The ability to rear insects in large masses is an important factor that enables insects to be produced in large quantities for food and feed. Successful mass rearing of any insect in controlled conditions largely depends on selecting suitable conditions in terms of feeds, space, and temperature (Gosh *et al.,* 2014; Ssepuuya *et al*., 2018). Insects are ectotherms and temperature and humidity will have a direct or indirect influence on their growth and development (Sánchez-Muros *et al.,* 2014). These factors can influence the insects' survival, length of the larva and adult development, fecundity, fertility, and fitness (Régnière *et al*., 2012; Jaworski & Hilszczanski, 2013; Yadav & Chang, 2013).

Previous attempts have reared locusts for experimental purposes in the laboratory under various conditions where temperature, relative humidity, cage sanitization, and densities have been done (Makkar *et al.,* 2022). Locusts like other insects are poikilotherms and thus it is important to keep them much warmer when rearing them in captivity to allow them to digest the food eaten properly. Temperature therefore can affect insects by extending or reducing their larval/nymphal growth (Jaworski & Hilszczański, 2013; Khaliq *et al*., 2014; Raheem *et al.,* 2018). Locusts have been reared in the laboratory under temperatures ranging from 28 °C to 39 °C and relative humidity of 40% to 80% (Gosh *et al*., 2014; Cheseto *et al.*, 2015; Egonyu *et al*., 2020; Meena *et al.,* 2021; Das *et al*., 2022). The enclosure or cages for rearing desert locusts in the laboratory are kept warm by using light bulbs of 40w or 60w mounted in the middle of the rearing cages to provide an extra source of heat for locusts to gather around (Quesada & Santiago, 2001; Cheseto *et al.*, 2015; Staub *et al*., 2019; Makkar *et al*., 2022). A metallic mesh tube is normally placed under the bulb inside the cage to permit the vertical movement of nymphs and to rest on, especially during the moulting period. Also in the cage, a container filled with sterile moist sand is placed at the bottom of the cage for oviposition (Quesada & Santiago, 2001).

The type and availability of food substrate provided to insects reared in confined environments affects insect biology and behaviour, including growth and development rates, survival, and fecundity (Meena *et al.*, 2021). The nutritional composition of insects is also influenced by the diet the insect consumes during its development period (Kababu *et al*., 2023). Insects fed with a diet that has low protein content will result in larvae or mature insect that has low amounts of proteins while insect feeds that have high protein content will result in insects that have high amounts of proteins. For example, a study was done on *Tenebrio molotor* (yellow meal worm) where the insects were fed on a formulated diet that had varying amounts of pea protein of between 10% to 80% inclusion in their diet. The results indicated that the yellow mealworm that was fed on a high percentage inclusion of pea protein resulted in larvae that had high protein while those fed on low protein inclusion resulted in larvae that had lower amounts of protein (Kroncke & Benning, 2023). This, therefore, shows that the protein content of insects increases with the increase in the protein content in their diet. It is therefore important to identify the most suitable food plants for the insect reared under controlled conditions since the rate of their growth, nutritional composition and feed consumption are highly correlated (Ssepuuya *et al*., 2018).

Grasshoppers and locusts are mostly polyphagous and they prefer a variety of plant species in a wide range of habitats therefore this means that feeding on different host plants will affect their nutrients (Meena *et al.,* 2021). Locusts can consume plants equal to their body weight daily (Shrestha *et al.,* 2021; Jeengar *et al.,* 2022). Some of the diets used in rearing locusts as cited in the literature include fresh feed materials such as wheat seedlings, barley, cabbage, ryegrass, lettuce, germinated maize, sorghum, cowpea, and tomatoes (Shrestha *et al.,* 2021; Meena *et al.,* 2021; Jeengar *et al.,* 2022; Makkar *et al*., 2022). Other authors have also experimented with dry feed sources such as maize stover, maize meal, and soya extracts (Makkar *et al*., 2022). Long-horned grasshoppers have been previously reared on formulated mixed artificial diets in the laboratory (Das *et al.,* 2022). Feeding experiments have also been done on locusts using formulated diets (Staub *et al.,* 2019). Formulated artificial diet for insects however requires ingredients like vitamin B, organic icons, amino acids, water, and carbohydrates (Leonard *et al*., 2022) for successful growth and development of the insect.

Despite all these efforts of rearing locusts under laboratory conditions, more work remains to be done to develop protocols for the efficient mass production of locusts and grasshoppers by small-scale farmers for food and feed under local conditions. There is limited knowledge of rearing experiments done under greenhouse conditions and other feed plants that are locally found in western Kenya. These feed plants should be able to promote desert locust maximum growth, nutrient input, rapid growth, low mortality, and high fertility at a lower cost of production. This will ensure sustainability since there will be a continuous supply of insect protein hence promoting food and feed security.

2.10 Insect Frass as Organic Fertilizer

Small-scale insect farming for food and fodder is expected to collect a large amount of frass as waste. Therefore, to contribute to the circular economy and look at zero waste, it is important to use all components of insects, including their frass, as organic fertilizer.

Insect faecal frass has the prospect of being utilized as organic fertilizer, especially by those who reared and raised them for food and feed. Frass is solid insect waste material that has been converted into a microbially rich substance by the digestion of insect food, resulting in a higher organic matter content (Chavez & Uchanski, 2020). Small-scale farming of insects can produce large amounts of frass which contains a combination of uneaten feeds, exuviae, and faeces, which can be collected during cleaning up of the insectary and when the substrate is decomposed it can be used as organic fertilizer in crop production, thereby leading to improved crop productivity (Anyega *et al.*, 2021). The most commonly used organic fertilizer in crop production around the world includes poultry manure (Soremi *et al*., 2017), and manure from livestock (Rayne & Aula, 2020), which is however not easily accessible by many crop producers due to many not being able to domesticate these animals.

The use of insect excrement as organic fertilizer is a relatively new concept and any agricultural adoption of new fertilizer products requires information about its effect on plant growth, nutrition, and yield compared to existing fertilizers. Using frass as an organic fertilizer to replace synthetic/artificial fertilizers can be a viable alternative to promote sustainable agriculture and a circular economy (Poveda, 2022), especially in developing countries. For example, experiments have been conducted on crop cultivation using BSF frass and the results have shown that the frass has a good potential to improve crop productivity in terms of yield, the height of plants, and chlorophyll content of the leaf plants as well as improving soil organic matter (Quillam *et al.,* 2019; Beesigamukama *et al.,* 2020; Anyega *et al.,* 2021; Agustiyani *et al.,* 2021). Some experiment was also conducted on the Basil plant using mealworm frass (*Tenebrio molitor*) and the results showed that the application of mealworm frass in the soil led to a significant increase in the aerial length part of the crop, fresh weight, width, and increase in chlorophyll content compared to the untreated soil (Poveda *et al.,* 2019). The positive growth of plants could be attributed to the minerals found in the insect frass. For example, BSF frass has been found to contain essential nutrients for plant growth such as phosphorus, potassium and nitrogen, which are deficient in common soils (Agustiyani *et al.,* 2021). Desert locusts produce frass that is rich in nitrogen as a result of their consuming vegetation, thus, this frass has the potential to enrich the soil for farming and crop production (Kietza *et al.*, 2021).

The insect frass including desert locust frass similarly contains exoskeletons that molt during insect growth. These exoskeletons normally known as exuviae, contain chitin which is the main constituent of the exoskeleton of insects (Chavez & Uchanski, 2020). A study done by Russel, (2013), on the application of arthropod chitin in agriculture, compared chitin to cellulose whose polysaccharide combines with compounds such as carbon that can be used to construct physical and mechanical barriers that provide structural stability to plant tissues. Soil that has been amended with chitin can also be used to control fungal diseases and crop pests and therefore plants grown using insect chitin can resist and or tolerate a range of pests, pathogens, and diseases (Quilliam *et al.,* 2019). For example, chitin was used to control cotton leafworm larvae (*Spodoptera lotoralis*) pest by incorporating it into the artificial diet of the pest, and the results after the pest fed on the diet registered 100% mortality in the pest (Russel, 2013). The diet containing chitin could have disrupted the digestive system of the cotton leafworm larvae hence causing their death. Some studies also show that soil that has been amended with chitin leads to the control of Fusarium wilts by inducing a delay in disease development in plants (Hadrami *et al.*, 2010).

Insect frass if used as an organic fertilizer will also have a positive effect on the biological properties of soil. A study done by Agustiyani *et al.,* (2021) using BSF as an organic fertilizer showed that BSF frass had a positive influence on the biological properties of soil. This is because the PMW-ase enzyme activity was higher in soils treated with BSF frass which is an indicator of quality and healthy soil. The main role played by the enzyme is to transform phosphorus compounds which can easily be assimilated by plants. The depleted soils can therefore be improved through the use of composted insect frass organic fertilizer which will significantly improve the soil quality and thereby increase the soil nutrient levels over time and hence increase crop performance and yield (Quilliam *et al*., 2020). One of the main roles of any organic fertilizer in the soil, therefore, is to rejuvenate the soil by creating a conducive soil-plant-microbial environment for healthy plant growth (Agustiyani *et al*., 2021).

The desert locust frass can also be explored as an organic fertilizer in vegetable crops and its effect on the growth of crops determined. This will help to increase food crop production hence saving on the cost of purchasing artificial fertilizer.

There is, however, little documented research on the use of locust frass as an organic fertilizer in the cropping system. This research, therefore, explored the utilization of locust frass as a novel organic fertilizer in the growth of *Brassica oleracea* (kales).

2.11 Summary of Literature and Knowledge Gaps

Several gaps exist regarding edible grasshopper/locusts' consumption and rearing practice, especially in Kenya. The western region of Kenya has been known to practice entomophagy for many years and some of the edible insects consumed are grasshoppers and locusts. However, there is limited documentation of the specific species being consumed and if they are still considered edible, especially during this time of globalization. There is also a lack of awareness of the nutritional value of grasshoppers and locusts as beneficial insects. The information on whether this region still considers grasshopper and locust consumption as part of their culture is also not known. Therefore, combining current indigenous knowledge about grasshopper and locust consumption in western Kenya with scientific research will improve the understanding of the role of edible insects as an important food nutrient for the human diet and protein for livestock feed (Hlongwane *et al*., 2021).

Although experimental studies have been carried out on grasshoppers and locusts on their growth and survival under laboratory conditions, there is very limited documented research on the growth performance of desert locusts under greenhouse conditions. For laboratory experiments, apart from the feeds, electricity is required to keep the insectary room warm for better growth of the insects. However, to encourage small-scale insect farming, desert locusts can also be reared in the greenhouse and there will be no cost of electricity, and the performance of the insects is expected to be as good as those reared in the laboratory. Better and cheaper technologies for efficient rearing of grasshoppers and locusts are therefore not known. Thus, good rearing technologies will enhance quantity production for both food and feed.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Research methods and Study area

The study involved both descriptive and experimental study methods.

The descriptive study involved describing the Socio-economic characteristics of the population of the western region of Kenya through the use of questionnaires that had both open and closed-ended questions (Appendix II). The survey study was carried out in the counties of Kakamega, Bungoma, Busia, and Vihiga, between April and May 2021.

Busia County covers an approximate area of 1695 km^2. It is located between longitude 33^0 55’ and 34^0 25’East and latitudes $0^0$30’ and $0^0$45’ North. It has a population of 893,681 people.

Bungoma County covers a land area of 2,068.5 Km^2. It is located between longitude $34^0$21.4’ and $35^0$04’ East, and latitude $0^0$25.3’ and $0^0$53.2’ North. It has a population of 1,670,570.

Kakamega County covers a land area of 3,020 km^2. It is located between longitude 34° 44' 59.99" East and Latitude: 0° 16' 60.00" North. The temperature range is 18 °C to 29 °C. It has a population of 1,867,579 people.

Vihiga County covers a land area of 530.9 km^2. It is located between longitude 34° 39' 59.99" East and Latitude 0° 03' 60.00" North. It has a population of 590,013 people (KNBS, 2019).

The experimental study involved the rearing of the desert locust under both laboratory and greenhouse conditions. This experimental study was carried out at the University of Eldoret (0°32’ 51.3972” N, 35°12’16' 11.2044" E) at an altitude of 2,140 m above sea level. The University of Eldoret area receives a mean annual rainfall of 1124 mm with temperatures ranging between 17°C and 26°C (Chebet *et al.*, 2017). The experiment was carried out between June and December 2021 and January to February 2022.

3.2 Current Knowledge, Practice, and Perceptions of Grasshoppers and Locusts as Food and Feed in Western Kenya

3.2.1 Sample size

To calculate the sample size of the number of households in the western region of Kenya (Bungoma, Kakamega, Vihiga and Busia), Cochran (1977) formula was used

$$n = \frac{Z^2Np(1-p)}{(e^2N)+(Z^2p[1-p])}$$

Where;

n = sample population

N = Population (number of households in western Kenya)

Z= 1.96 at a 95% confidence level

p = population sample proportion to be 0.5

e = acceptable margin of error of 5%

$$n = \frac{1.96^2 \times 1133520 \times 0.5(1-0.5)}{(0.05^2 \times 1133520) + 1.96^2 \times 0.5(1-0.5)}$$

$$= \frac{1088632.608}{2834.7604}$$

= 384 minimum number of households to be sampled

Questionnaires were administered to 901 households in four counties of the western region of Kenya (Bungoma n = 200, Busia n =190, Vihiga n = 224, and Kakamega n =287). The western region of Kenya was purposely selected because entomophagy has traditionally been practised by the inhabitants. The sampled areas are presented in Figure 3.1.

Figure 3.1: Survey study sites on grasshopper/locust consumption in Western Kenya (Source: Extracted from Google Maps).

3.2.2 Data collection procedure

Both open and closed-question formats were used in the questionnaire. Open-ended questions are questions without predetermined answers, while closed-ended questions are in the form of multiple-choice questions (Appendix II). The target population included households living in the western region of Kenya. The survey was conducted using personal interviews. This method is better because the respondent's problems and questions can be directly brought to the interviewer, who will explain them more clearly. This method also allows the use of a pictorial catalog (display) of locust/grasshopper species (Appendix IV), thus allowing respondents to identify edible species. This method is important to ask only one senior member of the household to answer the questionnaire. The survey was conducted between April and May 2021.

Samples were collected using a multi-stage sampling method for each of the four districts in western Kenya. Each of the four regions is divided into sub-administrative units called sub-regions. In each region, a random sample was taken from several sub-administrative divisions (sublocations). Sub-units (villages) were randomly selected to form the main sampling units in the following areas. The secondary sampling unit was the household selected from the respondents. To select households, every 3rd household with a random starting point (left or right) along the main village road was interviewed. In cases where target respondents were unavailable or unwilling to participate, the closest households were selected to ensure the required sample size was met.

3.2.3 The questionnaire

The questionnaire was pre-tested in a pilot study where the participants originating from the Western region of Kenya but residing in Uasin Gishu County were interviewed. A total of 10 participants were randomly selected to participate in the pilot study. The participants were both male and female. Based on the participants' comments on the pilot study, the questionnaire was adjusted to capture the desired objectives.

In the western region of Kenya, the interview was done using face-to-face administration conducted by trained enumerators from each of the four counties. The questionnaire (Appendix II) was divided into five sections. In the first section, the respondents answered questions on their socio-demographic information, that is, gender, age bracket, level of education, marital status, and occupation.

The second section contained information on general knowledge and information about edible grasshoppers/locusts. The respondents were asked to indicate their knowledge about grasshopper/locusts' consumption through a multiple-choice question. The multiple-choice questions were adapted from (Verbeke, 2015) with few modifications to suit our study.

The third section had both open and closed-ended questions on the availability of grasshoppers/locusts. This entails the times of the year when they are in abundance and their availability in the market.

The fourth part of the survey had questions on the perception of grasshoppers/locusts as food. The purpose of these questions was to examine the people's views and their perception of grasshoppers/locusts as being part of their diet. Each item was measured on a 5-point Likert scale which was slightly modified (Verbeke, 2015).

The fifth and last section of the questionnaire was on the perceived acceptance of grasshoppers/locusts as food and feed the respondents’ willingness to rear them and the purpose for rearing.

3.2.4 Data Entry and Analysis

The completed questionnaire data were checked for any inconsistencies in answering the questionnaire and the information was verified and entered in an Excel sheet. Data from the questionnaire were then coded in Statistical Package for Social Sciences (SPSS. version 20). To determine the statistical significance of the relationship between variables, the data were subjected to chi-square goodness of fit analysis. All data were considered statistically significant at $P<0.05$

3.3 Ethical consideration

According to the current study, ethics is a moral choice that affects the decision-making and behaviour of those who are the subject of the study (Saunders, 2009). Ethical considerations in the current research were taken from those proposed by Rubbin & Babbie (1997) that states, that participation in research should be voluntary and based on informed consent to avoid harm to participants and ensure anonymity, confidentiality and non-deceptive matters. During the exploratory study, consent was sought before the questionnaire was administered to the participant/respondent to ensure voluntary participation. The introductory note of consent contained the purpose of the study and the benefit of participating in the study. The autonomy of the respondent was ensured by the fact that their names were not mentioned in the questionnaire.

The permit for this research was granted by the National Commission for Science and Technology and Innovation with license No: NACOSTI/P/23/23437 (Appendix 1).

3.4 Growth performance and survival of the desert locust raised under laboratory and Greenhouse conditions

3.4.1 Insect parent stock

The starter colony of the desert locust was transported from Nairobi University, Chiromo campus. The insects being ferried were fed on wheat bran. Desert locusts were then divided into two groups of 20 (10 males + 10 females) each at the Insectary at Zoology Laboratory 1 at the University of Eldoret, and each group was kept in cages of the size (50 × 50 × 50 cm). The cages were made of wood and metal frame (1mm). A 40-watt lamp was installed in the middle of the cage to provide warmth to the insects inside the cage. The cage was placed on a bench 1 meter above the ground. The rearing room was thermostatically controlled to maintain a constant room temperature of 27 ± 5 °C, and relative humidity of 40–60% during a 12 h light: 12 h dark photoperiod (Cheseto *et al.,* 2015). The rearing room/insectary was always locked unless when feeding the insects.

The parent locust was fed with fresh wheat seedlings grown in the greenhouse and also wheat bran. Every morning, newly harvested fresh wheatgrass was introduced into the cages and the unconsumed removed. The ovicups (egg-laying containers) were filled with sieved, moist sterilized sand and suspended at the base of each cage to allow oviposition. The ovicups were checked every 24 hours for the presence of egg pods. The ovicups containing the eggs were collected and replaced with new ones for laying. The eggs were placed in the incubator for hatching at 27 °C. The emerged nymphs were used in the main experiment as described in section 3.4.3.

3.4.2 Experimental food plants

Green grams (*Vigna radiate*), wheat (*Triticum aestivum*), and sorghum (*Sorghum bicolor*) were cultivated in the greenhouse in 2 litres 17 cm diameter plastic pots and were filled with a mixture of red soil, compost, and sand (3:2:1, v/v/v) (Plate 3.1).

The seeds were watered every day until when the seedlings were approximately 24 days old. Enough feedplants were then uprooted from the pots every morning and were fed to the nymphs separately in their cages. The fresh plant stock was planted every day after every harvest to make sure that there was a continuous supply of seedlings during the experimental period.

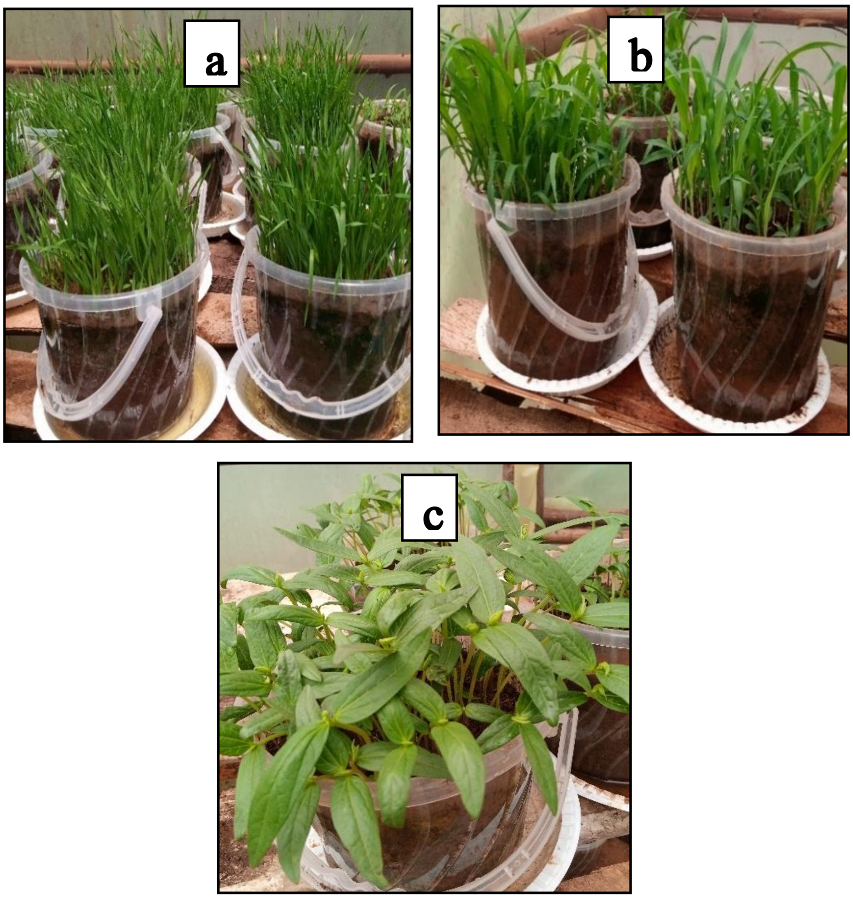

Plate 3.1. Feed plants diet for desert locusts (a) wheat (b) *s*orghum and (c)Green gram seedlings (Source: Author, 2021)

3.4.3 Rearing of desert locusts in the Laboratory on different feed plant diets

The collected eggs from the cages, inside the ovicups, were incubated at 27 °C until they hatched after 14 to 17 days. 240 newly hatched nymphs were selected randomly and kept in groups of 40 individuals in each of the six cages measuring (50×50×50cm) (Plate 3.2). The cages were arranged in a completely randomized design for the three diets and placed on a bench in the insectary room chamber. The three different feed diet treatments that were used to feed nymphs were replicated two times for each diet. The diets included wheat, sorghum, and green gram seedlings. Fresh feed diets were provided to the desert locust's nymphs every morning and any unconsumed feeds were removed from the cages. This feeding experiment continued until all the nymphs had moulted into mature adults. All the nymphs in the experiment were kept under the same conditions of a temperature of 27±5 °C and relative humidity of 40-60% RH (Cheseto *et al.*, 2015). The electrical supply system that provides power to the light had a time switch accurate to provide a variable photoperiod of 12H light: 12H dark. A Vivarian thermometer was kept in the room to record the temperature. To determine the effect of feed plant diet on the growth and survival of desert locusts, records of weight (in grams), size (in cm), number of days taken to molt from one instar to another, and the number of mortalities were recorded for each individual up to when all nymphs had matured to the adult stage at week 8.

