ECOLOGY AND NUTRITIVE VALUE OF THREE ABUNDANT TERMITE SPECIES IN WESTERN KENYA FOR ENTOMOPHAGY (Isoptera: Termitidea)

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A Thesis Submitted in Partial Fulfilment of the Requirements for the Award of the Degree of Doctor of Philosophy in Applied Entomology of Masinde Muliro University of Science and Technology

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DECLARATION

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The undersigned certify that they have read and hereby recommend for acceptance of Masinde Muliro University of Science and Technology a Thesis entitled **"Ecology and nutritive value of three abundant termite species in Western Kenya for entomophagy (Isoptera: Termitidea)''**

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DEDICATION

This Thesis is dedicated to my wife Florence for the encouragement and all the support she has given me all through the process.

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ABSTRACT

Winged social insects known as termites have existed on the planet for more than 100 million years. Food insecurity is a serious endemic issue in Kenya. In Western part of the Kenya, termite alates have a long history of use as food but little has been done to improve mass production. The main goal of this research was to establish if *Pseudocanthotermes grandiceps* , *Macrotermes jeanelli* and *Allodontermes tenax* are capable of being produced in large quantities as a solution to both food security and climate change by:1) Determining factors affecting swarming behavior of *P. grandiceps* , *M. jeanelli* and *A. tenax.*2) Compare the amino acid profiles of *P.grandiceps, M. jeanelli and A. tenax,* 3) Determine survival rates during laboratory study of *P.grandiceps, M. jeanelli and A. tenax* and 4) Determine food preference during laboratory study of *P.grandiceps, M. jeanelli and A. tenax.* Since biotic and abiotic factors affect termite alate swarming behaviour, these factors are critical in making swarming inducement decisions. Termites of all the three species have been observed swarming during the rainy season, but traditionally, *A.tenax* has been induced to swarm during the dry season. The three species investigated would aid nutritionists in deciding which termite species are most appropriate for human consumption. In order to determine the best substrate for mass production, it was necessary to evaluate different food substrates. Finally, when it comes to setting up procedures for mass production, swarming quantity is critical. The decision on the right species for mass production depend on the quantities collected during the normal swarming periods as it is uneconomical to raise the termites artificially then eventually collect so little alates after swarming. All abiotic factors affecting the swarming behaviour of the termite alates were recorded daily and at the time of swarming. Amino acid proximate composition was performed using the protocols described in AOAC (2000). Several food substrates were evaluated in a dark room at a steady temperature of 24±2 ºC and humidity of 80±5%. The samples were removed from the rearing chamber after 2, 4, and 6 weeks, and the remaining termites was counted. The number of surviving termite workers found from each treatment was used to calculate the survival rate. For swarming quantities three active termite mounds were identified for each species and then they were monitored for a period of one year for emergence of termite alates around Kitale area and west Pokot -Nasukuta livestock farm. The termite alates were collected using traditional methods. The quantity of alates from each mound was weighed in kilograms and recorded for each species. The mean weight of the three samples for every species was then determined. ANOVA was used to analyse the data, and the significance level was set at 0.05. Means±SE were separated by Fishers least significance difference (LSD) test. The statistical analysis software SAS 9.1 Copyright (c) 2002-2003 by SAS Institute Inc., Cary, North Carolina, USA, was used to do all calculations. Tables, bar graphs, and pie charts were used to illustrate the results after analysis. Results show that the best termite species for mass production is *A. tenax* since it can be induced to swarm during the dry season and its worker caste showed a higher survival rate during laboratory study. The three termite species were found to have the required essential and nonessential amino acids enough to supply all human age groups except in infants who have a higher protein requirement. The most preferred food item that increased survival rates of the three species was wheat straw. While the least preferred was pine wood in all the three species. Food preference and survival rates were highly dependent on the locality in which the termite species was found in abundance. Hence there is need for further studies to rear the species and hence increase chances for inducement. Secondly more studies are required to determine consumer acceptance especially in communities who do not consume termites as food and finally more studies are required to package them as value chain to the food items locally available in the areas where the termite species are found in abundance

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LIST OF ABBREVIATIONS AND ACRONYMS

ASAL	Arid and Semi-Arid areas
RH	Relative Humidity
LT50	Median Lethal time (time until death) after exposure of an organism to a toxic substance or stressful condition.
FST	Formosan Subterranean Termite
EPA	Eicosapentaenoic acid
DHA	Docosahexanoic acid
KHDS	Kenosha Human Development Services
GDP	Gross Domestic Product
KNBS	Kenya National Bureau of Statistics
AOAC	Association of Official Analytical Chemistry

CHAPTER ONE: INTRODUCTION

1.1 Background to the study

Termites are winged social insects that belong to the order Isoptera that have long history of consumption in western Kenya (Bagine *et al.,* 2014). They are a high-protein food and therefore play a crucial part in the diet. Termites have 560 calories per 100 grams, while rump steak has 322 calories and codfish has 74. The fat content of termites is among the highest (Itakura, 2006). They are distributed in different ecological zones in Kenya and they are varied in species (Wanyonyi *et al.,* 1984). Food insecurity has been a serious problem in Kenya for a long time, owing to recurrent problems with unreliable weather, as well as unpredictable and irregular rainfall that is caused by too much dynamism in the environment and inadequate agriculture strategies (Were *et al.,* 2008).

Termites first appeared on Earth more than 100 million years ago, during the Mesozoic or late Paleozoic eras. (Nyukuri *et al*., 2014; Wilson & Nowak, 2014). Termites can be classified based on a variety of characteristics, including external and internal morphology, food and nest type, chemical variations, and behavioral variations (Korb & Thorne, 2017). Yoro *et al* (2014) Mastotermitidae, Kolotermitidae, Termopsidae, Hodotermitidae, Rhinotermitidae, Serritermitidae, and Temitidae are the seven families into which identified termite species were split. Termitidae, the largest family, contains about 2600 species, 14 subfamilies, and 280 genera. (Pranesh & Harini, 2015). These seven families can be split into lower and higher termites based on how they digest their food. The first six groups make up lower termites, which rely on protozoan symbionts for digesting. Winged individuals (alates) have wings that are identical in size and form. Termites live in colonies that range in size from tens of thousands to millions of individuals. Termitidae are a medium-sized insect family of over 2600 species that are commonly recognized as an integral component of tropical and subtropical ecosystems (Pranesh & Harini, 2015).

The varied fauna and abundant termite population that characterize the tropical environment are renowned for their importance to the ecosystem. The seventh family, Termitidae, contains 74% of all termite species and more than 80% of all termite genera. (Yoro *et al*., 2014). Because of their advanced social activity, the Termitidae family is sometimes referred to as "higher termites" (Havlíčková, *et al*., 2019). The primary traits of this family are the absence of symbiotic intestinal protozoa, huge colonies (100,000 to millions), and the presence of a worker caste.

Due to its location in the tropics and climate with a wide dispersion of termite species, Kenya, like most tropical environments, has one of the most complex biotas in the world. (Maslin *et al*., 2014). A limited number of non-reproductive castes may provide a wealth of knowledge about termite colonies' breeding mechanism through genetic analysis (Korb *et al*., 2021). Allozyme analysis can rapidly classify monogamous breeding systems because they generate consistent Mendelian genotypic frequencies. This method also allows for the investigation of colony genetic stability over time, It is especially helpful for species whose delicate or diffuse nesting habits make direct monitoring problematic (e.g., Kalotermitidae, Mastotermitidae, Rhinotermitidae).. Despite the potential role of relatedness in fostering the preservation of isopteran eusociality (Scharf, 2015; Korb *et al*., 2021), previous research on the genetic structure of termite colonies has been minimal (Hyseni & Garrick, 2019) However, genetic studies have revealed important information about levels of relatedness within colonies (Korb *et al*., 2021) and have shown regional variation in some species' mating systems (Hartke, & Baer, 2011). Additional study into the genetic structure of isopteran colonies, similar to that done on hymenopteran eusociality (Yan *et al*., 2014), appears to likely help in the understanding of eusocial breeding system diversity (Elgar, 2014).