The weight of nymphs was taken every week by weighing them on a weighing scale to the nearest grams. The femur length was measured using a ruler (in centimetres) from the thorax to the posterior end of the femur. The moulting period was determined by counting the number of days all nymphs in the cage took to remove the outer exoskeleton from one instar to the next. The survival rate was determined by counting the number of mortalities weekly and the percentage of survival was calculated by subtracting the number of dead from the living.

Plate 3.2. Laboratory rearing of desert locusts (a) desert locusts mating and laying eggs (b) Incubation of the desert locust eggs (c) desert locust nymphs (d) Mature desert locusts (Source: Author, 2021).

3.4.4 Rearing of desert locusts on wheat under greenhouse conditions

Rearing of desert locusts was also carried out under greenhouse conditions to observe their growth and compare their performance with those reared in the laboratory and wheat plant diet was usedin this experiment.

The greenhouse was constructed using a PVC paper. The size of the greenhouse measured 4m by 4m by 5 m. Desert locusts egges from the laboratory experiment were taken to the greenhouse and placed on a bench inside the cage (Plate 3.3). The eggs were eggs were allowed to hatch by moistening them with water. All nymphs hatched after 19-21 days and they were randomly selected and transferred into two rearing cages each cage having fifty nymphs at the beginning of the experiment. Feeding started immediately and fresh feeds were given every morning until when they matured at week eight. The temperatures and relative humidity at the greenhouse varied significantly depending on the time of the day. The highest temperature was recorded in the afternoons at 37.7 °C and 38% RH while the lowest temperatures were in the early mornings and late evening at 15.1°C and 81% RH. To determine the growth and survival of desert locusts reared under greenhouse conditions, parameters of their weight, size, nymphal development, and survival rate were recorded every week up to week eight of their maturity.

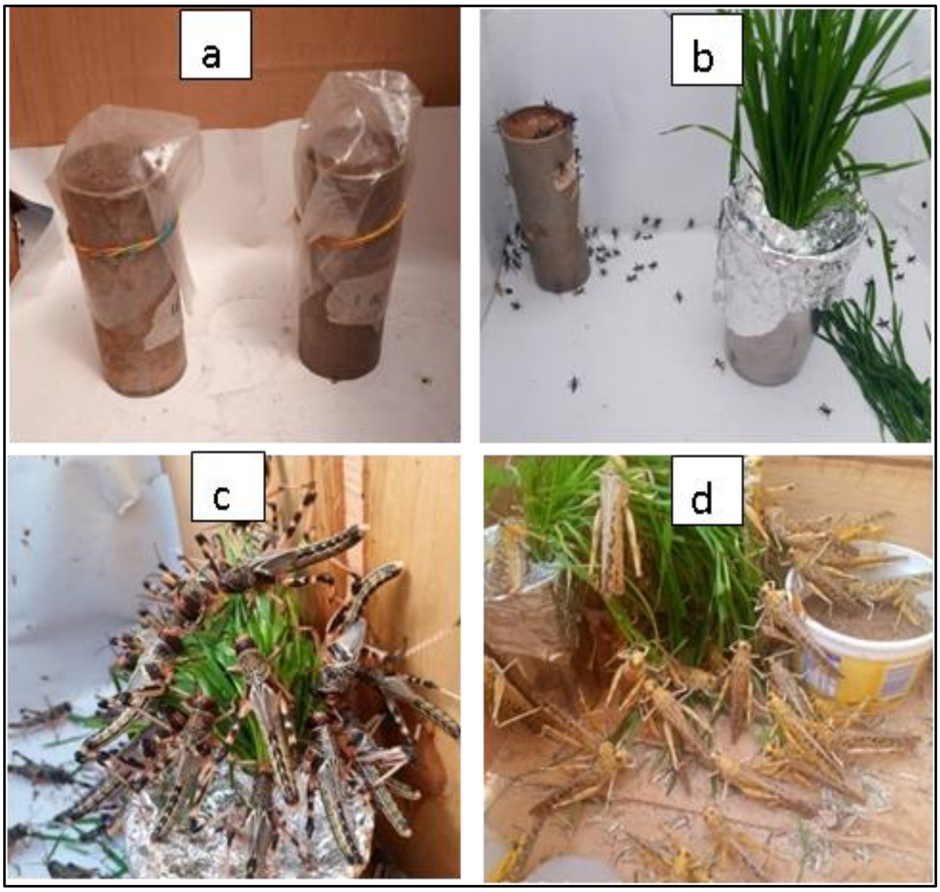

Plate 3.3: Desert locusts rearing under greenhouse conditions (a) eggs incubation (b) nymphs hatching from eggs (c) 3rd instar nymphs (d) Mature desert locusts

(Source: Author, 2021)

3.4.5 Data Entry and Analysis

Raw data were entered in Excel sheet software and statistically analyzed in STATGRAPHICS Centurion XVI. One-way analysis of variance (ANOVA) was used to determine the effect of plant diet and significant differences in mean on the growth (weight, size, nymphal development time) and survival of desert locusts. Means with a significant difference were separated using Fisher's least significant difference (LSD). All statistical differences were determined at $p<0.05$.

3.5 Nutrient composition of the desert locust reared on different feed plants diet

3.5.1 Rearing of the desert locust for nutrient composition analysis

Locust eggs from the F1 generation reared and raised under laboratory conditions as described in section 3.4.3 were hatched. Upon hatching, the nymphs were randomly selected and placed in three different cages each measuring (50×50×50cm). Each cage had 200 nymphs at the start of the experiment which were raised in the gregarious phase in the insectary rearing room chamber at the zoology laboratory, University of Eldoret. The nymphs in each cage were raised on three different feed plant diets; wheat, sorghum, and green grams seedlings respectively until they reached maturity at eight weeks.

At eight weeks, the locusts were harvested, starved for twenty-four hours, frozen, and dried under the oven at 80 ℃ for 8 hours. After drying, the appendages (legs and wings) were removed before grinding the mature locusts into powder form using a blender. Proximate analysis of crude protein, crude fiber content, crude ash, crude fat and carbohydrate content was then conducted on the locusts collected from the treatment cages using the standard methods recommended by the Association of Official Analytical Chemists (AOAC, 1999). All proximate analyses on the locust were conducted at the University of Eldoret, Chemistry and Biochemistry laboratory.

3.5.2. Moisture content of the desert locust

The mature locusts that had not been processed into powder were used in this experiment. The weights of the dishes (desiccators) (W1) to be used in this experiment were determined first. 3 g of each wet sample of desert locusts reared on different feed plant diets were weighed and placed in respective desiccators (W2/weight of desiccator plus weight of sample) and then dried in an air oven at 100 °C respectively for 2 hours until dry and the weight remained constant. The dishes (desiccators) and the dried samples of locusts were allowed to cool to room temperature and then reweighed (W3/ weight of dried sample + desiccator). The process was repeated until a constant weight was reached. The moisture content of the sample was expressed as a percentage of the initial weight of the sample using the following formula:

$$\% \text{ Moisture content} = \frac{(W2-W1)-(W3-W1)}{(W2-W1)} \times 100\%$$

Where;

W1 = the weight of the empty dish/desiccator;

W2 = the weight of the dish and wet sample of locusts before drying in the oven;

W3 = the weight of the dish and dried sample

3.5.3 Crude fat content of desert locusts

Three grams of locust dust/powder samples from each plant diet were weighed into a beaker containing a standard hexane solution and placed in a chamber for 4-6 hours to allow complete extraction. The extract was then evaporated at 70 ^{o}C to remove any remaining solvent. The defatted samples were then dried at 105°C for 20 minutes. The sample was removed and placed in a desiccator for 30 minutes to cool and then weighed. The fat content was then calculated using the formula below:

$$\text{Crude fat } (\%) = \frac{\text{weight of defatted sample (g)}}{\text{Weight of initial sample (g)}} \times 100\%$$

3.5.4. Crude Protein of desert locusts

Two grams of ground samples from each of the desert locusts fed on three different dietary treatments (that is, sorghum, wheat and green gram plant diet) were mixed with 10 ml of concentrated H_2SO_4 in a heating tube. A selenium catalyst tablet was placed in a tube and the mixture was heated in a fume hood, then transferred to distilled water. A 10 ml portion of the digestion mixture was then mixed with the same volume of 50 % NaOH solution and poured into the Kjeldahl distillation apparatus. The mixture was distilled into 10 ml of 20% boric acid solution to collect the ammonia. Boric acid was then titrated with 0.05 M H_2SO_4 and the titre value was recorded. The procedure was repeated three times for each treatment and the average value was taken. The protein content was then calculated from the percentage of nitrogen as follows;

$$\% \text{ Nitrogen} = \frac{\text{Vs-Vb x Nacid x 0.01401 x 100 x Total volume of digest}}{\text{Weight of sample x volume of pipette during distillation}}$$

Where: Vs = volume of acid required to titrate the sample

Vb = volume of acid required to titrate the blank

Nacid = Normality of acid 0.01N

The crude protein content was then determined by multiplying the % nitrogen by a constant factor of 6.25, i.e., % Crude Protein = % Nitrogen × 6.25

3.5.5. Ash content of desert locusts

The crucibles used in the experiment were first weighed before a sample of 5 g of desert locusts' powder for each locust treatment (that is reared on sorghum, wheat and green gram respectively) was placed in the crucible. The crucible that had the powder samples was ignited in the furnace at 550 °C until the powder turned light grey. The sample was allowed to cool to room temperature in a desiccator and then weighed. The difference in weight was expressed as a percentage of the total ash of the samples.

The ash content was then determined using the following formula:

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

3.5.6. Crude fiber Content of desert locusts

Grasshopper samples were first defatted using the method described by Kim *et al.* (2021) before crude fibre extraction. 200 g of ground grasshoppers from each feed treatment was mixed with a 99% organic solvent (100 ml of acetone and ethanol) and then stirred for 1 h at 20 °C. The organic solvent containing the insect fat was removed and the process was repeated five times until a clear solvent was obtained. The remaining solvent was evaporated in a fume hood at 20 °C for 12 hours. Cold pressure was used for degreasing at a feed rate of 4.18879 rad/s with temperatures of 80, 80, and 70°C for the top, middle, and bottom layers. The thickness of the cold oil cake was 0.5 mm. The extracted oil component was removed and the residue was sampled for crude fibre extraction.

For crude fiber extraction, the defatted samples (1.0 g) (W1) for each powdered locust raised on different diets were transferred to a 300 ml conical flask. 150 ml of preheated 0.128 M H_2SO_4 was poured into a conical flask and covered with a glass stopper. This was heated and boiled for 30 minutes, then filtered. The residue was washed three times with hot water and returned to the beaker. An additional volume of 150 ml of preheated 0.223 M KOH was added and boiled. Similarly, a few drops of defoamer were added and boiled slowly for 30 minutes and filtered. The residue was dried at 130°C for one hour and weighed (W2) and later burned at a temperature of 500 °C for 3 hours, cooled and weighed (W3).

The percentage of crude fiber was calculated as shown;

$$\text{Crude fibre (\%)} = \frac{W2-W3}{W1} \times 100\%$$

3.5.7. Carbohydrate content of desert locusts

Percentage carbohydrate content was determined by subtracting the sum of percentages of the above-discussed proximate composition (protein, fat, ash, and moisture) from the total matter basis of 100%.

% Carbohydrates = 100 % - (% fat + % moisture + % ash + % proteins + % crude fiber)

3.5.8. Mineral chemical analysis of desert locusts

To conduct mineral chemical analysis for the desert locust fed and raised on sorghum, wheat, and green gram seedlings; standards methods by (AOAC,1999) were used. Powdered desert locusts raised in three diets were weighed in a crucible and burned in a muffle furnace at 500°C for 3 hours. A solution of 5 ml of 1 N HNO_3 was added to the cooled sample, before the sample was evaporated to dryness in a stem bath. The dried samples were then heated at 400°C for 10–15 min in the furnace, then cooled after which there was an addition of 1 N HCl then filtered in a volumetric flask. In order to carry out an analysis for minerals such as manganese, zinc, magnesium, calcium, phosphorus, potassium, iron, and sodium, the filtrate was washed with 10 ml portion of 0.1 N HCl.

3.5.9. Proximate and mineral analysis of desert locust feed plants

The plant diets that were used in the study, that is sorghum, green grams, and wheat were harvested from five randomly selected pots at the greenhouse. The three weeks old plants were then washed under running tap water then later dried between sheets of paper and later on used in the proximate analysis experiment. Theplant dietwas then dried to a constant weight in an air dryer at a temperature of 70 ° C. Dry samples were ground to a fine powder using a pestle and mortar, sieved and stored in an airtight glass bottle. Proximate analysis of three plant samples was performed according to the standard method described by the Association of Official Analytical Chemists (1999).

Moisture content was determined by drying 5 g of fresh leaves for each plant sample to a constant weight at 105 °C in an air oven. Nitrogen levels in three samples were determined as described in Section 3.5.4. The value obtained for total nitrogen was multiplied by a conversion factor of 6.25 to calculate the crude protein level. Crude lipids/fats were determined using a Soxhlet apparatus by taking 5 g of plant food fed with petroleum ether for 6 hours. The crude fiber was determined using 5 g of defatted dry sample.

The ash level in food plants was determined by burning 5 g of the sample in a muffle furnace at a temperature of 550 °C for 5 hours. The carbohydrate percentage was calculated by subtracting % steam, % crude protein, % crude lipid, % crude fiber, and % ash from 100 percent. Mineral chemicals in plant feed, that is potassium manganese, zinc, copper, calcium, Phosphorus, sodium, magnesium and iron, were determined as described in section 3.5.8.

3.6 Statistical Analyses of the nutrient content of desert locusts and feed plants

The data obtained were statistically analyzed using the Statistical Package for the Social Sciences (SPSS) version 20.0. and Excel. Data were expressed as mean ± standard error of the mean (SEM). Analysis of Variance (ANOVA) was performed to determine significant differences in the mean composition of desert locusts raised on different diets. All statistical analyses were considered significant when the P value was less than 0.05 ($p < 0.05$).

3.7 The effect of the application of decomposed locust frass on the growth of kales (*Brassica oleracea*)

3.7.1 Preparation of Chicken and, Locust frass manure, and soil for experiment

Chicken manure collected from a chicken house near Eldoret University was moistened with water and allowed to decompose naturally for 28 days before being used in the experiment. Chicken manure was selected to compare it with decomposed frass and it is also one of the commonly used organic manure in vegetable gardens. Every five days, the manure was turned to allow for aeration and even decomposition.

Desert locust frass collected throughout the experimental period between June to December 2021 was used in this experiment as organic manure (Plate 3.4). The frass was collected during the cleaning of cages every day before new feeds were given to the nymphs. The collected desert locust frass was moistened with water and allowed to decompose naturally for 28 days before the commencement of the experiment.

Commercial fertilizer NPK was used as a positive control in the experiment while non-amended soil was used as a negative control.

Plate 3.4: **Desert locusts frass (a) before and (b) after decomposition (Source: Author, 2021**)

Soil that had not been used for any plant growth for at least a year was excavated from a farm near the University of Eldoret. The soil was used as a growth medium for all kale plants in the experiment. The soil was air-dried and sieved through a 2mm mesh before the experiment. Four kilograms (4 kg) of soil each was then filled in 36 gunny bags respectively ready for planting.

Certified *Brassica oleracea* seeds were sourced from an agrovet in Eldoret town, Uasin Gishu county, seedlings were raised in a nursery and were ready for transplanting after 21 days.

3.7.2. Experimental setup of several soil organic fertilizers treatments on Kales

The experiment was carried out in an open field in a randomized complete block design (RCBD) (Figure 3.2). There were six treatments of different compositions of organic manure and NPK fertilizer (growth medium) which were replicated six times. 4 Kg of soil was used in all the treatments used for planting the kales. The six growth medium treatments included;

- A: Plain soil that had no fertilizer (negative control)
- B: Soil + NPK (10g per planting hole)
- C: Soil + chicken manure (2:1)
- D: Soil +50 g of frass
- E: Soil +100 g of frass
- F: Soil +150g of frass.

The gunny bags (15 x 30cm) were filled with 4 kg of soil and soil plus the organic manures described above were added randomly to each bag. The seedlings from the nursery bed were then transferred to each treated gunny bag at one seedling per gunny bag.

The plant growth of kales was determined by collecting data on the following parameters; plant height and the number of leaves were recorded weekly from the time of transplanting (week one) to week seven. Chlorophyll content in the leaves of kales was also measured every week from week three of transplanting to week seven. At week seven, the kale leaves grown using different manure treatments were randomly selected and their nutritional composition analysis for fat, crude fiber, and minerals, that is nitrogen, potassium, and phosphorus determined using the methods described earlier in section 3.5 and statistical analyses done as described in section 3.6.

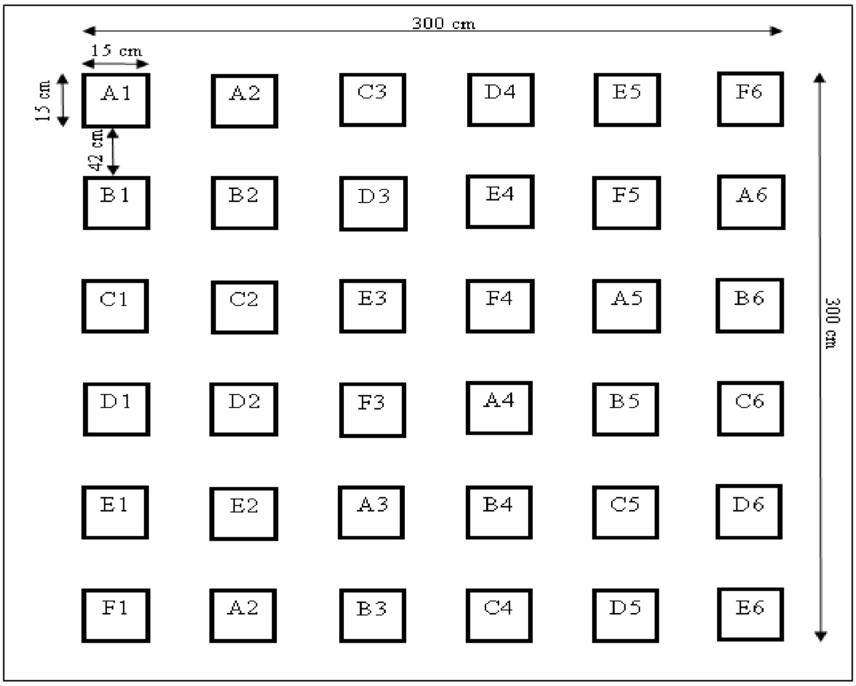

Figure 3.2: Experimental layout of *Brassica oleracea* (kales)

Key:

A: Plain soil (negative control)

B: Soil + NPK (10g per pot)

C: Soil + chicken manure (2:1)

D: Soil + 50 g of frass

E: Soil + 100g frass

F: Soil + 150g frass

Plate 3.5. Kales growing in gunny bags in an open field planted using different growth medium (Source: Author, 2021)

3.7.3 Measurement of Kale leaf chlorophyll: In vivo assay

The relative chlorophyll content was determined using the atLEAF CHL PLUS meter. The upper side of the leaf was always placed in the emitting window of the device and avoided the main vein. Each leaf was marked at three representative points and averaged. This method was intended to overcome the effect of the non-uniform distribution of chlorophyll in leaves and provide more detailed information.

The chlorophyll was measured between 10 am and 11 am every week from week three after transplanting the kales up to week seven for all the treatments (Limantara *et al*., 2015).

Plate 3.6: Invivo Measurement of Kales leaf chlorophyll content using atLEAF METER (Source: Author, 2021)

3.7.4. Data entry and Statistical analysis

Data from the field experiment on the cumulative number of leaves of kale, their height, and chlorophyll content measured were entered in an Excel sheet and analyzed using STATGRAPHICS centurion XVI software. One-way analysis of variance (ANOVA) was used to get the significant differences in means of height, number of leaves, and chlorophyll content of kales grown using different growth mediums. Means with a significant difference were separated using Fisher's least significant difference (FLSD). All statistical analyses were considered significant when the p-value was less than 0.05 ($p < 0.05$).