Nasutitermes is a highly derived genus of over 180 species (Boulogne, 2017) and is widely distributed, occurring in six of the eight main biogeographical regions (de Faria Santos, 2017). Since the beginning of time, people have consumed termite alates in many regions of the world.. Its delicacy is well-known in Kenya, and it has a high protein content (Katayama, *et al* 2009; Kagezi, 2010; Costa-Neto & Dunkel, 2016), as well as an unquestionable abundance (Katayama, *et al* 2009; Kagezi, 2010; Costa-Neto & Dunkel, 2016).

Food insecurity is still an issue in Kenya, and the government is attempting to address it. Kenya's population is expanding at a pace of 6% per year. More than 70% of Kenya's population historically depends significantly on agriculture for their livelihood. In the 1970s, favorable weather patterns and consistent agricultural growth of more than 10% per year led to an unparalleled increase in Kenya's GDP of more than 7% per year, ensuring that the nation's historic economic boom was sustained and eliminating difficulties with food security. The nation still largely relies on agriculture to drive the majority of its economic development, provide food, jobs, and the majority of the population's fundamental requirements despite the myriad issues that have plagued the sector (Boccara, 2020; Makila, 2018).

However, due to persistent issues with uncertain weather, as well as inconsistent and irregular rainfall, which can be linked to excessive dynamism in climatic circumstances and inadequate agricultural strategies, food insecurity has been a significant issue in Kenya for a long time. (Were *et al.,* 2008). Fertilizer prices have risen to an unaffordable level for small-scale farmers as trade liberalization and structural adjustment programs (SAPS) have been implemented (Boccara, 2020). Rather than relying solely on agriculture to engineer economic development, other food sources must be considered. Several food sources have been analyzed in an attempt to fill the country's food deficit. Animal and beef products and by-products have been used in all of these protein food sources. They include plant-based sources of protein like peas, beans, French beans, and soybeans as well as animal protein sources including chicken, beef, duck, turkey, and pig meals. Although they have long been sources of protein, they are become more and more expensive and out of reach for the majority of people. Additionally, having a large herd of cattle can result in frequent confrontations. Livestock is also vulnerable to diseases, drought, and a shortage of grass. To avoid the looming problem of food insecurity, new ways of improving protein sources are needed. However, in order for these diets to meet these requirements, they must satisfy the dietary requirements and be easily embraced by the target population. (Gatlin *et al*., 2007). As a result, there is a need to make such food available to meet the general public's demand and to produce it in large quantities for packaging.

1.2 Statement of the problem

Kenya relies heavily on agriculture to meet its food needs. Unexpected and unpredictable weather changes in recent years have caused diminishing yields and poor harvests. Therefore, there is a serious risk of ongoing and occasionally severe food shortages, which could have a negative impact on people's nutrition and general health. A variety of food sources, including termites, are needed in Kenya to lessen the country's ongoing food shortages. They are a cheaper source of proteins as compared to fish chicken and beef. Termites in western Kenya have a long history of being consumed during both the wet and dry seasons. They are a high-protein food and therefore play an important role in the diet. Termites have 560 calories per 100 grams, while rump steak has 322 calories and codfish has 74. The fat content of termites is among the highest (Itakura, 2006).

Human activity, on the other hand, has had a significant impact on termite's natural habitat, influencing the distribution of mounds as well as the swarming patterns and quantities of *Pseudocanthotermes grandiceps, Macrotermes jeanelli*, and *Allodontermes tenax* throughout the year. And some species may become extinct as a result of this trend. The three termite species that are most abundant in the research area should therefore be fully exploited for mass production and as indicators of climate change.

1.3 Justification

Since abiotic factors influence the swarming behavior of termite alates they are of great importance in making decisions for artificial inducement because *A. tenax* has been traditionally induced to swarm during the dry season (Bagine, 2014). The swarming quantity is of great importance when mounting protocols for mass production. The decision on the right species for mass production will depend on the quantities collected during the normal swarming periods. It is uneconomical to raise the termites artificially then eventually collect so little alates after swarming. Termite habitats need to be protected to avoid extinction of some species due to human activity.

The new study's findings will promote the use of termite alates in Kenya and lessen the nation's ongoing food shortages. The three species to be studied will help the nutritionists in determining the most suitable termite species to be used as human food.

1.4 Objectives

1.4.1 General objective

The main objective of this study is to establish whether the three termite species are appropriate for mass production as a response to food insecurity.

1.4.2 Specific objectives

1. To determine the actual values of humidity, temperature and rainfall that cause swarming of *P.grandiceps*, *M. jeanelli* and *A. tenax.*
2. To determine the amino acid content of *P.grandiceps, M. jeanelli and A. tenax.*
3. To determine survival rates of *P.grandiceps, M. jeanelli and A. tenax.* under laboratory study
4. To determine food preference under laboratory study of *P.grandiceps, M. jeanelli and A. tenax.*

1.5. Hypothesis

$H_0$1 the swarming behavior of termites is not influenced by abiotic factors

$H_0$2 the amino acid profile of termites does not render them as food for humans.

$H_0$3 the type of substrate has no effect on the survival of a termite colony under laboratory conditions

$H_0$4 There is no food preference of a termite colony under laboratory conditions

1.6 Scope of the study

The study was limited in scope geographically to Bungoma County and West Pokot County where the termite alates are consumed as food. In its content, the study was limited to the amino acid profiles and abiotic factors affecting the swarming behavior of termites. It was further limited to survival rates and food preference of workers on various food materials in the laboratory. This was done within a limited time scope of 3 years of study. The results are however, expected to be applicable where similar species of termites are found.

1.7 Limitation of the study

The study was only carried out for a period of two years.. However the information obtained from this study was applicable to areas where these species are available.

CHAPTER TWO: LITERATURE REVIEW

2.1 Swarming behavior

Termite soldiers are essential for a caste's survival (Johnston *et al*., 2018). According to Chouvenc (2019), during colony establishment in the laboratory, the number of soldiers found is influenced by group size, the season, and the initial soldier ratios. Workers were established in bigger groups of 1500 to 2500, while soldiers were made in smaller groups of 500 to 1000. The total number of termites that survived was found to be strongly correlated with the number of soldiers created in a group. Furthermore, overcrowding groups of soldiers had no negative effects on group survival (Chouvenc, 2015; Ishikawa, 2016; Johnston *et al*., 2018). Environmental factors were found to have a significant impact on alates development (Chouvenc, 2019; Rau & Korb, 2021). Temperature has been found to have a major effect on alate emergence and swarming induction in *A.tenax.* The best day for swarming was found to be one that was calm and sunny (Bagine, 2014). *Coptotermes, Reticulitermes,* and *Macrotermes natalensis* swarming was caused by temperature ranging from 27 to 28 degrees Celsius. The actual temperature, humidity, and rainfall that triggers swarming in *P.grandiceps, M. jeanelli,* and *A. tenax* has not been completely exploited, which is crucial when designing protocols for mass production and swarming inducement. Most flights are said to be restricted to an ambient temperature of 27–28°C, a pressure of 1,009–1,010 hPa, and a RH of 83–84%. The amount of trapped alates were found to be strongly correlated to atmospheric pressure and temperature (Ewart, 2016). On flight days, rain was not needed to cause alates dispersal of *Coptotermes gestroi* (Wasmann) (Connétable, 2012). The artificial induction of termite alates of A. tenax has also been discovered to be significantly influenced by environmental conditions. Bagine and Makila (2014) stipulate that the weather must have been dry for at least three months, the day must be sunny, and the nighttime must be peaceful. Termites depend heavily on temperature and humidity to survive (Woon *et al*., 2019).