CHAPTER FOUR

RESULTS

4.1 Knowledge, practice, and Perception of Grasshopper/locusts consumption in Western Kenya

4.1.1 Demographic information of the respondents in Western Kenya

Findings from the survey (Table 4.1) show that the majority age of the study population was below the age of 40 years 576 (64.0%) with few in the age bracket of 41-50 years. Male respondents were 51.6% while females accounted for 48.4%. In terms of literacy, a greater percentage had formal education (95.9%) and only a small percentage (4.1%) had no basic education. Most of the respondents were farmers (40.8%) followed by those who were self-employed (33.7%) including tailors, shopkeepers, motorbike business people women who sell commodities in the open market and then civil servants (8.2%).

Table 4.1. Demographic information of the study population on grasshopper/locust consumption in Western Kenya

Bio-data	Attribute	Frequency	Percent
County of residence	Bungoma	200	22.2
	Busia	190	21.1
	Vihiga	224	24.9
	Kakamega	287	31.9
	Total	**901**	**100**
Age	18-30 yrs.	316	35.1
	31-40 yrs.	260	28.9
	41-50 yrs.	141	15.6
	>51 yrs.	184	20.4
	Total	**901**	**100**
Gender	Female	436	48.4
	Male	465	51.6
	Total	**901**	**100**
Education status/level	None	37	4.1
	Primary	284	31.5
	Secondary	354	39.3
	Tertiary	226	25.1
	Total	**901**	**100**
Occupation	Self-employed	303	33.7
	Student	98	10.9
	Farmer	368	40.8
	No job	58	6.4
	Civil servant	74	8.2
	Total	**901**	**100**

4.1.2 Knowledge, familiarity, and Experience with grasshoppers and locust consumption

A large proportion of 91.6% indicated knowing grasshoppers and locust consumption while 8.4% did not know of them being edible (χ^2 = 70.56, d.f.=1, $p < 0.0001$). There was no significant difference ($p < 0.05$) by gender or age regarding the knowledge of grasshopper/locust consumption.

The most widely known edible grasshopper/locust species based on the picture catalogue presented to the respondents was *Cyrtacanthacris tatarica* (the brown-spotted locust) accounting for 58.63% followed by *Schistocerca gregaria* (the desert locust) at 25.71% while *Ruspolia differens* (long-horned grasshopper) was least mentioned at 1.25% compared to the other species (Figure 4.1). Some respondents were able to identify the local names given to the above grasshopper/locust species (Appendix III).

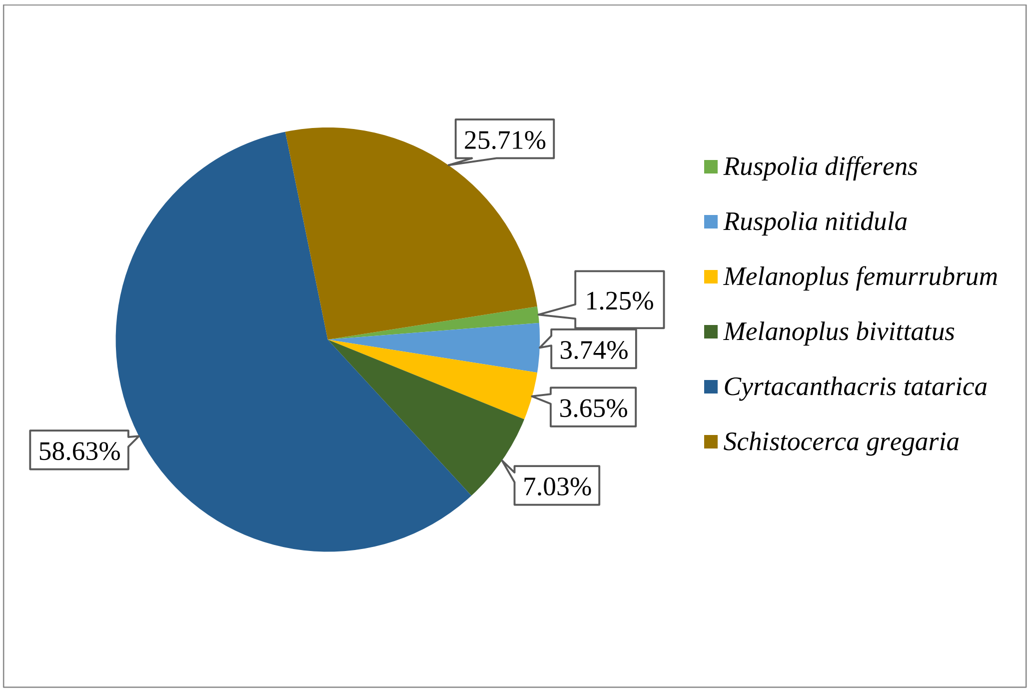

Figure 4.1: Percentage citations by respondents on Knowledge of edible grasshopper /locust species in Western Kenya

In terms of grasshoppers/locust consumption, 51.2% had ever consumed while 48. 2% had never consumed hence no significant difference (χ^2 = 0.04 d.f.=1 p= 0.8415). However, there was a difference in gender in association with consumption where more males (57.5%) than women (42.1%) had ever consumed the grasshoppers/locust (χ^2 =

15.4, d.f.=3, p= 0.0001). Regarding the age of the participants who had ever consumed, there was also a significant difference such that a lower percent of 17.4% of the ages between 41-50 years had ever consumed, followed by the ages of 18-30 years at 23.6%. However, ages of 31-40 years, and above 51 years had both consumed at 29.3% (χ^2 = 76.9, d.f.=3 p< 0.0001).

Approximately 91.6% of the respondents who had ever consumed the grasshoppers and or locusts liked the insect, whereas 8.4% never liked them. In terms of frequency of consumption, 43.7% indicated having consumed the insect on a few occasions. This was closely followed by 36.4% of the respondents who indicated that they only ate them when in season, while 19.9% said that they had consumed them only once.

The majority of the study population who had consumed grasshoppers/locusts were introduced to the culture of insect consumption by their relatives (60.3%), followed at a distance by those who were introduced to this culture by friends (34.0%) while those who introduced themselves were least at 5.7%.

For the respondents who had never consumed grasshoppers/locusts, a majority (53.8%) indicated they were not willing to try eating them. Lack of interest and neophobia were the main reasons given by the respondents to justify their lack of concern in trying to consume the insect.

To increase the acceptance of edible insects' consumption for new consumers, a significant proportion of the respondents (35.8%) were willing to consume if the insect is processed into flour and mixed in foods such as cakes, and bread, while 26.6% pointed out that mixing in porridge flour would increase the acceptance. Only 5.8% of the respondents who had not eaten edible grasshopper/locust pointed out that they would consume the whole insect mixed into food like rice (Table 4.2).

Table 4.2: Knowledge and Consumption of edible grasshopper/locust in Western Kenya

Question	Attribute	Frequency	Percent	Chi-square
Ever heard about people eating grasshoppers/locusts?	Yes	825	91.6	χ^2=70.56; d.f.=1; p< 0.0001
	No	76	8.4	
	Total	**901**	**100.0**	
Have you ever eaten/tried eating any before as part of your diet?	Yes	461	51.2	χ^2 = 0.04; d.f.=1; p= 0.8415
	No	440	48.8	
	Total	**901**	**100**	
If YES, did you like it	Yes	427	91.6	χ^2=70.6 d.f.=1 ; p< 0.0001
	No	39	8.4	
	Total	**466**	**100**	
If YES, how often have you eaten/tested them?	I have tried it on a single occasion	92	19.9	χ^2 = 8.9; d.f.=2 p=0.0113
	I have tried on a few occasions	202	43.7	
	I eat them when in season	168	36.4	
	Total	**462**	**100**	
Who introduced you to eating edible grasshoppers/locusts?	Friends	154	34	χ^2 = 43.76; d.f.=2 p<0.0001
	Relatives	273	60.3	
	Self	26	5.7	
	Total	**453**	**100**	
If not eaten before, would you consider to eat them?	Yes	52	11.9	χ^2 = 26.48; d.f.=2 p<0.0001
	Maybe	150	34.3	
	No	235	53.8	
	Total	**437**	**100**	
	Covered in Chocolate	35	10.7	

If not eaten, would it help if the whole insect was for;	The whole insect Mixed into food like rice	19	5.8	χ^2 = 29.15; d.f.=4 p<0.0001
	Ground and mixed in cakes and bread.	117	35.8	
	Grounded and mixed in porridge flour.	87	26.6	
	Eaten as an extract e.g., protein isolate.	69	21.1	
	Total	**327**	**100**	

4.1.3 Season of the year of grasshoppers/locust availability in Western Kenya

The respondents were asked open-ended questions about the season of the year when grasshoppers/locusts are available. A good number of respondents cited the rainy season (41.0 %) as the time of the year when the population of grasshoppers and locusts is high while some respondents (22.8 %) felt that the grasshoppers and locusts are more during the dry season. Only 2.2% and 1.9% of the respondents mentioned that grasshoppers/locusts were mostly seen during the planting season and throughout the year respectively (Figure 4.2).

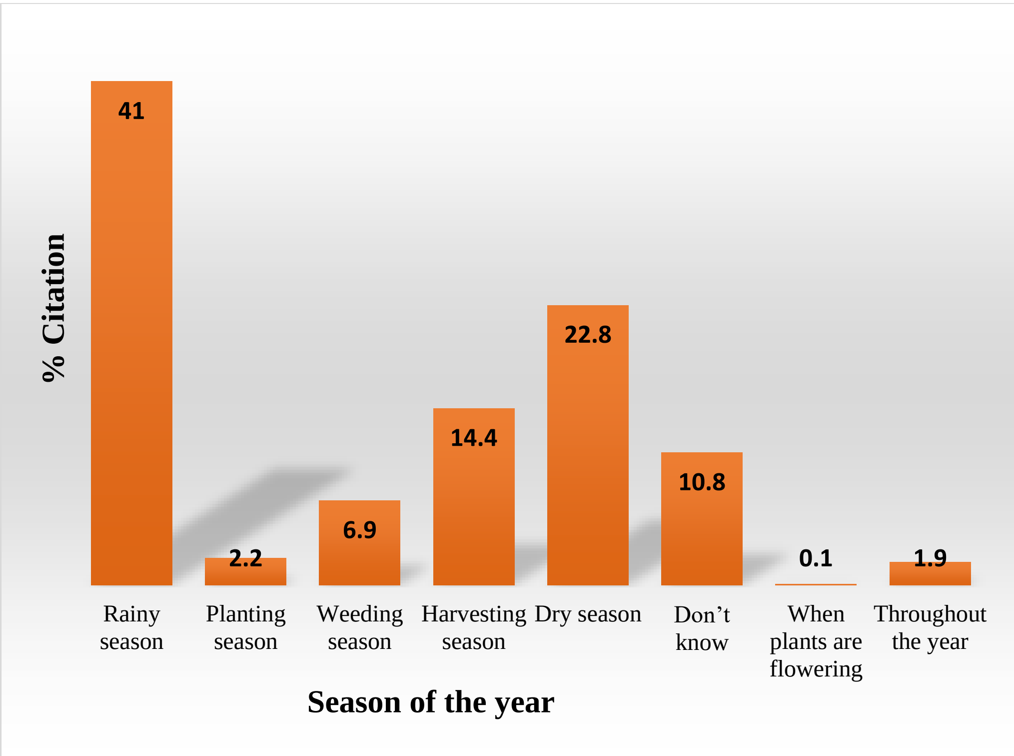

Figure 4.2: Seasonal occurrence of grasshoppers/locusts according to the respondents in Western Kenya

Respondents were also asked whether they had ever bought any edible grasshoppers/locusts before. A majority of the respondents (97.9 %) indicated that they have never bought any edible grasshoppers/locusts while 2.1 % had ever purchased the edible insects. Those who had never bought gave various reasons such as unavailability of the insects in the market (78.4 %), not willing to buy (14 %), while few (5.0 %) indicated they did not like the insects and thus could not buy them. There were significant differences in the responses between those respondents who were willing to buy grasshoppers or locusts from those who were not willing to buy them if they were available in the market in western Kenya (χ^2 = 17.2 d.f.=2, p=0.0002) (Table 4.3).

Regarding gender and the willingness to buy edible grasshoppers/locusts, there was a significant difference where more males (64.2%) than women (35.0%) were willing to buy the insect should it be available in the market (χ^2 = 29.9, d.f.=6, p< 0.0001)

Table 4.3: Participants' response towards the purchase of edible grasshoppers/locusts in western Kenya

Question	Attribute	Frequency	Percent	Chi-square
Have you ever bought any edible grasshoppers/locusts before?	Yes	19	2.1	χ^2 = 92.2; d.f.=1 p<0.0001
	No	882	97.9	
	Total	**901**	**100**	
If NO what could be the reason(s) for not buying	Not available in the market	692	78.4	χ^2 = 152.6; d.f.=3 p<0.0001
	Not willing to buy	124	14.0	
	Are available freely in nature	23	2.6	
	I do not like them	44	5.0	
	Total	**883**	**100**	
If NO and you come across them in the market, will you consider buying them?	Yes	260	29.3	χ^2 = 17.2; d.f.=2 p=0.0002
	Maybe	168	19.0	
	No	458	51.7	
	Total	**886**	**100**	

4.1.4 Knowledge of harvesting Methods for Grasshoppers and Locusts in Western Kenya

Various traditional methods used for harvesting the grasshoppers and locusts were cited by the respondents. Hand-picking (65.9 %) was the most mentioned method while other methods included chasing and catching (9.7 %), beating with twigs (4.9 %), use of sweep nets/traps (3.3 %), and trapping with light (0.4 %) were also mentioned though at lower frequencies. However, (15.8 %) of the respondents indicated that they had no idea how grasshoppers and locusts were harvested (Figure 4.3).

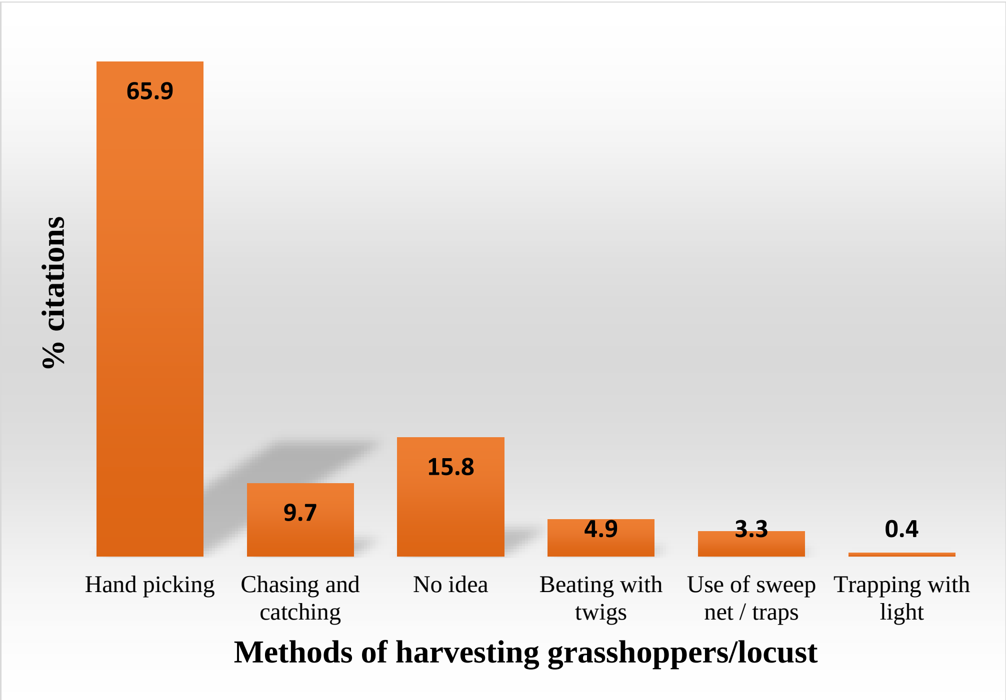

Figure 4.3: Knowledge on grasshopper/locust harvesting methods according to respondents in Western Kenya

4.1.5 Host plants for grasshoppers/locusts according to respondents in Western Kenya

Respondents were also asked to mention any grasshoppers/locusts host plants known to them. The grass was mentioned by the majority (70.5%) which was followed at a distance by other green vegetation (20.6%). Other host plants were also mentioned at the following percentage frequencies, maize (7.0%), bean leaves (0.4%), sorghum (0.2%), sugarcane leaves (0.1%), millet (0.3%), kales (0.2%), banana leaves (0.5%) and cassava leaves (0.1%) (Figure 4.4).

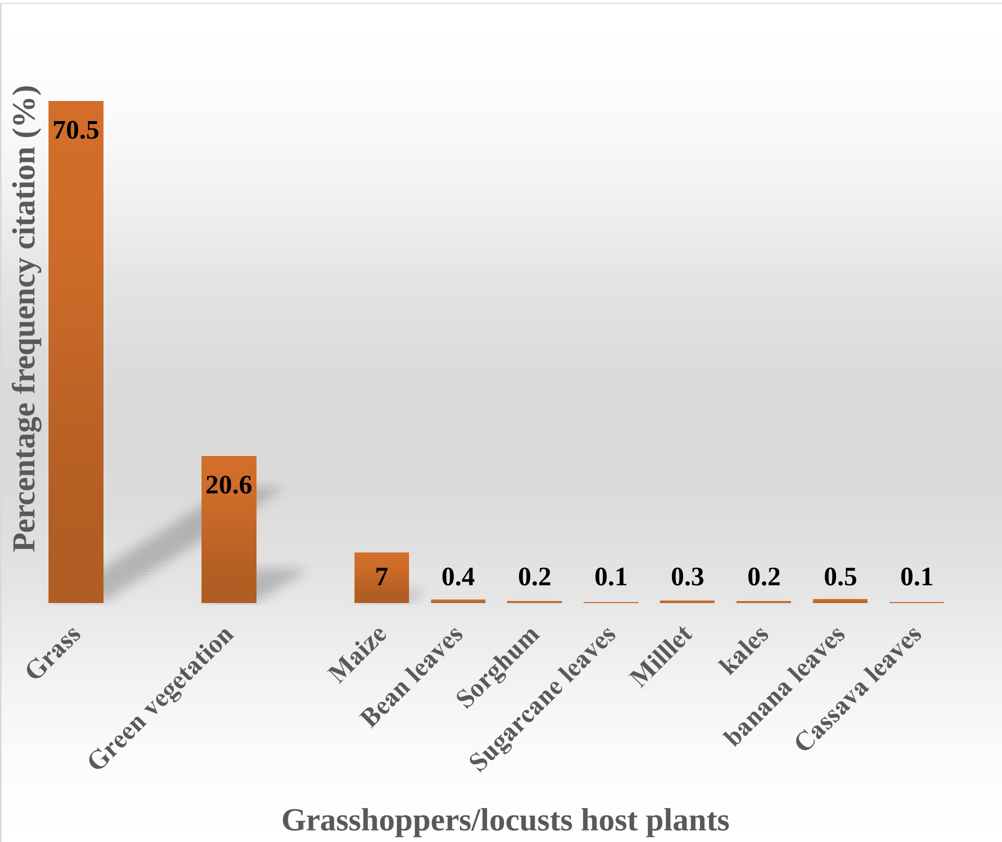

Figure 4.4: Grasshopper/locust host plants cited by respondents in Western Kenya

4.1.6 Perception of Grasshopper and locust consumption in Western Kenya

Respondents were assessed on their feelings about consuming edible grasshoppers/ locusts as food (Table 4.4). They were provided with a Likert scale in which the first statement was that the idea of eating grasshoppers/locusts makes them feel nauseous in which the majority disagreed (69.1%) while a few (13.1%) agreed with the statement. However, regarding the age group, a majority of the respondents (48.3%) between the ages 18-30 years agreed with the statement that the idea of grasshoppers/locusts makes them nauseous while only a small percentage of 8.5% of those ages above 51 years agreed with the statement.

The majority of the respondents also disagreed (72.3%) with the statement that the idea of eating grasshoppers/locusts makes them sick while a few (6.5%) strongly agreed, 10.4% agreed and 10.8% neither agreed nor disagreed. A question on disgust was also asked and a majority of the respondents disagreed with the statement that the idea of eating grasshoppers/locusts is disgusting (60.2%) with few (6.0%) strongly agreeing with the statement (χ^2 = 70.2, d.f.=3, $p<0.0001$). Similarly, the majority of the respondents disagreed with the statement that if a grasshopper/ locust crawls on their favourite food they would not eat it (67.9%) with few (6.2%) strongly agreeing with the statement. In the context of the taste of grasshoppers/locusts, 46.2% disagreed with the statement that grasshoppers/locusts have a bad taste, while 36.6% were neutral about the statement but few (6.2%) strongly agreed with the statement. The respondents also gave their responses on the statement about grasshopper/locusts' consumption not being part of their culture. The majority (50.1%) disagreed with the statement that grasshopper and locust consumption is not part of their culture, 20.9% agreed while 24.8% were neutral about the statement (χ^2 = 43.2, d.f.=3, $p<0.0001$).