Termite dispersal flights are the culmination of a number of complex and well-coordinated behavioral responses by various castes to a variety of cues (Nunes *et al*., 2017). Each year, *Macrotermes natalensis* (Haviland) developed only one brood of alates (puche &su, 2001). These alates flew away from their parent nests in dispersal flights in Kitale from late September to early December, with an October peak. Rainfall served as the main stimulatory element that induced flight, with the initial flight beginning at a 5 mm threshold. Later in the season, larger flights became more frequent and required more precipitation. Temperature, light intensity, and wind all played a role in the start and length of individual flights. The temperature threshold for swarming flights was 17–19 °C (Woon *et al*., 2019). The flight was canceled if the temperature fell below this level. Between 39% and 90% relative humidity was used for flight, and the species did not fly when it rained. Windless conditions favored flight, ensuring that alates were not dispersed widely enough to jeopardize the chances of finding a mate and that the female sex pheromone was not dispersed widely enough to jeopardize the chances of finding a mate. Males were unsuccessful in seeking partners. Flight times varied during the flight season due to light intensity, and alates left the nest at dusk in low light intensities varying from 1 to 30 lux. A waxing moon coincided with the bulk of swarming flights (Mitchell, 2008).

Three species of the soldierless, underground Anoplotermes built specialized launching towers to discharge the alates and shield them from predators. Both Armitermes euamignathus and Cornitermes cumulans constructed launching platforms on their nests for alates, but in their defense they exhibited the typical termitid behavior known as the "blanket defense" (Traniello, 2000). In most species most swarming occurs between April and June in most parts of the world (Martius, 2001). Human activity has had a significant impact on termite natural habitat, impacting the distribution of mounds, swarming patterns, and swarming quantities of *Pseudocanthotermes grandiceps, Macrotermes jeanelli*, and *Allodontermes tenax* throughout the year but some species may become extinct as a result of this trend. Furthermore alate production was observed to be highly affected by environmental factors (Martius, 2001b; Alan, 2007; michelle2008;). There has been a season change in their swarming patterns Okwakol (2000) over the years and their quantities vary based on distribution of mounds, rainfall Patterns, temperature regimes and human activity. These aspects have not been fully exploited and documented.

2.2 Protein Content and Amino Acid Composition

Several experiments evaluate nutrient content in several species of termites (Itakura, *et al.,* 2006; Katayama, 2009; Kagezi, 2010). Among the species that have been evaluated include *Reticulitermes flavipes, Syntermes* soldiers, *Macrotermes nigeriensis, Coptotermes formosanus* Shiraki and *Reticulitermes speratus (*Kolbe*). Pseudacanthotermes militaris, Macrotermes bellicosus, Macrotermes subhylanus, and Pseudacanthotermes spiniger.*

The termite head had the largest protein content, accounting for nearly 64% of the total dry weight in sexuals, and had a higher quantity of amino acids than workers. It's interesting to note that tryptophan, which is typically scarce in food insects (Costa-Neto & Dunkel (2016), was present, in adequate amount, in the head portion (Costa-Neto & Dunkel, 2016) *Macrotermes nigeriensis* had a high fat content that was primarily made up of unsaturated fatty acids. (Igwe *et al*, 2011). Consistently high levels of fat (50–67%) were found in *M. subhylanus, P. militaris, M. bellicosus*, and *P. grandiceps,* indicating potential nutritional and public health relevance.. (Kinyuru, 2013). Due to their high protein content, termites are an essential part of the diet. A rump steak has 322 calories per 100 grams. Termites have 560 calories per 100gm, compared to 74 calories per 100 grams for codfish. Termites have some of the highest fat content of any insect (Itakura, 2006).

2.3 Substrate Selection for Laboratory Studies

The social structure of termites, which live in colonies, includes a queen, major soldiers, minor soldiers, workers, and alates. Termites cause harm to people by remaining in one location for at least thirty years. According to accounts from around the world, termites damage wood, wooden structures including houses and telephone poles, railroad ties, bridges, and even crops(Connetable *et al*, 2012; Patel *et al*., 2020). On the other hand termite alates have been used as human food for decades in western Kenya (Ayieko, 2010; Kagezi, 2010). Therefore, it is necessary to establish a rearing method for termites which have not been artificially reared according to Becker (2012; Patel *et al*., 2020), so as to enhance mass production as a response to food security and climate change.

Connetable (2012) established a rearing procedure which involves the use of a culturing container like a box under predetermined conditions in the laboratory by using old tree, distilled water, rearing box with temperature and humidity maintained at 20^0- 25 ^{0}C and of 70% to 90% respectively. This method is useful in collecting the necessary data (Kyusik lee, 2004; Katayama, 2009). *Macrotermes michaelseni* and *odontotermes montanus* were able to build faecal combs in laboratory studies, *M. michaelseni* produced more fungus combs than *O. montanus* (Anwar & Nandika, 2020).

A sample that was fully devoid of alates suggested that it was not a mature colony, but a mature colony may go through periods without alates (Elgar, 2014).

2.4 Food preference for laboratory study

Pine wood is thought to be the best material for laboratory experiments with *P. millitaris* (Smythe & Carter, 1970; Perkins, 2012). Several food substrates including a standard mixture of sand and water in a ratio of (5:1 v/v), sand, vermiculate, pine wood, sand and vermiculate (1: 1) at various moisture contents were evaluated on *R. virginicus (Banks), Coptotermes formosanus shiraki, and Reticulitermes flavipes (koller)*. Sand was the best because termites were easily separated from sand than from vermiculate (Gallardo, 2016). *Reticulitermes flavipes* (koller) had a higher prefence for pine wood as food as compared to the other substrates(Gallardo, 2016). *Heterotermes aureus* (Snyder) foraging behavior was also studied using tissue paper rolls (Haverty, 2000). Because of its greater water holding capacity, the vermiculate and sand and vermiculate combination proved to be the best for long-term tests (12 weeks or more) (Kard, 2003).

The development of reproductive individuals of *Cortaritermes fulviceps* (Silvestri, 1901) began in October (spring) and peaked between December and February (summer). Colony establishment was claustral and accomplished by pleometrosis, with varying degrees of success depending on soil type (Swaby, 2013). In mixed soil (80%) and humus soil (75%), more colonies were established. 45% of the colonies were only established in clay soil. And a similar percentage was also observed on a fungus comb (Swaby, 2013). 30 and 45 days following the testing, the first royal chambers and nymphs, respectively, were seen Pre-soldiers and employees were discovered 75 days after the testing began, whilst soldiers were detected 120 days later. Colony foundation success was just 52.9% in test plates with humus, and nymphs and workers weren't discovered until 150 days later. (Menzel & Diehl, 2010).