Table 4.4: Perception of Grasshopper and locust consumption in Western Kenya

Question on disgust and perception	Strongly agree	Agree	Neutral	Strongly disagree	Disagree	Total (%)	Chi-square (χ^2)
The idea of eating grasshoppers/locusts makes me nauseous	81(9)	118(13.1)	78(8.7)	1(0.1)	623(69.1)	901(100.0)	χ^2 = 154.6, d.f.=4 $p<0.0001$
The idea of eating grasshoppers/locust make me sick	59(6.5)	94(10.4)	97(10.8)	-	651(72.3)	901(100.0)	χ^2 = 118.2, d.f.=3, $p<0.0001$
Eating grasshoppers/locusts is disgusting	54(6)	184(20.4)	121(13.4)	-	542(60.2)	901(100.0)	χ^2 = 70.2, d.f.=3, $p<0.0001$
If a grasshopper/ locust crawls on my favourite food I won't eat it	56(6.2)	140(15.5)	93(10.3)	-	612(67.9)	901(100.0)	χ^2 = 100.7, d.f.=3, $p<0.0001$
I fear that grasshopper/ locust-based food has a bad taste	32(3.6)	96(10.7)	357(39.6)	-	416(46.2)	901(100.0)	χ^2 = 55.1, d.f.=3, $p<0.0001$
I believe eating grasshoppers/locusts is not part of our culture	39(4.3)	188(20.9)	223(24.8)	-	451(50.1)	901(100.0)	χ^2 = 43.2, d.f.=3, $p<0.0001$

Numbers in brackets are in percentages (%)

4.1.7 Knowledge of Grasshopper and Locust preparation methods in Western Kenya

Knowledge of different techniques for the preparation of grasshoppers and locusts for consumption was mentioned by the respondents. Smoking/roasting was the most preferred method of preparation of grasshopper/locusts for consumption compared to other methods such as salting, boiling, deep frying, and using the powdered form in porridge and bread. Smoking/roasting was highly preferred by the respondents at 53.3% in contrast to the other methods of preparation (χ^2 = 79.4, d.f.=3, p<0.0001). The preparation methods that were not preferred by the respondents at higher percentages include; salting then boiling (85.5%), eating them raw (96.7%) and salting then deep frying (62.0%). Similarly, on value addition of grasshoppers/locusts through grinding them into powder form and enriching foods such as porridge or bread, there was a significant difference in response among the respondents where only 18.1% moderately preferred, 4.3% highly preferred while a higher percent of 46.5% did not prefer (χ^2 = 58.7, d.f.=4, p<0.0001) (Table 4.5).

Table 4.5: Knowledge of grasshopper/locust Preparation methods according to the respondents in western Kenya

Cooking methods of edible grasshoppers	Highly preferred	Significantly preferred	Moderately preferred	Least preferred	Not preferred	Total (%)	Chi-square (χ^2)
Eating them raw	-	-	-	30(3.3)	871(96.7)	901(100.0)	χ^2 = 88.4, d.f.=1, p<0.0001
Salting, then boiling	1(0.1)	4(0.4)	22(2.4)	104(11.5)	770(85.5)	901(100.0)	χ^2 = 277.5, d.f.=4, p<0.0001
Salting, then deep-frying	57(6.3)	62(6.9)	62(6.9)	161(17.9)	559(62.0)	901(100.0)	(χ^2 = 115.1, d.f.=4, p<0.0001
Smoking/roasting	480(53.3)	86(9.5)	109(12.1)	22(2.4)	204(22.6)	901(100.0)	χ^2 = 79.4, d.f.=3, p<0.0001
Ground and mixed with flour (for porridge, bread)	39(4.3)	64(7.1)	163(18.1)	216(24.0)	419(46.5)	901(100.0)	χ^2 = 58.7, d.f.=4, p<0.0001

Numbers in brackets are in percentages (%)

4.1.8 Willingness and reasons for rearing edible grasshoppers/Locusts by respondents in Western Kenya

When asked whether they were willing to rear edible grasshoppers/locusts and the reasons for rearing if they were shown how to do so, a majority of the respondents were willing (50.1%) while few were undecided (21.0%) but 29.0% were not willing to rear the insect. Regarding gender and the willingness to rear, more males (59.4%) than women (39.9%) were willing to rear the grasshoppers/locusts (χ^2 = 27.887, d.f.=6, $p<0.0001$). Regarding different occupations, farmers (42.4%) were more willing to rear the grasshoppers as compared to civil servants (9.1%), self-employed (32.9%), students (10.0%), and the unemployed (5.6%).

For those who were willing to rear, a majority (52.6%) indicated that they would rear them for multiple uses like human food, animal feed, and for sale. The remaining respondents stated that they would rear them for single or dual uses as follows: for food only (3.8%), for feed only (2.8%), for both food and feed only (16.0%) and for sale (25.2%). The respondents also mentioned various forms of selling the insect to the consumers as, raw (48.2%), roasted (19.0%), fried (17.3%), both roasted and fried (4.4%) and also depending on the preference of the customer (11%) (χ^2 = 56.6, d.f.=4, $p<0.0001$) (Table 4.6).

Table 4.6: Willingness to rear edible grasshoppers and locusts by the respondents in western Kenya

Questions on perceived acceptance of edible grasshoppers as food and feed	**Attribute**	**Frequency**	**Percent (%)**	**Chi-square (χ^2)**
If you are shown how to rear grasshoppers/locusts, would you rear them?	Yes	451	50.1	χ^2 = 13.4, d.f.=2, p=0.0012
	Maybe	189	21	
	No	261	29	
	Total	**901**	**100**	
What will be your purpose for rearing them?	For food only	22	3.4	χ^2 = 85.4, d.f.=4, p<0.0001
	For feed only	18	2.8	
	For feed and food only	103	16	
	For sale	162	25.2	
	For food, feed, and sale	338	52.6	
	Total	**643**	**100**	
If you were to rear and sell them, in what form would you sell them?	Raw	284	48.2	χ^2 = 56.6, d.f.=4, p<0.0001
	Roasted	112	19	
	Fried	102	17.3	
	Roasted as well as fried	26	4.4	
	Any depending on the market	65	11	
	Total	**589**	**100**	

Respondents were also asked to state the most preferred reasons for rearing grasshoppers and locusts in terms of alternative protein sources for food and animal feed. A majority of the respondents highly preferred edible grasshoppers for human food (χ^2 = 56.4, d.f.=4, p<0.0001) and chicken feed (χ^2 = 184.2, d.f.=4, p<0.0001). A high Percentage of respondents did not prefer to rear the insect for livestock feed (48. 8%) and feed for pets and museum animals (50.5%). (Table 4.7).

Table 4.7: Reasons for rearing grasshoppers/locusts according to preferences by respondents in Western Kenya

Reasons	**Highly preferred**	**Significantly preferred**	**Moderately preferred**	**Least preferred**	**Not preferred**	**Total (%)**	**Chi-square (χ^2)**
Food for man	324(50.4)	88(13.7)	77(12.0)	72(11.2)	82(12.8)	643(100.0)	χ^2 = 56.4, d.f.=4, p<0.0001
Feed for livestock (e.g. cattle)	49(7.6)	74(11.5)	89(13.8)	117(18.2)	314(48.8)	643(100.0)	χ^2 = 54.5, d.f.=4, p<0.0001
Feed for chicken	462(71.9)	147(22.9)	18(2.8)	3(0.5)	13(2.0)	643(100.)	χ^2 = 184.2, d.f.=4, p<0.0001
Feed for fish	131(20.4)	150(23.3)	126(19.6)	88(13.7)	148(23.0)	643(100.0)	χ^2 = 2.7, d.f.=4, p=0.6092
Feed for pets and museum animals	52(8.1)	91(14.2)	100(15.6)	75(11.7)	325(50.5)	643(100.0)	χ^2 = 60.9, d.f.=4, p<0.0001

Numbers in brackets are in percentages (%)

4.2 Growth performance of desert locusts raised on different feed plant diets under laboratory and greenhouse conditions

4.2.1 Growth by weight of desert locusts reared on various feed plants diet

The nymphal weight of desert locusts throughout the eight weeks of growth fed on the different food plant diets increased linearly (Figure 4.5). Under laboratory conditions (lab), desert locust nymphs fed on a wheat diet showed the highest average total weight gain of 2.48±0.33 g after eight weeks of growth followed by locusts raised on a green gram plants diet with a weight of 2.12±0.22 g. The lowest weight attained after 8 weeks was recorded when desert locust nymphs were fed on a sorghum diet (1.42±0.06 g).

The mean weight gain of desert locust nymphs raised on a wheat diet under greenhouse (GH) conditions after 8 weeks was 2.97±0.14 g.

The mean weight gain for desert locusts raised in the laboratory on a wheat diet did not differ from those raised in the greenhouse ($t=-0.7262$, $p=0.4796$) after eight weeks of growth.

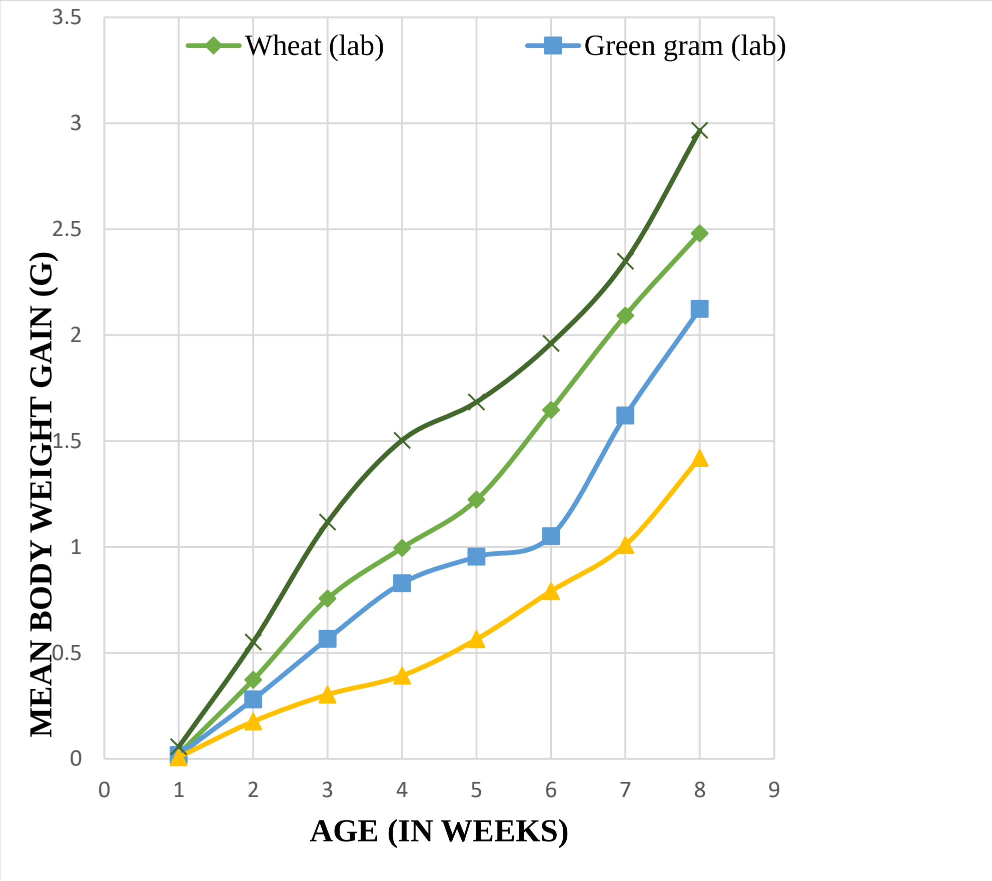

Figure 4.5: Mean body weight (g) of desert locust nymphs reared on three diets

4.2.2 Mean femur length of desert locust nymphs reared on various feed plants

For the desert locusts raised under laboratory conditions, the highest mean femur length at week 6 of growth was recorded in desert locusts raised on a wheat diet (1.20±0.17) cm compared to desert locusts raised on the green gram (0.70±0.11) cm and sorghum diet (0.6±0.15) cm that recorded the least mean femur length.

Desert locust nymphs raised on a wheat diet under greenhouse (GH) conditions also resulted in high mean femur length (2.47±0.15) cm at week six of growth which was significantly higher compared to femur length from locusts fed on other feed treatments in the experiment (Figure 4.6).

There was a significant difference in femur length for locusts raised on a wheat diet in the laboratory from those raised in greenhouse conditions at $p<0.05$.

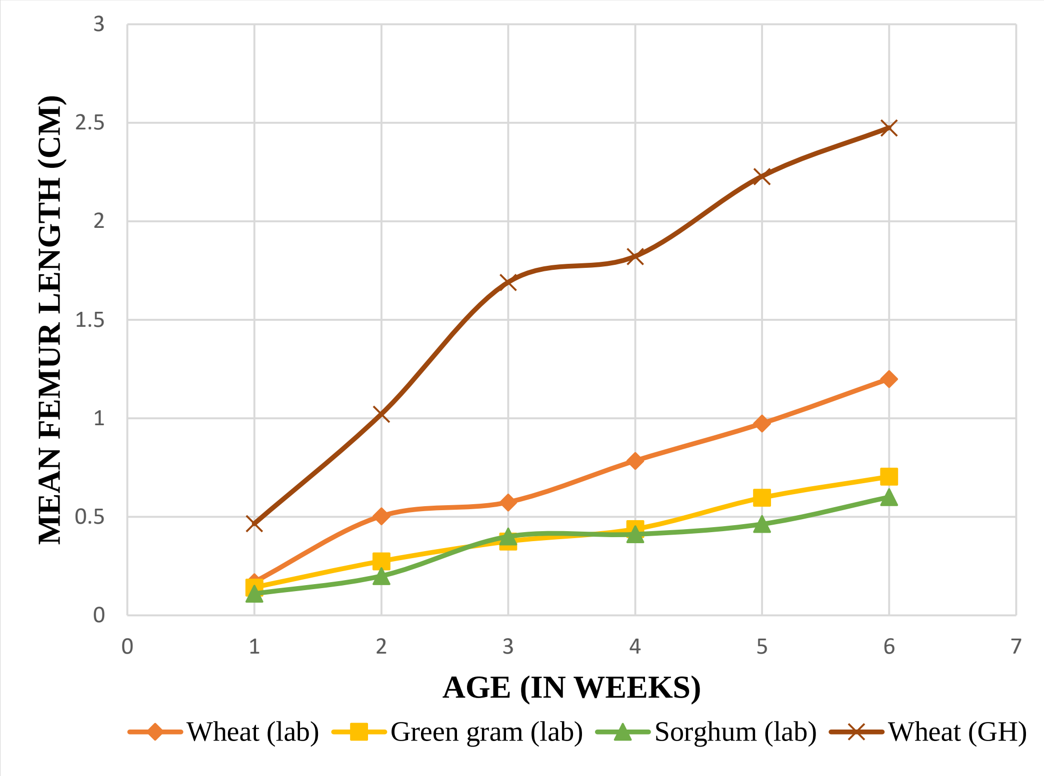

Figure 4.6: Mean femur length (cm) of desert locust raised on different feed diets

4.2.3 Survival rate of desert locusts reared on different food plants' diet

The average percentage survival rate of desert locusts fed on various plant diets during the eight weeks of growth and raised under both laboratory (lab) and greenhouse (GH) conditions was determined. In the laboratory experiments, the locust nymphs were fed on a wheat, sorghum and green gram diet while for the greenhouse experiment, locusts were fed on a wheat diet only. The average percentage (%) survival rate was high in locusts fed on a wheat diet (GH) (96.56%) followed by those fed with wheat (lab) (90.31%), however, those fed on a sorghum diet had the lowest survival rate of 76.41% ($F_{0.05}$ (3, 28) =6.22, p=0.0023). The survival rate of locust nymphs fed on wheat significantly differed from those that fed on sorghum (lab). The survival rate of locusts fed on the green gram diet (lab) was also different from those that fed on the Wheat diet (GH) while the survival rate of locusts fed on sorghum (lab) was different from those fed on the Wheat diet (GH) at $p<0.05$ (Figure 4.7).

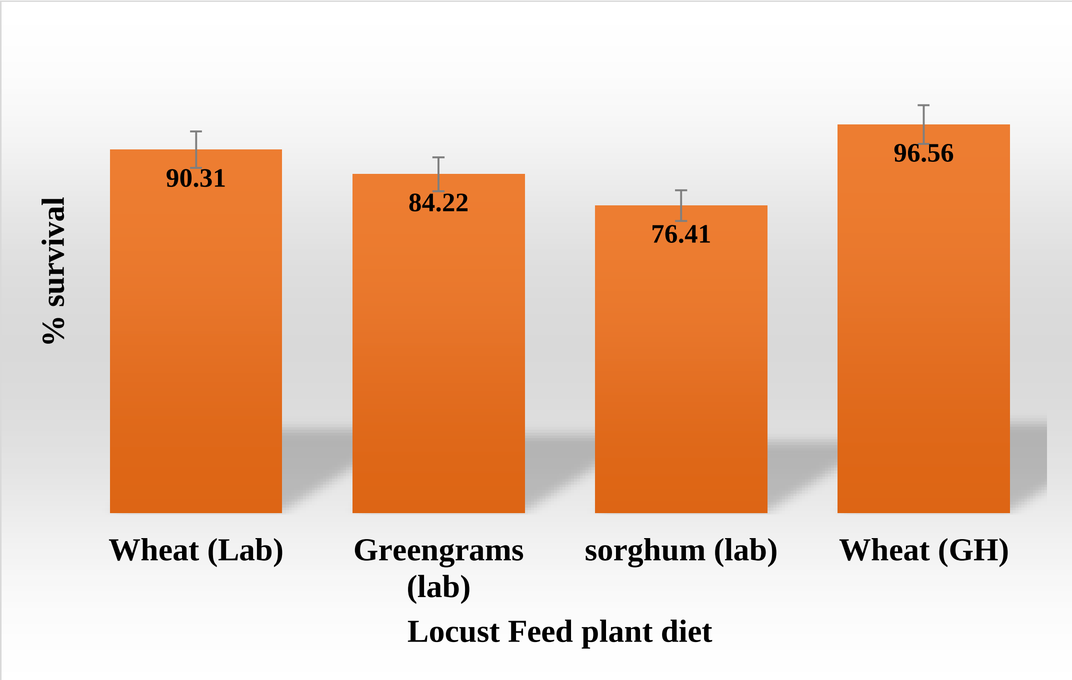

Figure 4.7: Mean Percentage survival rate of desert locusts reared on different feed plants diet (Error bars in the graph above represent standard errors of the mean).

4.2.4 Nymphal development period of desert locusts raised on different diets

The nymphal development of desert locusts raised on three diets under laboratory conditions (lab) and on a wheat diet under greenhouse (GH) conditions was determined. In the first instar, locust nymphs fed on wheat and green gram diet (lab) and wheat (GH) had the fastest development compared to nymphs fed on sorghum under (lab) conditions.

In the second and third instar, nymphs fed on wheat (GH) took the shortest time to develop while those fed on sorghum (lab) took the longest period. However, the period of development in the second and third instars significantly differed in nymphs fed on wheat and green gram diet (lab).

In the fourth and fifth instars, feeding of nymphs on sorghum (lab) led to a longer nymphal development period, which was significantly different from that of nymphs fed on wheat, green gram (lab), and wheat (GH).

Summing up these findings, the nymphs that were fed on a sorghum diet under laboratory conditions took the longest time (54.29) days to complete their nymphal development. The shortest duration of nymphal development (37.49) days was recorded for the group of desert locusts nymphs raised on a wheat diet under laboratory conditions and 36.56 days on a wheat diet under greenhouse conditions.

Total nymphal period development in the nymphs raised on three diets under laboratory experiments was therefore significantly different. There was no significant difference in developmental time for nymphs raised on a wheat diet under laboratory and greenhouse (GH) conditions ($F_{0.05}$ (1, 3) =78.56, $p<0.0001$) (Table 4.8).

Table 4.8. Mean developmental time of desert locust nymphs raised on different diets

Treatments	The mean developmental period of instars in days (mean±SD)						
	I	**II**	**III**	**IV**	**V**	**average duration**	**total period**
Wheat (lab)	7.14±0.90[a]	8.29±0.76[b]	7.54±0.82[b]	7.03±0.49[a]	7.49±0.77[a]	7.50±0.75[a]	37.49a
Green gram (lab)	8.03±0.85[a]	9.07±0.58[b]	7.54±0.82[b]	7.99±0.86[b]	8.46±0.80[b]	8.22±0.78[b]	41.09b
Sorghum (lab)	9.03±0.72[b]	10.07±1.20[c]	11.50±0.96[c]	11.49±0.78[c]	12.20±0.63[c]	10.86±0.86[c]	54.29c
Wheat (greenhouse)	8.03±0.85[a]	7.03±0.82[a]	6.46±1.02[a]	7.54±0.46[ab]	7.50±0.40[a]	7.31±0.71[a]	36.56a
F- Ratio	6.03	15.34	41.64	64.11	78.56	78.56	78.56
P value	0.0033	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

The Mean±SD in the same row and followed by a similar superscript is not significantly different ($p < 0.05$)

4.3 Nutritional composition of desert locusts raised on different plant diets

4.3.1 Proximate composition of the mature desert locust

The nutritional composition of desert locusts reared on three diets (sorghum, wheat, and green gram plants diet) was determined as described in section 3.5. The moisture content of desert locust raised on a sorghum diet (35.10±0.2) was significantly higher compared to that raised on wheat (25.02±0.1) and green grams plant diet (12.99±0.2). On the other hand, desert locusts raised on a diet of green gram plants recorded significantly higher protein, fat and crude fiber content compared to locusts grown on a diet of sorghum and wheat. However, the carbohydrate and ash content of locusts reared on wheat diets was significantly higher than that of locusts reared on sorghum and green gram diets. The highest calculated energy was the locust reared on the green gram diet, while the locust-fed sorghum and wheat diet recorded the lowest energy (Table 4.9).