2.5 Colony establishment

Colony formation occurs either through the emission of swarms of sexuals or through budding, as in *Reticulitermes lucifugus*, (Neoh & Lee, 2009b). Swarms are most common on hot, still dry days, the sexuals are weak fliers and 500 meters was a good flight distance (Neoh & Lee, 2009b). As the sexuals spread, the swarm break up. As soon as they land, the sexuals lose their wings. When searching for a male, the females either run around aimlessly until they find one , stand still, produce a pheromone to attract them (Kings), or both (Jordan, 2013). The female responds to the male's advances by hitting him with her head. This is followed by mutual caressing of the antennae. The male then makes further advances, which are then followed by additional mutual caressing of the antennae. This cycle repeats itself four or five times before the female decides whether or not to embrace the male. If she does, she "tandem runs," leaving him right behind her as she flees. After mating on a suitable piece of wood, the King and Queen take turns digging a tunnel that ends in a nuptial chamber, sealing themselves within, and starting to construct the nest (Eggleton, *et al*., 2002). The Queen initially lays five to six eggs, which she and the King tend to. Initially fed by the Queen's regurgitation after hatching, these larvae soon start nibbling on wood and expanding the nest. As soldiers mature over a year, the new nest will still only have 10 workers and one soldier after two years. After several more years, the nest begins to discharge sexuals (Eggleton, *et al*., 2002).

2.6 Geographical distribution

As one moves closer to the equator there is increase in termite species and density (Muvengwi & Witkowski, 2020). Temperature and rainfall have been linked to termite distribution (Dambros *et al*., 2017). Their distribution is located in the north and south, respectively, between latitudes 45^0 and 50^0. Except in semi-permanently waterlogged areas and some deep cracking vertisols, termites have been present in all forms of soils (Dambros *et al*., 2017). With the exception of Australia, where the number of termite species north and south of the tropic of Capricorn is roughly equal, termite diversity rises closer to the equator and at lower altitudes (Ashton, 2017). The Macrotermitinae family includes many essential pest genera that are mostly found in the Middle East and Asia (Ahmad, 2020). Central America and Australia are devoid of them (Ashton, 2017).

2.7 Economic significance

Termites are typically consumed by people all around the world and have a lot of protein and calories (Pearce, 1997). Many people eat the mushrooms that grow out of termite mounds, which are high in protein and other vital nutrients (Chang & Miles, 2008). Termites change the soil profile and re-distribute organic matter (Lee & Wood, 1971). Due to the scarcity of earthworms in Africa, termites play a critical role in recycling and regenerating soil matter (Pearce, 1997). According to Lee et al. (2003), who investigated the connections between termite activity and soil properties in Kenya, termites eradicate 30–70% of the litter on farms. However, as termites consume the majority of the discarded litter to make fungal combs, the return of nutrients to the soil is impeded. The amount of nutrients given to the soil in the form of saliva and feces during the construction of mounds and sheetings and finally enriching the topsoil is small in comparison to the nutrients consumed by crops(Keller, 2010). Keller (2010), the soil's aeration and rootability are improved by termite tunneling, and the formation of a soil matrix made up of pellets tends to dictate the soil's moisture properties and aggregated composition. Termites can contribute to the cleanup of landfills and other places where a lot of trash has been dumped.

Termites use cellulose, a plant fiber, in all of its forms. It is challenging to digest cellulose because it is a rich source of energy (as seen by the quantity of energy released while burning wood). Termites rely on symbiotic protozoa (metamonads), such as Trichonympha, Mixotricha, and other microorganisms, to eat cellulose and its byproducts in their intestine. To make some of the necessary digestive enzymes, Trichonympha and mixotricha, intestinal protozoa that create cellulases and glycolytic enzymes, depend on symbiotic bacteria that fix nitrogen, such Citrobacter and Enterobacter. This partnership is one of the best illustrations of animal mutualism.

Most "higher termites," particularly those belonging to the Family Termitidea, are capable of producing their own cellulase enzymes (Krishna, 2010). They do, however, rely mostly on bacteria and have a diversified gut flora. It is believed that the gut flora of termites is related to that of the ancestors of wood-eating cockroaches, such as those in the genus Cryptocercus (Abdul Rahman, 2016).

Some termite species engage in fungiculture. They maintain a 'garden' of specially adapted Termitomyces fungi, which are nourished by the insects' waste. After the fungi are eaten, their spores proceed intact into the termites' intestines and finish the cycle by sprouting in brand-new faecal pellets. (Pervez, 2018; Ahmad *et al*., 2018).