Table 4.9: Proximate composition (%) of mature desert locusts fed on different plant diets

Proximate (%)	Green gram diet	Sorghum diet	Wheat diet
Moisture	12.99 ± 0.2^{c}	35.10 ± 0.2^{a}	25.02 ± 0.1^{b}
Protein (N×6.25)	48.14 ± 0.6^{a}	41.86 ± 0.5^{c}	45.38 ± 0.3^{b}
Fat	36.08 ± 0.2^{a}	16.42 ± 0.2^{b}	12.03 ± 0.2^{c}
Ash	1.62 ± 0.1^{c}	2.30 ± 0.3^{b}	3.20 ± 0.2^{a}
Crude fiber	12.89 ± 0.6^{a}	10.45 ± 0.3^{b}	9.40 ± 0.0^{c}
Carbohydrate	1.23 ± 0.6^{c}	4.32 ± 1.0^{b}	14.37 ± 0.5^{a}
Energy[1] (kJ/g 100g)	2184.95^{a}	1391^{c}	1453^{b}

^{abc} Average values (±S.E) in similar rows having the same superscripts are not significantly different ($p < 0.05$, N = 3).

[1]Calcualted by multiplying with Atwater's factor (FAO, 2003) where energy (kJ) = (% carbohydrates×16.736 kJ/g) + (% protein×16.736 kJ/g)+ (% oil×37.656 kJ/g)

4.3.2 Mineral Composition of Mature desert locust raised on different plant diets

The mineral composition of desert locusts raised on the three feed diets is shown in Table 4.10. Desert locusts fed on a sorghum diet recorded the highest amounts of minerals; Calcium, Zinc, Magnesium, iron (Fe), and Potassium (K), compared to desert locusts fed on a wheat and green gram diet. However, locusts raised on the green gram diet recorded high amounts of Phosphorus, copper (Cu), and sodium (Na), which was also significantly different from the locusts raised on wheat and sorghum diets at p< 0.05. Desert locusts raised on a wheat diet had only one mineral element, that is, Manganese (Mn) whose content was higher compared to desert locusts raised on a sorghum and green grams diet (Table 4.10).

Table 4.10. **Mineral composition of desert locusts raised on different feed diets**

Minerals	**Green grams diet**	**Sorghum diet**	**Wheat diet**	**F-Ratio**	**p-Value (p<0.05)**
P %)	0.45 ± 0.01^{a}	0.31 ± 0.01^{c}	0.38 ± 0.01^{b}	163.62	<0.0001
Ca (Mg/100g)	26.91 ± 0.41^{c}	38.42 ± 0.20^{a}	32.85 ± 0.46^{b}	714.07	<0.0001
Zn (Mg/100g)	16.08 ± 0.88^{c}	19.68 ± 0.47^{a}	18.26 ± 0.24^{b}	28.07	0.0009
Mg (Mg/100g)	37.80 ± 0.11^{c}	53.08 ± 0.12^{a}	42.83 ± 0.09^{b}	15036.04	<0.0001
Fe (Mg/100g)	12.84 ± 0.21^{c}	15.56 ± 0.07^{a}	14.55 ± 0.18^{b}	210.64	<0.0001
Mn (Mg/100g)	1.56 ± 0.08^{c}	2.10 ± 0.07^{b}	3.13 ± 0.07^{a}	356.06	<0.0001
Cu (Mg/100g)	1.07 ± 0.04^{a}	0.69 ± 0.03^{c}	0.91 ± 0.00^{b}	166.90	<0.0001
K (%)	7.08 ± 0.50^{c}	15.47 ± 1.20^{a}	9.09 ± 0.48^{b}	89.39	<0.0001
Na (%)	2.17 ± 0.15^{a}	1.35 ± 0.08^{b}	0.92 ± 0.04^{c}	120.42	<0.0001

^{abc} Average values (±S.E) in similar rows having the same superscripts are not significantly different (p < 0.05, N = 3).

4.3.3 Proximate constituents of plant diet fed to desert locusts

Proximate analysis of nutrients in the leaves of wheat, sorghum, and green gram is shown in (Table 4.12). The green gram plant diet had significantly high amounts of fats, proteins, and fiber compared to the wheat and sorghum plant diet. On the other hand, the Sorghum plant diet recorded high amounts of moisture and carbohydrates compared to the wheat and green gram plant diet which had the lowest amounts. However, the wheat plant diet had significantly higher ash content ($F_{0.05}$ (2, 6) =866.96, p<0.0001) compared to the green gram and sorghum diet. Total energy was high in the sorghum plant diet and lowest in wheat.

Table 4.11: Proximate composition (%) of desert locust feed plants' diet

Proximate (%)	Green gram	Sorghum	Wheatgrass	F-Ratio	p-Value
Moisture	0.04 ± 0.00^{a}	0.06 ± 0.00^{b}	0.04 ± 0.00^{a}	16.62	0.0036
Ash	13.27 ± 0.29^{a}	11.87 ± 0.21^{b}	19.40 ± 0.20^{c}	866.96	<0.0001
Fat	6.11 ± 0.17^{a}	2.62 ± 0.08^{b}	2.42 ± 0.03^{b}	1119.98	<0.0001
Proteins	17.23 ± 0.15^{a}	9.47 ± 0.42^{b}	13.75 ± 0.28^{c}	490.94	<0.0001
Crude fibre	11.40 ± 0.53^{a}	2.00 ± 0.20^{b}	10.33 ± 0.61^{c}	343.87	<0.0001
Carbohydrate	51.95 ± 5.51^{a}	73.98 ± 8.20^{b}	54.44 ± 4.28^{c}	25036.04	<0.0001
Energy[1] (kJ/g 100g)	1387.87±100.00	1495.28±100.00	1232.36±100.00	7.82	0.0213

^{abc}Average values (±S.E) in similar rows having the same superscripts are not significantly different ($p < 0.05$, N = 3)

4.3.4 Mineral composition of desert locust feed plants' diet

For mineral composition, the green gram plant diet had the highest levels of minerals; Phosphorus, Calcium, iron (Fe), potassium (K), and sodium (Na) compared to wheat and sorghum plant diets. Sorghum plant diet, on the other hand, had the highest significant (p<0.05) levels of Zinc, Magnesium and Copper while wheat had the highest levels of Manganese though not significantly different from manganese levels in sorghum (Table 4.12).

Table 4.12: Mineral composition of desert locust feed plants diet

Minerals	Green gram	Sorghum	Wheatgrass	F-Ratio	p-Value
P (%)	0.45±0.01^{a}	0.31±0.01^{b}	0.38±0.01^{c}	163.62	0.0000
Ca (Mg/100g)	12.87±0.22^{a}	3.90±0.07^{b}	4.31±0.17^{c}	2782.74	0.0000
Zn (Mg/100g)	0.35±0.01^{c}	0.43±0.01^{a}	0.40±0.02^{b}	27.02	0.0001
Mg (Mg/100g)	21.17±0.04^{a}	26.15±0.80^{b}	13.44±0.14^{c}	556.45	0.0000
Fe (Mg/100g)	0.97±0.03^{a}	0.49±0.03^{b}	0.17±0.02^{c}	639.1	0.0000
Mn (Mg/100g)	0.20±0.01^{a}	0.22±0.01^{ab}	0.23±0.01^{b}	8.84	0.0162
Cu (Mg/100g)	0.21±0.01^{a}	0.27±0.01^{b}	0.06±0.01^{c}	200.36	0.0000
K (%)	155.55±3.66^{a}	62.98±1.93^{b}	42.57±4.31^{c}	915.73	0.0000
Na (%)	5.68±0.43^{a}	3.32±0.26^{b}	1.91±0.10^{c}	125.11	0.0000

^{abc} Average values (±S.E) in similar rows having the same superscripts are not significantly different ($p < 0.05$, N = 3)

4.4 Performance of kales on composted desert locust frass

4.4.1 Chemical characteristics of locust frass and chicken manure used to grow *Brassica oleracea* (Kales)

The amounts of nutrients in chicken manure and locust frass were evaluated before and after 28 days of decomposition. Fresh and decomposed locust Frass had high amounts of macro and micronutrients compared to chicken manure. Decomposed desert locust frass had significantly high levels of Phosphorus, Nitrogen, Calcium, Carbon, potassium, sodium, and Magnesium compared to decomposed chicken manure (Table 4.13).

Table 4.13: **Chemical characteristics of the experimental organic manures**

Mineral	Frass manure		Chicken manure			
	Fresh	decomposed	Fresh	decomposed	F-Ratio	p-Value
P (%)	2.53±0.01[a]	2.30±0.09[b]	1.63±0.01[c]	1.20±0.02[d]	528.86	0.000
N (%)	9.76±0.14[a]	7.56±0.17[c]	9.36±0.10[b]	7.12±0.08[d]	303.42	0.000
Ca (Mg/100 g)	1.47±0.08[a]	1.06±0.05[c]	1.31±0.01[b]	0.92±0.08[d]	46.84	0.000
C (%)	24.16±0.45[a]	20.88±0.24[c]	23.08±0.30[b]	19.40±0.39[d]	109.43	0.000
K (%)	2.41±0.45[a]	1.91±0.48[ab]	1.60±0.27[b]	1.44±0.48[b]	3.04	0.093
Na (%)	3.93±0.14[a]	3.48±0.08[c]	3.70±0.03[b]	2.77±0.04[d]	104.11	0.000
Mg (Mg/100 g)	14.03±0.74[a]	10.35±0.18[b]	8.04±0.58[c]	5.99±0.25[d]	144.90	0.000

[*abcd*] Average values (±S.E) in the same rows having the same superscripts are not significantly different ($p < 0.05$, N = 3)

4.4.2 Performance of kale leaves growth on decomposed locust frass, chicken manure, and NPK fertilizer

The number of kale leaves increased throughout the experiment. From week one to week four after planting, the increase in the number of kale leaves planted using different manures and NPK fertilizers did not vary significantly ($p< 0.05$). However, from week five to seven after planting, the growth increase in the number of kale leaves planted using different manures and fertilizers differed significantly. Soil treated with 100 g decomposed locust frass produced kales with a significantly ($p< 0.05$) higher number of leaves than kales from soil treated with; NPK fertilizer, soil + chicken manure, soil + 50 g frass, soil+150g frass and untreated soil (negative control) (Table 4.14).

Table 4.14: Number of kale leaves throughout growth period from soil treated with different organic and NPK fertilizers

	Soil (-ve control)	Soil + NPK (10g per pot)	Soil+chicken manure (2:1)	Soil + 50g frass	Soil + 100gfrass	Soil + 150gfrass	F ratio	P value
Wk1	2.83±0.41	3.17±0.75	3.33±0.52	3.50±0.84	3.33±0.52	3.00±0.63	0.92	0.4843
Wk2	5.00±0.58	5.33±0.82	5.17±0.75	5.50±1.38	5.83±1.72	4.83±0.75	0.70	0.6307
Wk3	6.67±1.03	7.17±1.47	7.67±0.82	7.67±1.97	8.17±1.83	6.83±1.33	0.91	0.4864
Wk4	8.33±1.00	9.17±1.60	9.33±1.03	9.50±1.87	8.50±1.38	11.00±2.68	2.00	0.107
Wk5	9.50±0.76[a]	11.00±1.41[b]	11.33±1.51[bc]	11.33±1.51[bc]	12.67±1.97[c]	10.67±1.86[ab]	2.92	0.0282
Wk6	10.17±0.98[a]	12.50±1.87[b]	13.00±2.10[bc]	12.83±1.47[bc]	14.83±1.83[c]	11.67±1.86[ab]	4.81	0.0024
Wk7	11.00±0.63[a]	14.17±1.83[bc]	15.00±2.10[cd]	14.50±1.38[bc]	16.67±1.63[d]	12.83±1.47[ab]	9.06	<0.0001

[abcd] Average values (±S.E) in the same rows that have the same superscripts are not significantly different at $p < 0.05$, N = 3

4.4.3 Height of kales planted using locust frass, chicken manure and NPK fertilizer.

The plant height of kales grown on decomposed locust frass, chicken manure and NPK (fertilizers) followed an increasing trend throughout the experiment (Figure 4.15). From week one to week four the height of kales planted using different manures and fertilizers did not differ significantly at $p < 0.05$. There was a significant difference in the height of kales planted with different soil fertilizers in week five only at $p < 0.05$. Tere was also no significant difference in the height of kales planted with different soil treatments in weeks six and seven at $p < 0.05$.

Table 4.15: Kale height from soil treated with different organi and NPK fertilizer

Weeks	Soil	Soil+ NPK (10g per pot)	Soil+ chicken manure	Soil+ 50g frass	Soil+100g frass	Soil+ 150g frass	F-ratio	p-Value
Week 1	6.33±1.63	5.17±1.13	6.50±1.38	5.75±0.99	5.92±1.36	6.08±0.66	0.89	0.5013
Week 2	8.08±1.66	6.50±1.48	8.25±1.81	7.08±0.86	7.42±1.91	6.83±0.41	1.36	0.267
Week 3	9.42±1.74	8.42±1.72	10.42±1.83	8.58±1.11	9.42±2.58	8.50±0.77	1.22	0.3228
Week 4	10.92±1.56	10.00±2.45	13.25±2.51	11.33±1.63	11.33±2.56	10.83±1.69	1.57	0.198
Week 5	$13.25±0.88^{a}$	$12.25±2.88^{a}$	$17.17±2.32^{b}$	$14.33±2.80^{ab}$	$14.00±3.08^{a}$	$13.25±2.73^{a}$	2.63	0.0439
Week 6	14.73±0.99	14.08±3.11	18.08±1.99	16.17±2.48	15.67±2.99	14.67±2.75	2.01	0.1057
Week 7	16.50±1.22	16.17±3.79	19.83±2.14	17.92±2.04	17.67±2.75	16.50±2.55	1.75	0.1536

^{ab} Average values (±S.E) in the same rows having the same superscripts are not significantly different at p < 0.0, N = 3

4.4.4 Leaf chlorophyll content of kale leaves grown using different organic and NPK fertilizers

Leaf chlorophyll content of kales grown using decomposed locust frass, chicken manure and NPK was significantly different for all treatments ($p<0.05$) throughout the experiment (Table 4.16). Throughout weeks three, four and five, chlorophyll content from kales planted with different treatments of decomposed locust frass, chicken manure and NPK, showed a significant difference in the leaf chlorophyll content at ($p<0.05$). However, kales planted in plain soil (negative control) registered lower amounts of chlorophyll throughout the experiment. There was no significant difference in leaf chlorophyll content from kales planted with the five different fertilizers, that is decomposed locust frass, chicken manure and NPK fertilizer at ($p<0.05$).

Table 4.16: Leaf chlorophyll content of kale leaves grown using different organic and NPK fertilizers

Weeks	Soil (negative control)	Soil + NPK (10g per pot)	Soil + chicken manure (2:1)	Soil+ 50g locust frass	Soil+ 100g frass	Soil+ 150g frass	F-Ratio	P-Value
Week 3	45.48 ± 2.01^{a}	49.03 ± 4.07^{bc}	47.47 ± 3.17^{ab}	49.90 ± 1.72^{bc}	51.57 ± 1.71^{c}	49.93 ± 1.35^{bc}	4.31	0.0045
Week 4	47.05 ± 1.97^{a}	52.33 ± 3.81^{b}	51.43 ± 1.63^{b}	51.95 ± 1.32^{b}	53.88 ± 0.47^{c}	51.68 ± 1.80^{b}	7.21	0.0002
Week 5	49.57 ± 1.65^{a}	54.27 ± 3.90^{bc}	54.03 ± 1.60^{bc}	54.17 ± 1.89^{bc}	56.20 ± 1.00^{c}	53.52 ± 2.04^{b}	5.90	0.0007
Week 6	51.50 ± 1.37^{a}	56.57 ± 4.14^{b}	56.83 ± 2.05^{b}	57.55 ± 2.56^{b}	57.93 ± 2.05^{b}	56.48 ± 1.87^{b}	5.29	0.0013
Week 7	53.83 ± 1.67^{a}	59.95 ± 5.68^{b}	60.95 ± 2.85^{b}	61.92 ± 2.08^{b}	61.68 ± 3.23^{b}	58.45 ± 2.17^{b}	5.31	0.0013

^{abc} Mean values (±S. E) in similar rows having the same superscripts are not significantly different at $p < 0.05$, N = 3

4.4.5 Influence of decomposed Locust frass, chicken manure, and NPK fertilizers on the nutritional quality of kale leaves

The nutritional composition of kale leaves grown on 6 different soil treatments was determined. The highest percentage of ash was recorded in kales harvested from soil that was treated with chicken manure while ash content from kale leaves harvested from soil treated with NPK fertilizer recorded the lowest amount with a significant difference ($F_{0.05}$ (5, 12) =282.31, $p < 0.0001$). Kale leaves harvested from soil that was not treated with fertilizer (negative control) had high amounts of fat content (7.47±0.40%), however, there was no significant difference in the amount of fats in kale leaves grown in the soil treated with NPK, chicken manure, soil + 50g of frass and soil +150g of frass at $p<0.05$.

The crude fiber content of Kale leaves from soil treated with 100 g decomposed locust frass recorded the lowest amount of fiber, while crude fiber of kale leaves from soil treated with the remaining fertilizers recorded high amounts of crude fiber which were not significantly different at $p<0.05$. Nitrogen content of kale leaves planted with soil +NPK fertilizer had the highest percent (5.07±0.03%) while kale leaves from soil treated with 150g decomposed frass recorded the lowest percentage of nitrogen with a significant difference ($F_{0.05}$ (5, 12) =1232.69, $p<0.0001$).

Kale leaves from Soil treated with 50 g of decomposed frass resulted in leaves with the highest percent of Potassium (K) while kale leaves from soil treated with 100 g frass had the lowest percent of potassium among all kale leaves from other treatments. A high percentage of phosphorus in kale leaves was recorded in plants that were planted in untreated soil (negative control) while kale leaves from soil treated with 150 g frass resulted in plants with significantly low levels of Phosphorus (Table 4.17).

Table 4.17. **Nutritional composition of kale leaves grown using different organic and NPK fertilizers**

Components	**Soil**	**Soil+NPK**	**Soil+chicken Manure**	**Soil+50g Frass**	**Soil+100g frass**	**Soil+150g frass**	**F-Ratio**	P-Value
Ash (%)	12.80 ± 0.26^{a}	11.60 ± 0.20^{b}	18.33 ± 0.50^{e}	17.93 ± 0.25^{e}	14.60 ± 0.20^{c}	13.77 ± 0.12^{d}	282.31	0.0000
Fat (%)	7.47 ± 0.40^{c}	7.05 ± 0.18^{bc}	6.90 ± 0.18^{b}	6.87 ± 0.29^{b}	6.43 ± 0.10^{a}	6.97 ± 0.08^{b}	6.02	0.0052
Crude fiber (%)	6.20 ± 0.10^{a}	6.10 ± 0.56^{a}	6.17 ± 0.35^{a}	5.83 ± 1.10^{a}	4.37 ± 0.55^{b}	6.00 ± 0.10^{a}	4.53	0.0150
N (%)	4.65 ± 0.05^{a}	5.07 ± 0.03^{b}	4.94 ± 0.02^{c}	4.77 ± 0.03^{d}	3.77 ± 0.09^{e}	2.34 ± 0.06^{f}	1232.69	0.0000
K (%)	8.20 ± 0.38^{cd}	7.50 ± 1.46^{bcd}	7.02 ± 0.55^{abc}	8.61 ± 0.48^{d}	6.06 ± 0.73^{a}	6.70 ± 0.48^{ab}	4.56	0.0146
P (%)	0.54 ± 0.00^{a}	0.53 ± 0.01^{d}	0.48 ± 0.00^{b}	0.48 ± 0.00^{c}	0.52 ± 0.01^{d}	0.32 ± 0.00^{a}	876.17	0.0000

abcde The Mean values (±S.E) in the same row that have the same superscripts are not significantly different at $p < 0.05$, N = 3

CHAPTER FIVE

DISCUSSION

5.1 Current Knowledge and Perceptions of edible grasshoppers/locusts as Food in Western Kenya

5.1.1 Knowledge, familiarity, and Experience with edible grasshoppers/locust consumption.

The studied population was more knowledgeable about grasshopper/locust consumption and a good number of the population still consume the insect. These results are in line with those of Ayieko *et al*., (2012) and Kinyuru *et al*., (2013) who reported that grasshoppers and locusts are part of the local diet in Western Kenya and are still consumed by the majority of the population.

Concerning the edible grasshoppers/locusts known to them, the majority identified *Cyrtacanthacris tatarica* (the brown-spotted locust) followed by *Shistocerca gregaria* (desert locusts) as the most preferred edible species. These findings are in line with the study done by Leonard *et al*., (2020) who also through their survey study in Muranga and Kilifi counties of Kenya, respondents identified the brown-spotted locust as a common edible grasshopper species. In Cameroon, the brown-spotted locust is also the most commonly consumed species by the inhabitants (Van Huis, 2020). Contrary to our expectation, *Ruspolia differens* (the long-horned grasshoppers) were least identified as being edible even though in their study, Kinyuru *et al*., (2013) had indicated that long-horned grasshoppers are commonly eaten in the Western part of Kenya. The respondents did not consider the long-horned grasshopper species as being edible because they had some cultural beliefs attached to it. Culturally, the sampled region considers long-horned grasshoppers (senene) as an insect that brings them good luck once they land on their homestead and that is why they did not consume them. However, the few respondents who had ever consumed the long-horned grasshoppers were mostly Ugandans found at the Kenya and Uganda Busia border. Nonetheless, the long-horned grasshoppers are widely harvested and consumed in some regions in Zambia, and the Lake Victoria region basin, covering Tanzania, and Uganda (Kinyuru *et al*., 2013; Kelemu *et al.*, 2015; Mmari *et al.*, 2017).

Regarding age and entomophagy in western Kenya, a higher percentage of the respondents above 51 years had consumed edible grasshoppers and locusts compared to those aged between 18-30 years and 41-50 years. This means that the older generation in the study area knows more about edible insect consumption than the younger generation. Hlongwane *et al*., (2021) in their study also state that the older generation is more familiar with insect consumption than the younger generation.

The majority of the respondents in western Kenya who had ever consumed grasshoppers and or locusts said that their relatives, that is, grandparents, uncles, or aunties introduced them to the culture of edible insect consumption. These findings are in support of the study done by Hlongwane *et al*., (2021) who agree that the older generation in the community will pass the knowledge and information about edible insects to the younger generation. Those who introduced themselves to grasshopper/locust consumption explained that it was out of curiosity at their younger age that made them eat the grasshoppers/locusts. In their study, Alhujaili *et al*., (2023) state that the curiosity of consumers about edible insects revolves around the novelty and taste of the insect and this factor can motivate a consumer to try and accept insect food.

5.1.2 Frequency of grasshopper/locust consumption in Western Kenya

The current rate or frequency of edible grasshoppers/locust consumption in the sampled region however was low since only 36.4% of the respondents still consume them whenever the insects are in season. The respondents gave various reasons for the decline in consumption. One of the reasons the majority gave was that, the grasshoppers/locusts are not available throughout the year, and when available, they are very few hence not enough for consumption. Arena *et al*. (2020) and Abdullahi *et al.* (2021) also gave similar reasons for the decline in entomophagy whereby they stated that edible insects are seasonal and hence not available throughout the year posing a major challenge that hinders their consumption to many insect consumers. To solve the problem of availability, this study therefore has proposed the rearing of grasshoppers and locusts on a small scale, which will ensure a continuous supply of insect protein.

Some respondents in our current study, also explained that the pesticides used in farming practices have chemicals that induce toxic residues in host grasshoppers and locusts when they consume these crops and therefore pose a health risk to them if they consume the insects that have fed on such crops. Aman *et al.* (2016), also had the same view on the reasons for the reduced consumption of edible insects, that people are hesitant to consume edible insects due to fear of traces of chemicals in the insect meal. The problem of fear of traces of chemicals in the insect protein can be solved through rearing the insects and feeding them known feed substrates which are free from chemicals.

Other respondents cited a lack of interest and fear in trying new foods such as insects. Lack of interest towards insect consumption especially to new consumers is also one of the major reasons for the decline in entomophagy in many populations across the world

Abdullahi *et al.,* (2021). Some respondents who were still hesitant about consuming grasshoppers and locusts can be encouraged to consume by creating awareness of the nutritional value of the grasshoppers and locusts and teaching them various ways of preparation that encourage palatability. This can be done through seminars and workshops organized in the region.

5.1.3 New consumers readiness towards grasshopper/locust in Western Kenya

The study examined the readiness to include insects in the diet of the respondents who had never consumed grasshoppers/locusts. Only 11.9 % of the respondents indicated to were ready to consume grasshoppers/locusts as a food product, while another 34.3% were undecided. Even though these numbers are not huge, they show the readiness and willingness of new consumers to try to consume grasshoppers/locusts as an alternative protein source. The willingness of new consumers to try and consume processed and value-added insect products that make the insect more appealing and palatable was also higher. The majority were more willing to consume the insects that had been ground into powder and mixed in foods such as cakes, bread, and porridge. The respondents felt that the processed insect is invisible and this will increase their chances of consumption. These responses are consistent with Hartman *et al*., (2015) and Schardong *et al*., (2019) who pointed out that consumers without previous experience of eating insects tend to consume edible insects in processed form because the insects become invisible reducing the disgust associated with eating whole insects.

The processed insect also increases the self-satisfaction or enjoyment of the novel food to the new consumer hence reducing psychological barriers to its acceptance (Ruby *et al.,* 2015). However, in the current study, some respondents who had never consumed the grasshoppers/ locusts still insisted that they were not interested in consuming them. The choice not to eat the grasshoppers and or locusts in this study is therefore primarily influenced by having no interest as well as fear, and this was also pointed out by Verbeke (2015) in his study. Arena *et al.,* (2020) stated that the reluctance of new consumers to accept insects as food is attributed to a lack of interest in trying novel foods.

5.1.4 Availability of edible grasshopper/locusts in Western Kenya

The availability of edible insects is one main factor that may determine their consumption. The availability in this study entailed being available and sold in the market as well as harvesting them in the wild.

The respondents in the western region of Kenya had never seen grasshoppers/locusts being sold in the market unlike the situation in Uganda, and hence never bought them. In Kenya, it is not common to find grasshoppers and locusts being traded in the local markets or sold as snacks on roadsides. The main reason for not buying the grasshoppers/ locusts was cited as unavailability of the insect in the market while some respondents claimed that they could easily get them from the wild whenever a need arose. However, termites (*Macrotermes sp*.) which is another edible insect commonly consumed in western Kenya, are commonly seen being sold in open markets in most parts of the region whenever they are in the season (Anyuor *et al.,* 2022). The termite protein is a highly sought-after insect protein source in this region such that a kilogram is sold at Ksh. 500 to 1000 (Waswa *et al*., 2016).

Although grasshoppers/locusts are not openly sold in Kenya, the long-horned grasshoppers are commonly sold along the roadside, in markets, supermarkets and in the streets in Uganda and Tanzania (Mmari *et al.,* 2017), and in Cameroon (Ngoute *et al*., 2021). Still in Niger and Senegal, the grasshoppers are often sold in the open markets and this enables the insect gatherers to earn an income. For instance, one kilogram of grasshopper in Senegal costs approximately 1.1 US$ which is close to the price of a kilogram of beef at 1.4US$. In Uganda too, when the long-horned grasshoppers are in season between November and January, the traders fetch a good amount of money as a kilogram is sold at 10 US$ and this price at times may be higher than a kilogram of meat (Van Huis, 2022). Selling edible insects is, therefore, an enterprise that offers livelihood opportunities to traders of our neighbouring countries who have embraced edible insect consumption, especially grasshoppers.

The study population was asked about the time of the year when the grasshoppers/locusts are in plenty and the type of plants they feed. Most respondents cited that grasshoppers and locusts are normally in plenty during the long rainy season since this is the time when the green vegetation which is their food is in plenty and there is more foliage thus leading to their high population. This response is in line with Kariuki *et al*., (2019) who cited that grasshopper diversity and population increase with an increase in vegetation.

5.1.5 Wild harvesting of grasshoppers/locusts and their preparation methods

According to the respondents, grasshoppers and locusts are harvested mainly through chasing and hand-picking. This method is similar to those used in West Nigers (FAO, 2013; Egonyu *et al*., 2021) and Mexico (Fombong *et al*., 2021). Light trap as a method of harvesting grasshoppers was least mentioned, which is a method commonly used in Uganda and Tanzania (Mmari *et al.,* 2017). The light method is used for grasshoppers that are not consumed in Western Kenya. Despite the various methods used in harvesting grasshoppers and locusts around the world, the main objective of harvesting them for consumption is always achieved by those involved in harvesting. Therefore, knowledge of grasshopper and locust harvesting methods enables the consumers to access them easily for food and feed whenever the insect is in season.

Tradition and culture influence how edible insects are cooked, and not knowing how to prepare edible insects for consumption can negatively affect acceptance, especially among new consumers (Alhujaili *et al*., 2023). In the current study, grasshoppers and locusts are prepared, albeit minimally based on knowledge passed down from older generations. For instance, the present study shows that smoking/roasting was highly preferred as compared to other methods of cooking such as boiling, salting, and deep frying as well as consuming them in raw form.

5.1.6 Willingness and reasons for rearing grasshopper/locusts in Western Kenya

A majority of the respondents from the study were willing to rear the edible insects if taught how to do it and hence this would encourage and increase the availability of protein sources in their diet. A greater number of male respondents were more willing to venture into rearing the grasshoppers/locusts than females. The possible reasons for this could be males are more adventurous and always ready to try new foods (Orkusz *et al.*, 2020) while women mainly associate insects with uncleanliness and hence develop a fear towards insect consumption (Bao & Song, 2022).

At the same time, more farmers than those in occupations such as civil servants and self-employed were more willing to venture into insect farming. This could be attributed to the fact that farmers are already into farming practices and therefore venturing into insect farming as an additional venture would be easily acceptable to them. The respondents that were willing to rear the insects mentioned that they would rear them for multiple purposes such as for human food, animal feed, and for sale of the surplus to earn an income.

In terms of rearing grasshoppers/locusts for animal feeds, the majority of the respondents preferred rearing them for chicken feed compared to cattle, fish and museum specimen feeds. A few studies have been done on the use of grasshoppers and locusts as alternative protein sources in animal feeds. For example, the inclusion of 30% of locust meals in the Tilapia fish diet had no adverse effect on nutrient utilization and the growth of fish (Yousif *et al.*, 2022). Similarly, in the Philippines, free-range chicken fed on grasshoppers or locusts has a preferred taste and they fetch a higher market price compared to chicken fed on commercial feeds (Makkar *et al*., 2014). These observations, therefore, encourage the use of locusts and grasshoppers in animal feed for better growth performance of the animal.

Apart from grasshoppers/locusts being used as food and feed, they are also believed to have health benefits. In our current study, some respondents in our discussion also associated *Schistocerca species (*desert locusts) with medicinal purposes. According to the respondents, the thorax was roasted and crushed and its ash was used to treat colds and flu. However, many of these claims are based on conventional wisdom, as there is no clinical data or chemical studies to support these claims.

5.2 Growth performance of desert locusts raised on different feed plant diets under laboratory and greenhouse conditions

The growth performance and survival of any organism including insects depend on the quality of food consumed during its development period. For better growth and development as well as other metabolic activities, an animal requires nutrients such as protein, carbohydrates, and fats including macro and micronutrients (Gosh *et al*., 2014). The maximum growth rate of any insect, therefore, is measured by its ability to ingest, digest and assimilate food substances into its body hence increasing its rate of survival to adulthood (Gosh *et al.,* 2014). Desert locusts are a group of acridids that are highly polyphagous and are therefore able to feed on a wide variety of plants equal to their body weight daily (Jeengar *et al.*, 2022). The survival and proper nymphal development of desert locusts are thus crucial in the mass production of the insect.

The present study determined the growth performance and survival rates of *Schistocerca gregaria* (desert locust) reared on different food plants diet, that is, wheat (*Triticum aestivum*), sorghum (*Sorghum bicolor*) and green grams (*Vigna radiate*), plants diet to find a suitable plant feed for the mass rearing of the desert locusts under controlled conditions.

In the current study, a shorter nymphal development period, greater weight accumulation, increase in femur length and higher survival rate were recorded in the desert locust raised on a wheat plant diet under both laboratory and greenhouse conditions. This performance could be attributed to the wheat diet provided to the nymph during its development period. Wheat grass according to Aate *et al.*, (2017), is a nutritional power house that is rich in chlorophyll, antioxidants and minerals. The antioxidants are believed to help resist oxidative stress in any organisms and this could be the reason why the locust performed better when raised on a wheatgrass diet. Rai *et al.*, (2012) also reported good performance of *Locusta migratoria* when raised on a wheatgrass diet under laboratory conditions where weight gain in nymphs was higher, there was a shorter development period in nymphs and a higher survival rate was recorded compared to *Locusta migratoria* raised on the other food plants diet in the same experiment. When the duration of nymphal development is short, the chances of survival to adulthood are also increased and this will translate to less amount of food that is required to feed the insect (Gosh *et al*., 2014). This, therefore, means that for locust farmers, less food will be needed to feed the insect up to maturity hence making the production of locusts for protein sources less costly. Locust nymphs raised on a wheat diet had shorter nymphal development periods and the survival rate was higher, hence making the wheat diet a better option for raising this insect under a controlled environment.

The poor performance of desert locusts in terms of low weight gain, longest nymphal development period and lower survival rate when raised on the sorghum diet in the current study could be attributed to the sorghum diet having lower protein content compared to the other diets used in the experiment. Sorjonen *et al.*, (2020), state that inadequate protein quantity in any insect feed diet affects the development period of immature insects and this also increases their mortality. The present results are in line with the studies done by Gosh *et al*., (2014) whereby the short-horned grasshopper *Oxya hyla hyla* raised on a sorghum grass diet had little average weight gain in nymphal development, and at the same time the nymphs took the longest time to develop while the survival rate was also low compared to the short-horned grasshopper that was raised on *Cynodon dactylon* under same conditions. Similar results were also recorded by Kroncke & Benning, (2023), who also found that feeding yellow meal worms on a diet that had lower protein content resulted in the larvae with the lowest weight compared to those whose feeds had high protein content.

Locust nymphs raised on a wheat diet in the current study performed better in terms of mean weight gain, shorter nymphal development period, and higher survival rate. Therefore, we can reject our hypothesis that there is no difference in the growth and development of locust nymphs when raised on wheat, sorghum and green gram plant diet. This is because desert locust nymphs raised on the wheat plant diet performed better in terms of growth and development compared to the nymphs raised on a sorghum and green gram plant diet. Based on these results, small-scale insect farmers can be trained on the best way to rear locusts under greenhouse conditions and the best feed diet to use to increase the survival rate and hence high quality and quantity harvest of the locust protein.

5.3 Nutritional composition of desert locusts raised on different plant diets

Desert locusts are edible insects that are beneficial in terms of nutrients and can be mass-produced and thus sustainable. The nutritional composition of any insect greatly varies due to habitat and food consumption as well as the stage of sampling (nymphs/adults) (Mariod *et al*., 2017; Ssepuuya *et al*., 2018).

The results of this study show that locust is rich in protein, fat, carbohydrates and minerals such as zinc, phosphorus, magnesium and calcium. These nutrients are essential for human health and nutrition. However, the nutritional composition of the desert locusts analyzed in this study varied due to the diet of food plants consumed during the insect's developmental period. Locusts fed on a green gram plant diet had high amounts of crude protein content compared to those fed on wheat and sorghum. This could be attributed to the protein content present in their feed, for example, the green gram diet had high protein content while the sorghum diet had the lowest amounts of protein and this could have affected the protein content of the mature desert locust. These results, therefore, enable us to reject our hypothesis that, there is no difference in nutrient composition of desert locust meal when locust nymphs are raised on sorghum, wheat and green gram plant diets. This is because, from the results in the current study, locusts raised on a green gram diet had more protein content while those raised on a sorghum diet had the lowest amount of proteins. Farmers can hence rear the desert locust on wheat and green gram for faster development and more protein. They can also raise them in a variety of local plants to maximize production.

The crude protein content of desert locusts reared on different diets in the present study was higher than the most commonly consumed proteins, for example, beef (40.5%) as stated by Gosh *et al*., (2017), raw pork chop protein, and chicken breast which average 18.1% and 24.2% respectively (Ahmad *et al*., 2018). Kababu *et al*. (2023) reported that protein from fish, beef, chicken, egg, soy, and lamb ranges from 13% to 32%, which is lower than the amount analyzed in the current study. The high crude protein content of locusts evaluated in this study makes them a viable alternative that can provide an adequate amount of basic protein to a growing population, thereby helping to reduce nutritional deficiency, especially in Kenya.

However, the protein content of locust meal in this study was lower than the work done by Mariod *et al*. (2017) and Clarkson *et al*. (2018) who reported protein contents of 52.3 and 50.79% respectively. However, Egonyu *et al*., (2021), analyzed the protein content of locusts caught in the wild in Kenya and found it to be 46.3% which was not different from the current study result. The variations in the protein content from different studies in the locust meal could therefore be attributed to the type of feed materials available for the insects' consumption, the stage of the insect during analysis, inconsistencies in the methods of analysis used, environmental conditions, and the period of sampling (Shumo *et al.,* 2019; Egonyu *et al*., 2021). The high protein content in the current study, therefore, gives the confidence to encourage the population to consume locusts since the protein content is comparable to commonly consumed vertebrate proteins such as beef, fish and eggs (Ssepuuya *et al*., 2018). To increase acceptance, especially to new consumers, locusts can therefore be processed into powder form and incorporated into familiar food products such as biscuits, bread, porridge and pasta (Arena *et al.,* 2020).

The moisture content of desert locusts raised on different feed plant diets in the present study was higher compared to the study done by Mohamed, (2015) where the moisture content of migratory locusts was lower. However, the present study's moisture content in the locust contradicts the study done by Samira & Abeer, (2019), whose results showed higher moisture content in *S. gregaria*. Food that has high moisture content normally has a short shelf life, and this a determinant of the quality and susceptibility of food to microbial spoilage (Anaduaka *et al*., 2021). In terms of longer shelf life or storage of locust meal protein especially during preparation for consumption, locusts raised on a sorghum diet may not be a good option because of their high moisture content which makes them more susceptible to spoilage. For longer shelf life, therefore, we conclude that rearing locusts on a wheat and green gram diet could be the best option since their moisture content is lower.

Fat is very important in the human diet because, apart from increasing the palatability of food, it improves the taste of food by absorbing and maintaining its taste (Idowu *et al*., 2019). It is also important for the structural and biological functions of cells, transports soluble vitamins in food (Siulapwa *et al*., 2014) and provides energy for various body functions (Kababu *et al*., 2023). The fat in grasshopper meals is related to the nutrients the food plants consume while growing. The desert locusts raised on a green gram diet had the highest amount of crude fat, while wheat-fed locusts registered the least amount. The difference may be attributed to the feed diet given to the locust as the green grams diet had a higher fat content (6.11%) while the wheat diet's fat content was lower (2.42%). The fat content in the current study on desert locusts fed on green grams was considerably higher compared to the study done by Clarkson *et al.,* (2018) whose fat content was 34.9% in *L. migratoria.* Egonyu *et al.,* (2021), analyzed the wild locust in Kenya, and the fat content was 29.8% which was higher than the locust fed on a wheat diet in the present study. Lower fat content (18.6% to 29.6%) was also observed by Oonincx & van der Poel (2011) although these amounts are higher compared to the locust fed on sorghum and wheat diet in the current study. However, the composition of fat in locust meals studied by Mariod *et al*., (2017) was considered the lowest at 12.0%. The differences in the fat content in the present study with previous studies could be attributed to the habitat and type of feed locusts consumed in their development stage. The results of fat content observed in desert locusts in this study demonstrate that locusts can offer a good amount of fat content for the human diet. In their study, Cheseto *et al*., (2020), found out that the oil extracted from locusts is also rich in omega-3 fatty acids, vitamin E, and flavonoids than most commonly used plant oils therefore locust oil is essential, especially in young developing children and the old age. From the present study, it can therefore be concluded that the nutritional quality of desert locusts is high and hence suitable for human consumption. This is because the high-fat content in insects translates to high quality insect food (Zhou *et al*., 2022).

Carbohydrate is an important requirement in the human diet as the main energy source. The carbohydrate in edible insects is therefore essential in supplying energy for the human body (Kababu *et al*., 2023). The high content of carbohydrates in locusts fed on a wheat diet is comparable to that recorded by Clarkson *et al*., (2018) in *L. migratoria*. However, this is slightly lower compared to the observation made by Mariod *et al*., (2017) on locusts. Other previous studies have also recorded lower amounts compared to the current study when locust was fed on a wheat diet. For example, Egonyu *et al.,* (2021) recorded low amounts of carbohydrates in locusts harvested from the wild at 9.9%, and Mohamed (2015) also reported low amounts of carbohydrates in *L. migratoria* at 4% and 14%. Carbohydrate content differences can be attributed to the type of feed the locusts consume and the environment in which the locusts live.

The ash content of locusts raised on a sorghum diet was comparable to that obtained by Clarkson *et al*., (2018) on *L. migratoria*. However, Mariod *et al*., (2017) and Egonyu *et al*. (2021) observed that the ash content in locusts is significantly higher compared to the current study. Siulapwa *et al*. (2014) reported that the ash content of the given sample is related to the mineral content of the sample. The mineral composition of the studied desert locusts shows that they are a fair source of mineral elements.

Proximate analysis of the mineral composition of locusts raised on wheat, sorghum and green gram plants diets correlated with the mineral composition in these diets. This indicates the amounts of minerals present in the locusts meal are good for human health especially when supplemented in their meals. Therefore, children and the the sick meal can be enhanced with locust.

To enhance small scale grasshopper and locust farming as an alternative protein, it is important to develop a farming system that is less costly and can be replicated by most farmers. The type of feed substrate given to them during their growth could influence their growth pattern as well as the nutritional composition of which the current study has established. The performance of desert locust under greenhouse conditions was excellent in terms of survival and weight growth, hence it is possible to rear them under these conditions for protein sources. Cricket farming under a greenhouse as one of the housing structures has been successful (Ayieko *et al.,* 2016) and this indicates that small-scale locust farming can also be successful under a greenhouse structure.

The three tested feed plants' diet fed to locusts resulted in considerable amounts of proteins and other nutrients in the mature locust meal which was comparable to or higher than the most commonly consumed proteins. The feed plant diet used in this experiment can easily be accessed by interested locust farmers. The information from this study can therefore be used to train farmers on the best way to rear the locust under greenhouse conditions since less space and lower cost are required to install the rearing structure. This will also improve food security because insect protein sources will be easily accessible to many people.

5.4 Performance of *Brassica oleracea* L (kales) on composted desert locust frass

There is limited information on insect frass as organic fertilizer even though there has been intensive research in exploiting insects as food and feed. Chicken manure is the most commonly used organic manure by Kenyan small holder farmers in the kitchen gardens. While the chemical characteristics of chicken manure will vary due to the types of feeds they consumed, the chemical characteristics of chicken manure selected in the current study were comparable to those of decomposed frass. This confirms that desert locust frass has a high fertilizer potential similar to that of chicken manure. The current study, therefore, provides evidence of the possibility of incorporating decomposed desert locust frass as an organic fertilizer for improving the growth, yield, and nutritional quality of vegetables. Subsequently, incorporating decomposed desert locust frass into the kitchen gardens to improve crop production could provide an additional source of income through the production of edible insects for both food and feed, while at the same time producing locust frass organic fertilizer as a viable placement, or complement for expensive synthetic fertilizers.

Kales planted using the composted locust frass of 100g, NPK fertilizer and chicken manure were comparable in terms of increasing the number of kale leaves, chlorophyll content and nutritional quality of kales. The high growth rate and yield associated with kale grown using 100g of decomposed locust frass may be due to the better availability and supply of nutrients from the newly introduced frass manure (Beesigamukama *et al.*, 2020). The increased yield could also be attributed to the complementary and synergistic effects of frass fertilizer on the growth of crops and yield. The low growth of kales planted in plain soil (untreated) indicates high levels of nutrient depletion in the soil that was used for the experiment in this study as well as it could be due to phytotoxicity that is found in the soil (Anyega *et al*., 2021). The high chlorophyll content in kales planted with 100 g decomposed locust frass signifies higher amounts of green pigments responsible for the production of food for plants. From these results, we can therefore agree with our hypothesis that there is no difference in the growth performance of kales planted using decomposed locust frass and chicken manure.

The higher nitrogen, phosphorous, and crude fats concentrations achieved in kales using decomposed 50 g locust frass as an organic fertilizer indicate that besides enhancing better growth in crops and increasing the chlorophyll content of crops, decomposed desert locust frass has also the potential to improve the nutritional quality of vegetable grown. The higher concentrations of nitrogen, phosphorous, and crude fats achieved using 50 g locust frass can be linked to the high nitrogen uptake and other nutrients by kale grown utilizing this organic manure (Anyega *et al*., 2021).

There are however no studies done yet using decomposed desert locust frass as organic fertilizer in crop production, nonetheless, a few studies have been done using black soldier fly frass (BSFF) fertilizer. A study done by Anyega *et al*., (2021) using BSFF fertilizer on the growth of kales among other crops investigated, indicated that the use of BSFF fertilizer in the growth of kales had a positive influence on the growth as the number of leaves and height of kales increased with weeks of growth compared to the other fertilizers used in the same experiment. Studies have also been done on the growth of pakchoi (*Brassica rapa L*) using BSFF fertilizer, and the results showed a maximum increase in the number of leaves and plant height of pakchoi when BSFF was used in planting compared to control and NPK treatment that was used in the study (Agustiyani *et al*., 2020). Other studies were done on growing maize using BSFF fertilizer and the results also showed an increase in the height of maize plants when compared to other artificial fertilizers that were used in the experiment (Beesigamukana *et al*., 2020). Chlorophyll content was observed to be higher in Pakchoi (*Brassica rapa L*) leaves whose plants were grown using 15% BSSF fertilizer (Agustiyani *et al*., 2020). These observations indicate that insect frass has the potential to increase chlorophyll content in crops.

Therefore, this study shows the high efficiency of desert locust decomposed frass as a fertilizer to increase the growth and nutrition of kales, so it has the potential to be used as an organic fertilizer similar to chicken manure. However, information on the growth performance and nutritional quality of plants grown with dec desert locust frass is still very scarce. Therefore, the current study is the foundation for future research work.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The conclusions of this study are as follows;

(i) To determine the current knowledge and perceptions of edible grasshoppers/locusts as food in western Kenya.

The study survey done in western Kenya showed that the inhabitants of this region are knowledgeable about grasshopper/locust consumption and the brown-spotted locust was the most frequently cited as being edible. The observed knowledge of edible grasshopper/locust species and experience in their consumption indicates that entomophagy is still practised in western Kenya. The population also showed the readiness to venture into grasshopper/locust farming for food and feed.

(ii) Growth performance of desert locusts raised on different feed plant diets under laboratory and greenhouse conditions

The current research shows that grasshoppers and locusts can be produced on locally available diets such as sorghum, green gram and wheat plant diets. For small-scale farming at the greenhouse, the study has shown that locusts can be raised on a wheat plant diet successfully since growth performance and survival rate were higher. Green gram plant diet can also be used in raising desert locusts since their growth performance under laboratory conditions was also good. The cost of farming at the greenhouse is relatively lower since no electricity is required, unlike laboratory rearing.

(iii)Nutritional composition of desert locusts raised on different plant diets

The results from this study revealed that desert locusts could be farmed successfully to produce high quality protein that has the potential to replace fully or partially the conventional animal and plant protein sources. However, a green gram and wheat diet would likely serve as a better food diet for locust rearing owing to the locust having high amounts of protein when raised on these diets.

(iv)Performance of *Brassica oleracea* L (kales) on composted desert locust's frass

The growth performance of kales when planted using decomposed locust frass was as good as those planted with chicken manure. Therefore, the present research provides proof that the soil treated with the decomposed desert locust frass as organic manure can create favourable soil conditions for the cultivation of kale leading to increased crop yields. Therefore, locust frass has the potential to be used as an organic fertilizer similar to chicken manure.

6.2. Recommendations

To encourage the consumption and rearing of edible grasshoppers/locusts, this study recommends the following;

1. The promotion of rearing grasshoppers/locusts is a strategy that can be used to improve the supply and abundance of edible insects throughout the year and hence contribute to sustainable protein sources as well as the development of insect value chains. Small-scale insect farmers can raise desert locusts under

greenhouse conditions successfully and they could feed the insect on wheat and green gram diet.

2. Due to its mineral composition, the utilization of locust frass as an organic fertilizer has shown potential for use in cropping systems and thus may assist in reducing the utilization of artificial/synthetic fertilizers and thus assist in the improvement of feasible agriculture.
3. To promote entomophagy, the government needs to create incentives aimed at educational centers for the study and development of graduate and post-graduate studies on edible insects. This can be achieved through multidisciplinary collaboration and cooperation between technical and social sciences.

6.3 Further Research

More research on cropping systems is needed to understand whether locust frass can be used as a replacement for synthetic fertilizers or not. This study was hence used as a benchmark since no study has been carried out yet using decomposed desert locust frass as an organic fertilizer.

More experiments are to be done on other locally available feed diets for locust/ grasshopper rearing to find a suitable wide range of feeds for insect farming.

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APPENDICES

Appendix I: NACOSTI Research Permit

REPUBLIC OF KENYA

NATIONAL COMMISSION FOR SCIENCE, TECHNOLOGY & INNOVATION

Ref No: **446306**

Date of Issue: **27/January/2023**

RESEARCH LICENSE

This is to Certify that Ms.. Sylvia Mmbone of , has been licensed to conduct research as per the provision of the Science, Technology and Innovation Act, 2013 (Rev.2014) in Bungoma on the topic: Rearing of edible grasshoppers/locusts as alternative proteins in western kenya for the period ending : 27/January/2024.

License No: **NACOSTI/P/23/23437**

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See overleaf for conditions

Appendix II: **The Questionnaire used in the survey in the Western region of Kenya**

QUESTIONNAIRE

Introduction

This survey questionnaire aims to assess the knowledge, availability, perception and acceptance of edible grasshoppers/locusts in Western Kenya. Also, the survey wants to investigate the willingness to rear them if shown and hence be able to sell and earn some income from them. In this survey, you will be asked some questions about your views on the consumption of edible grasshoppers/locusts as food and feed.

The information you give will be handled with at utmost privacy. Your PARTNERSHIP in this research is thus highly valued.

This interview will take between 5-10 minutes only. Thanks for your time and cooperation.

1.1 Demographical data *(Please tick (√) or fill in the blank spaces as appropriate*).

1. Give information on the following about your location

County……………Constituency………Ward……………Sub location……….

2. Could you please fill in your details in the boxes below?
   Age: 18-30 [ ]   31-40 [ ]   41-50 [ ]   51+ [ ]
   Sex: Female [ ]   Male [ ]
3. Your educational status:
   None [ ]   Primary [ ]   Secondary [ ]   Tertiary [ ]
4. Your Profession:
   …………………………………………………………………………………….

SECTION B

1.2 General knowledge and information about edible grasshoppers/locusts
Questions on the familiarity of edible grasshoppers/locusts as food

1. i) Have you ever heard about people eating grasshoppers/locusts?
   YES [ ]   NO [ ]
   ii) If YES, what type of edible grasshopper/locust do you know **{refer to picture catalogue}** (*give name(s*) if known)

…………………………………………………………………………..

2. Have you ever eaten/tried eating any before as part of your diet?
   YES [ ] NO [ ]
   i) If YES, did you like it
      YES [ ] NO [ ]

   ii) If YES, how often have you eaten/tested them? (tick (√) one)

I have eaten only once	
I have eaten a few times	
I consume them occasionally (when in season)	
I eat them regularly(at least once per week)	

   iii) Who introduced you to eating edible grasshoppers/locusts? (*tick (√) one*)
      Friends [ ]
      Relatives [ ]
      Self [ ]
      Any other……………………………………………..
   iv) If not eaten before, would you consider to eat them?

      Yes [ ]

      Maybe [ ]

      No [ ]

   v) If not eaten, would it help if the whole insect was for example (*Please feel free to choose (√) more than 1 in the table below?*)

Covered in Chocolate bar	
The whole insect Mixed into food like rice	
Grounded and mixed in cakes, bread, mandazi	

Grounded and mixed in porridge flour	
Consumed as a protein extract	

1.3 **Question on the availability of edible grasshoppers/locusts**

i) What time of the year do you normally see many grasshoppers/locusts?
…………………………………………………………………………………….

ii) Have you ever bought any edible grasshoppers/locusts before?

YES [ ]

NO [ ]

iii) If **NO** what could be the reason(s) for not buying?..

iii) If **NO** and you come across them in the market will you consider buying them?

YES [ ] NO [ ] MAYBE [ ]

iv) What traditional methods do you normally use to harvest grasshoppers/locusts?
……………………………………………………………………………………..

vi) What plants do you think grasshoppers/locusts like feeding on
……………………………………………………………………………

1.**4 Question on disgust and perception about grasshoppers as food**

i) What is your feeling about consuming edible grasshoppers/locusts as food? (Please choose one in each)

Question on disgust and awareness	Strongly agree	Agree	Neutral	Strongly disagree	Disagree
The idea/ thought of consuming grasshoppers/locusts is distasteful					
The thought of consuming grasshoppers/locusts is sickening					

consuming grasshoppers/locusts is disgusting					
If a grasshopper/locust falls on my favourite food I won't partake of it					
Grasshopper/locust food products have negative taste properties					
Grasshopper/locust consumption is not part of our tradition					

ii) Using a scale of 1 to 5; where: 1= highly preferred, 2=significantly preferred, 3=moderately preferred, 4=least preferred, and 5=not preferred, please rank the following preparation/ cooking methods of edible grasshoppers/locusts according to your preference.

Cooking/proces s-sing methods	**1(**highly preferred)	**2(**significa ntly preferred)	**3**(moderately preferred)	**4**(least preferred)	**5(**not preferred)
Eating them uncooked					
Salting, then boiling					
Salting, then deep-frying					
Salting, Pan-Fried and sun-drying					
Smoking/roastin g					
Insects milled into flour and mixed with (porridge, bread)					

1.5. Questions on recognition of edible grasshoppers as food and feed

i) Will you be willing to rear grasshoppers/locusts if shown how to rear them?
YES [ ] MAYBE [ ] NO [ ]

ii) What will be your purpose for rearing them? (feel free to *choose (√) more than one)*
For food [ ] For feed [ ] For sale [ ]
Any other………………………

iii) If you were to rear and sell them, in what form would you sell them (*feel free to choose (√) more than 1)*
Raw [ ] Roasted [ ] Fried [ ] Any other………………….

iv) Using a scale of 1 to 5, where: 1= highly preferred, 2= significantly preferred, 3= moderately preferred, 4= least preferred, 5=not preferred, please rank the following reasons for rearing grasshoppers according to your preference.

Preference	**1(**highly preferred)	**2(**significantly preferred)	**3(**moderately preferred)	**4(**least preferred)	**5 (**not preferred)
Food for man					
Livestock feed					
Chicken feed					
Fish feed					
Animal museums and pet feeds					

Thank you for the information and time taken to answer this questionnaire.

Appendix III: Local names associated with grasshoppers/locusts in Western Kenya.

Scientific name	**Common name**	**Local name(s) (Luhya)**
Ruspolia differens	Long-horned grasshopper	Esenene/senene
Ruspolia nitidula	Cone-headed grasshopper	Namulikho
Melanoplus femurrubrum	Red-legged grasshopper	Ocharigiro/khonje
Melanoplus bivittatus	Two-stripped grasshopper	Kakulaugeni
Cyrtacanthacris tatarica	The brown spotted locust	Namwirundo/ lidede/ kamatete/ talamwet/ Nambalalwe/ odalala/ sanja
Schistocerca gregaria	The desert locust	Esike/ Likongolo/ Parapara

Appendix IV: Grasshoppers and locusts picture catalogue used during the survey

1. *Ruspolia nitidula*

2. *Ruspolia differens*

3. *Melanoplus bivittatus*

4. *Melanoplus femurrubrum*

5. *Cyrtacanthacris tatarica*

6. *Schistocerca gregaria*

Appendix V: List of areas surveyed in the western Kenya region

County	Constituency	Sub /Ward location	village
BUNGOMA	Kanduyi	Bukembe East	Munyore sipala
	Kabuchai	West Nalondo	Kabuchai Muyaayi
		Chwele	Busakala Mupeli
	Webuye West	Bokoli	Bokoli Lufwinduri
		Misikhu	Sirisia Musemwa
	Tongareni	Mbakalo	Kananachi Musembe
		Kabuyefwe	Sirakaru Naitiri
	Webuye East	Ndivisi	Marinda Sinoko
BUSIA	Funyula	Ageng'a Nanguba	Sigalame Nanderema
		Bwiri	Busembe Namuduru
	Butula	Kingandole	Namwitsula Kingandole
		Marachi Central	Esikoma Bukhalarire
	Teso South	Amukura Central	Kaliwa Apatit
		Ang'orom	Alupe Amerikwai
	Matayos	Matayos south	Busende Nango'ma
VIHIGA	Sabatia	N. Maragoli	Mudete Kigama
		Chavakali	Igunga Walodeya Evojo
	Hamisi	Shiru	Jeptulu Imusunji
		Banja	Givoji Jemange Kapsotik
		Shamakhokho	Serem Jivovoli
KAKAMEGA	Lurhambi	Butsotso Central	Shiyunzi Shibuli
		Butsotso East	Murumba Indagalasia
	Malava	Kabras North	Matete Masakha
		Kabras South	Mukhonje Shamberere
		Kabras Central	Butali

			Tande
	Ikolomani	Idakho East	Lirhembe Ivonda
		Idakho West	Shimanyiro Shikulu
	Khwisero	Kisa	Emasatsi Mwikalika

Appendix VI: Demographic data of Four counties surveyed in Western Kenya

Age of respondent					
Constituency	**18-30**	**31-40**	**41-50**	**>51**	**Total**
Butula	9 (16%)	12 (22%)	11 (20%)	23 (42%)	**55 (6%)**
Funyula	20 (35%)	11 (19%)	11 (19%)	15 (26%)	**57 (6%)**
Hamisi	44 (40%)	27 (24%)	16 (14%)	24 (22%)	**111 (12%)**
Ikolomani	27 (35%)	27 (35%)	11 (14%)	13 (17%)	**78 (9%)**
Kabuchai	20 (40%)	13 (26%)	5 (10%)	12 (24%)	**50 (6%)**
Kanduyi	12 (46%)	5 (19%)	8 (31%)	1 (4%)	**26 (3%)**
Kwisero	14 (45%)	8 (26%)	5 (16%)	4 (13%)	**31 (3%)**
Lurhambi	23 (35%)	23 (35%)	8 (12%)	12 (18%)	**66 (7%)**
Malava	43 (38%)	32 (29%)	19 (17%)	18 (16%)	**112 (12%)**
Matayos	6 (30%)	6 (30%)	5 (25%)	3 (15%)	**20 (2%)**
Sabatia	42 (37%)	37 (33%)	15 13%)	19 (17%)	**113 (13%**
Teso South	23 (40%)	18 (31%)	3 (5%)	14 (24%)	**58 (6%)**
Tongaren	14 (27%)	16 (31%)	10 (19%	12 (23%)	**52 (6%)**
Webuye East	2 (8%)	11 (42%)	5 (19%)	8 (31%)	**26 (3%)**
Webuye West	17 (37%)	14 (30%)	9 (20%)	6 (13%)	**46 (5%)**
Total	**316 (35%)**	**260 (29%)**	**141 (16%)**	**184 (20%)**	**901**

Education Level					
Constituency	**None**	**Primary**	**Secondary**	**Tertiary**	**Total**
Butula	5 (9%)	27 (49%)	14 (25%)	9 (16%)	**55 (6%)**
Funyula	8 (14%)	27 (47%)	14 (25%)	8 (14%)	**57 (6%)**
Hamisi	1 (1%)	31 (28%)	41 (37%)	38 (34%)	**111 (12%)**
Ikolomani	1 (1%)	22 (28%)	30 (38%)	25 (32%)	**78 (9%)**
Kabuchai	2 (4%)	9 (18%)	24 (48%)	15 (30%)	**50 (6%)**
Kanduyi	0 (0%)	10 (38%)	7 (27%)	9 (35%)	**26 (3%)**
Kwisero	0 (0%)	11 (35%)	12 (39%)	8 (26%)	**31 (3%)**
Lurhambi	1 (2%)	23 (35%)	36 (55%)	6 (5%)	**66 (7%)**
Malava	3 (3%)	38 (34%)	41 (37%)	30 (27%)	**112 (12%)**
Matayos	0 (0%)	1 (5%)	10 (50%)	9 (45%)	**20 (2%)**
Sabatia	2 (2%)	36 (32%)	50 (44%)	25 (22%)	**113 (13%**
Teso South	4 (7%)	16 (28%)	28 (28%)	10 (17%)	**58 (6%)**
Tongaren	6 (12%)	12 (23%)	16 (31%)	18 (35%)	**52 (6%)**
Webuye East	0 (0%)	5 (19%)	11 (42%)	10 (38%)	**26 (3%)**
Webuye West	4 (9%)	16 (35%)	20 (43%)	6 (13%)	**46 (5%)**
Total	**37 (4%)**	**284 (32%)**	**354 (39%)**	**226 (25%)**	**901**

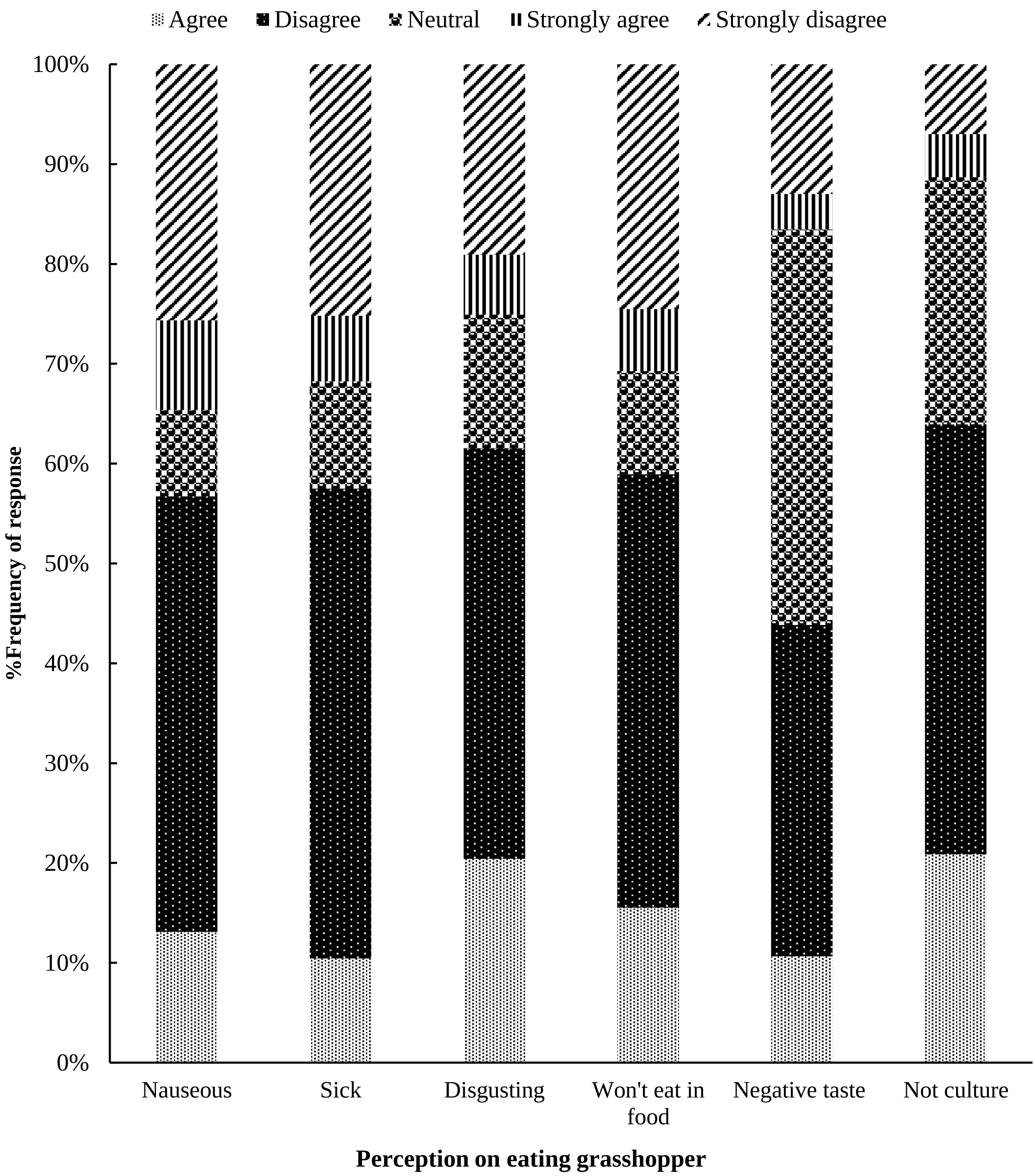
Gender			
Constituency	Female	Male	**Total**
Butula	31 (56%)	24 (44%)	**55 (6%)**
Funyula	28 (49%)	29 (51%)	**57 (6%)**
Hamisi	44 (40%)	67 (60%)	**111 (12%)**
Ikolomani	35 (45%)	43 (55%)	**78 (9%)**
Kabuchai	32 (64%)	18 (36%)	**50 (6%)**
Kanduyi	15 (58%)	11 (42%)	**26 (3%)**
Kwisero	10 (32%)	21 (68%)	**31 (3%)**
Lurhambi	30 (45%)	36 (55%)	**66 (7%)**
Malava	51 (46%)	61 (54%)	**112 (12%)**
Matayos	8 (40%)	12 (60%)	**20 (2%)**
Sabatia	58 (51%)	55 (49%)	**113 (13%**
Teso South	33 (57%)	25 (43%)	**58 (6%)**
Tongaren	18 (35%)	34 (65%)	**52 (6%)**

Marital Status					
Constituency	**Divorced**	**Married**	**Single**	**Widowed**	**Total**
Butula	1 (2%)	42 (76%)	7 (13%)	5 (9%)	**55 (6%)**
Funyula	2 (4%)	40 (70%)	11 (19%)	4 (7%)	**57 (6%)**
Hamisi	0 (0%)	75 (68%)	36 (32%)	0 (0%)	**111 (12%)**
Ikolomani	3 (4%)	55 (71%)	20 (26%)	0 (0%)	**78 (9%)**
Kabuchai	0 (0%)	31 (62%)	12 (24%)	7 (14%)	**50 (6%)**
Kanduyi	1 (4%)	17 (65%)	7 (27%)	1 (4%)	**26 (3%)**
Kwisero	1 (3%)	19 (61%)	11 (35%)	0 (0%)	**31 (3%)**
Lurhambi	0 (0%)	50 (76%)	16 (24%)	0 (0%)	**66 (7%)**
Malava	1 (1%)	85 (76%)	26 (23%)	0 (0%)	**112 (12%)**
Matayos	0 (0%)	16 (80%)	3 (15%)	1 (5%)	**20 (2%)**
Sabatia	1 (1%)	77 (68%)	34 (30%)	1 (1%)	**113 (13%**
Teso South	0 (0%)	37 (64%)	17 (29%)	4 (7%)	**58 (6%)**
Tongaren	0 (0%)	38 (73%)	12 (23%)	2 (4%)	**52 (6%)**

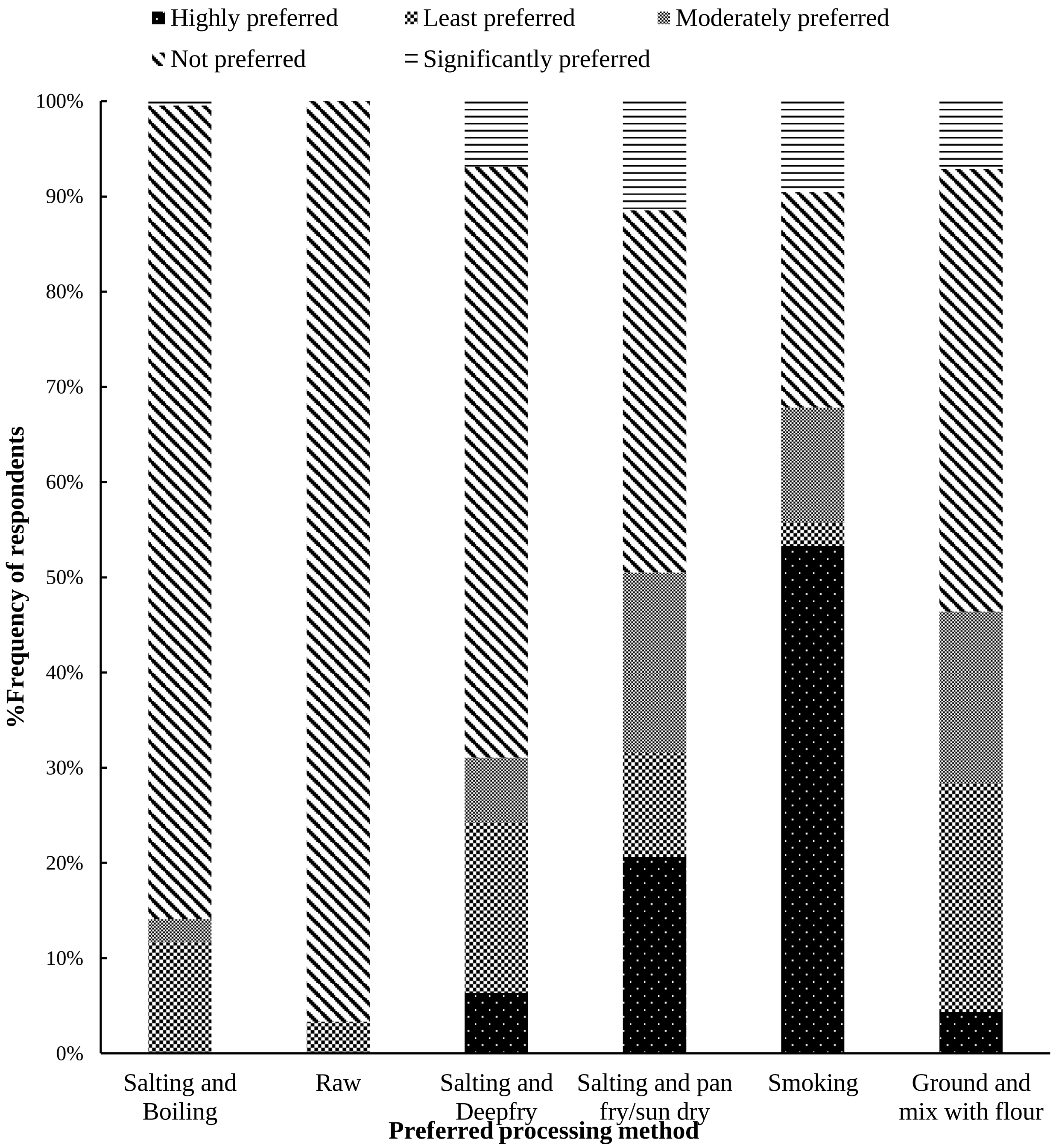
Webuye East	11 (42%)	15 (58%)	**26 (3%)**
Webuye West	31 (67%)	15 (33%)	**46 (5%)**
Total	**435 (48%)**	**466 (52%)**	**901**

Webuye East	0 (0%)	24 (92%)	2 (8%)	0 (0%)	**26 (3%)**
Webuye West	1 (2%)	37 (80%)	6 (13%)	2 4%)	**46 (5%)**
Total	**11 (1%)**	**643 (71%)**	**220 (24%)**	**27 (3%)**	**901**

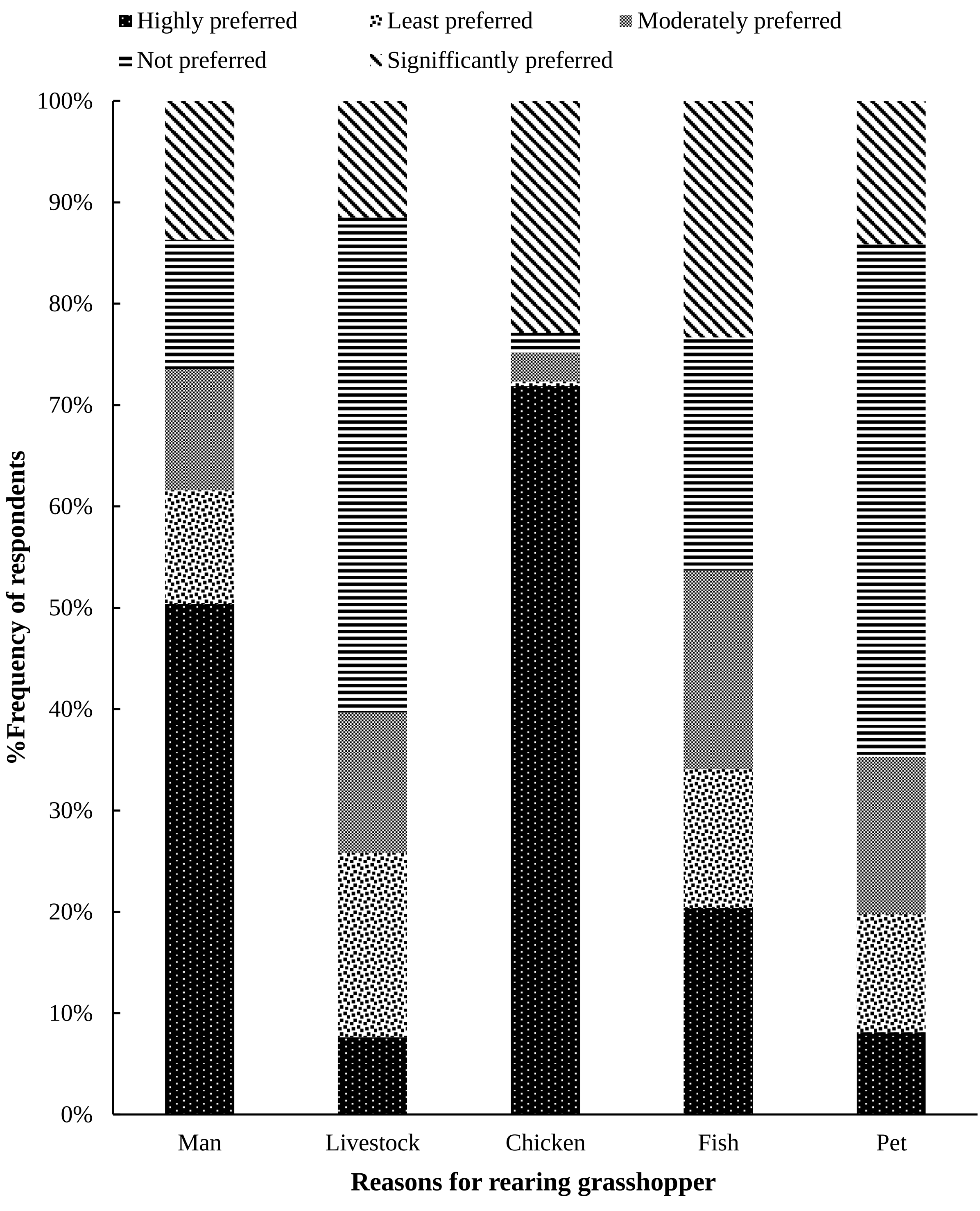
Appendix VII: The perception towards edible grasshoppers/locust consumption by respondents from Western Kenya



Appendix VIII: The preferred methods of grasshoppers/locust preparation for consumption



Appendix IX: Preferred reasons for rearing grasshoppers/locusts



Appendix X: Chi-square analysis of demographics data and their influence on entomophagy in Western Kenya

(a) Influence of age of respondents to having eaten grasshoppers/locusts before

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	76.911[a]	3	.000
Likelihood Ratio	79.333	3	.000
Linear-by-Linear Association	74.248	1	.000
N of Valid Cases	901		

a. 0 cells (0.0%) have an expected count of less than 5. The minimum expected count is 68.86.

(b) Influence of age versus perception (the idea of eating grasshoppers/locusts makes me nauseous)

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	60.851[a]	12	.000
Likelihood Ratio	66.421	12	.000
Linear-by-Linear Association	48.141	1	.000
N of Valid Cases	901		

a. 4 cells (20.0%) have an expected count of less than 5. The minimum expected count is .16.

© Influence of age versus perception (I believe eating grasshoppers/ locusts is not part of our culture)

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	50.961[a]	9	.000
Likelihood Ratio	53.443	9	.000
Linear-by-Linear Association	43.002	1	.000
N of Valid Cases	901		

a. 0 cells (0.0%) have an expected count of less than 5. The minimum expected count is 6.10.

(d) Influence of Gender of respondents to having eaten grasshoppers /locusts before

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	15.423[a]	3	.001
Likelihood Ratio	15.851	3	.001
Linear-by-Linear Association	12.770	1	.000
N of Valid Cases	901		

a. 4 cells (50.0%) have an expected count of less than 5. The minimum expected count is .49.

(e) Influence of gender on willingness to rear grasshoppers/locusts as an alternative protein

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	27.887[a]	6	.000
Likelihood Ratio	29.201	6	.000
Linear-by-Linear Association	26.522	1	.000
N of Valid Cases	901		

a. 6 cells (50.0%) have an expected count of less than 5. The minimum expected count is .21.

(f) Influence of gender on willingness to buy grasshoppers/locusts

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	29.951[a]	6	.000
Likelihood Ratio	30.934	6	.000
Linear-by-Linear Association	23.094	1	.000
N of Valid Cases	886		

a. 6 cells (50.0%) have an expected count of less than 5. The minimum expected count is .19.

(g) Influence of occupation on willingness to rear grasshoppers/locusts

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	46.468[a]	28	.016
Likelihood Ratio	52.263	28	.004
Linear-by-Linear Association	1.562	1	.211
N of Valid Cases	901		

a. 20 cells (44.4%) have an expected count of less than 5. The minimum expected count is .84.

Appendix XI: Correlation between desert locust nutrient composition and the plant diet fed to desert locusts

Nutrients and mineral	Green gram	Sorghum	Wheatgrass
% Moisture	-0.8122	0.9608	0.9177
% Ash	0.9177	-0.9608	-1.0000*
% Fat	-0.7271	0.3360	-0.4590
Protein	-0.3041	0.9983*	0.4911
% Crude Fibre	0.7639	-0.3518	0.9955
% P	1.0000*	1.0000*	1.0000*
Ca (Mg/100g)	0.9967	-0.9826	0.0857
Zn (Mg/100g)	0.9945	-0.9687	-0.9690
Mg (Mg/100g)	0.4009	0.3252	-1.0000*
Fe (Mg/100g)	0.9859	0.5542	0.8131
Mn (Mg/100g)	-0.6178	0.8596	-0.8680
Cu (Mg/100g)	0.3892	0.9899	0.4449
% K	-0.6256	0.7046	-1.0000*
% Na	0.9508	-0.5960	0.1555

Appendix XII: **The Life cycle of desert locusts**

Desert locusts *Schistocerca gregaria* (Forsk, 1775) are members of the grasshopper family Acrididae which includes most of the short-horned grasshoppers (Kietzka *et al.,* 2021). Locusts differ from grasshoppers because they can change their physiology and behaviour in response to changes in density. Locusts in general have two different phases, that is, the solitarious and the gregarious phase. In the solitarious phase, locusts are inactive and avoid each other and this phase happens when locusts are at low densities while the gregarious phase is when the locusts cluster into dense groups and the locusts are very mobile (Shrestha *et al.,* 2021). Depending on the ecological conditions and weather, a desert locust can live for about 3 to 5 months.

Just like all other arthropods, the life cycle of desert locusts consists of three stages, that is, an egg, a nymph with several instars, and an adult.

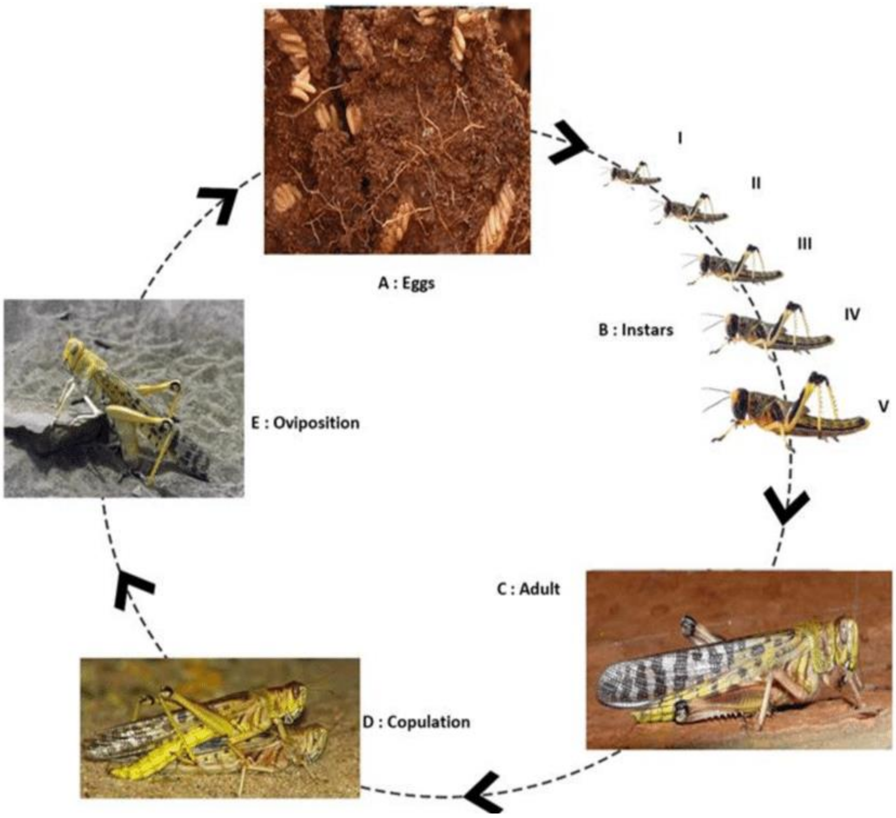


Figure: Life cycle of desert locusts (Shrestha *et al.*, 2021)

The female locust lays eggs in areas of bare moist sandy soil about 5-10 cm below the soil. For the female to lay her eggs, she drills a hole into the ground using the ovipositor at the tip of the abdomen (Plate 2.1a). Yellow eggs are laid in batches called pods which resemble rice grains (Plate 2.1b) and these eggs are bound together by a frothy secretion substance (Symmons & Cressman, 2001). Later on, the colour of the eggs changes to brown while in the soil (Shrestha *et al.,* 2021). In its lifetime, one female may lay one to four egg pods and the number in every pod may vary from twenty to a hundred (Shrestha *et al.,* 2021). The moist soil allows locust eggs to absorb sufficient moisture to complete their development (FAO, 2021). The *S. gregaria* eggs may therefore take up to two weeks or much longer before hatching and this depends on the temperature (Showler & Allan, 2013).

Plate. Female desert locusts lay eggs in the moist sand desert locusts eggs in pods (author, 2021)

The eggs hatch into nymphs (hoppers) who work their way up through the froth plug of the egg batch to the surface. They immediately moult into the first instar (Symmons & Cressman, 2001). During moulting from one instar to another, the nymphs shed off their exoskeleton known as exuviae (Plate 2.2) five or six times depending on the environmental conditions. The process of moulting involves the hard cuticle splitting from its body thus allowing the body to expand, while the new exoskeleton is still soft (Scowler, 2013).

Plate. Exuviae of desert locusts (Source; author, 2021)

At the final molt from the last instar a young winged adult known as the fledgling emerges (Symmons & Cressman, 2001). The young adult is first soft and pink (Figure 2.2) with drooping wings but after a few days, the cuticle hardens and hemolymph is pumped into the wings, which harden them. The fledgling (young adult) develops into a mature adult in 3 to 8 weeks when the conditions for development are optimum and there is a good supply of food (Shrestha *et al.,* 2021), however, the locust may take as long as six months to mature if the conditions are not conducive (Scowler, 2013). Adults living in habitats that have fresh green vegetation with maximum temperatures of about 35^{o}C can lay their eggs within three weeks of fledging (FAO, 2021). *Schistocerca gregaria* males mature first and release a pheromone that stimulates females' maturation on maturing, the insects then turn yellow and the female abdomen starts swelling with developing eggs (Scowler, 2013). Females take about ten days to develop eggs under optimum conditions when they are ready to be laid. Where temperatures are below 15 ^{o}C, eggs in females will unlikely occur and they are likely to remain immature for long. (Symmons & Cressman, 2001; FAO, 2021).

Figure. The fledgling (young adult of a desert locust)

Appendix XIII: Similarity Report

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