The termites are tiny and do not create large mounds at heights of about 1800 meters. They are harvested in various ways. About a meter from where the termites are anticipated to emerge, a hole of about 22 centimeters in diameter and 22 centimeters in depth is drilled. Smooth, precisely overlapping leaves line the inside. Twigs are used to support a piece of hide that is hung from the termite escape hole to the dug pit in order to block the sunlight. Initially unable to fly, the emerging sexuals creep toward the light at the end of the hide-covered tunnel and fall into the pit, from which the smooth leaf lining prevents them from escaping. They are collected in bags and transported elsewhere (Kinyuru, 2013).

Ominde's (1988), Kenyan, Tanzanian, and Ugandan cuisines are all included in the African Cookery Book's real African recipes. It contains recipes for insects served as delicacies such fried grasshoppers and locusts and termite alates.

2.8 Component of food in the diet

In human beings, nothing is more important than balanced nutrition and adequate food. If the food is not consumed or if man is unable to utilize the food because of some nutrient deficiency, then there will be no growth. An undernourished person cannot maintain his /her health and be productive, regardless of the quality of the environment (Tejpal, 2020).

Research, quality assurance, and biological assessment are required for the creation of meals for humans that are nutritionally balanced. Poor diet undoubtedly reduces human productivity and worsens health until recognizable disorders appear (Ingenbleek & Kimura 2013). It is exceedingly challenging to draw a line between overt disease and deteriorated health on the one hand, and stunted growth and poor health on the other. There is little doubt that as our knowledge grows, the causes of deviations from the norm become easier to understand and address. However, one of the most important aspects of dietary competence will always be the ability to spot performance declines early on and take appropriate action.

2.8.1 Protein requirements

Because protein consumption typically dictates growth (protein growth has, in general, priority), has a high cost per unit, and requires high levels per unit of foods, protein is the most crucial element of the diet of humans (Wolfe *et al*., 2018). Dietary protein is necessary to provide essential amino acids and nitrogen for the synthesis of non-essential amino acids. About 23 amino acids make up protein in bodily tissues; 10 of them must be obtained from diet because man cannot synthesis them (Dideriksen *et al*., 2013). In order to maintain, grow, reproduce, and replenish tissues, amino acids are required. The majority of the amino acids that humans consume are converted into energy, and they are well-adapted to doing so when there is an excess of protein available. Ammonia is released when proteins are broken down (Nowak, 2006).

Studies on the natural population provided the first insights into the needs of humans for protein and amino acids. The typical natural diet is high in protein and has a healthy balance of amino acids, and it includes meat, fish, and some insects. (Nowak, 2006). The nutritional value of dietary proteins varies widely. A protein source's digestibility and amino acid composition determine its nutritional value. Lack of essential amino acids results in inadequate protein use, which affects development, live weight gain, and feeding efficiency(Almokbel, 2016).

In extreme circumstances, insufficiency diminishes the body's capacity to fight off illnesses and the efficiency of the immune system. For instance, research has revealed that methionine shortage causes lens cataracts while tryptophan insufficiency causes scoliosis in humans(Almokbel, 2016). The average fish typically has 40–50% crude protein and 35–45% digestible protein (DP). However, it is necessary to supply protein or amino acids in accordance to digestible energy (DE). Ammonia excretion is enhanced by increasing these ratios, and as the energy is utilised less effectively, dissolved oxygen requirements are also raised (Almokbel, 2016).

The fundamental explanation of the greater protein requirements is that while the absolute requirement for protein (g/kg body weight growth) is lower, the protein requirement in terms of dietary concentration (% of diet) is higher. Man has a lower absolute energy need than other mammals, which accounts for this. This leads to greater food efficiency (gain: food) and equivalent body weight gain/g protein intake as in mammals. Second, protein (amino acids) is a significant source of energy. If other dietary fuels are present in sufficient quantities, some savings may be possible in this area. For instance, increasing the lipid (fat) composition of the diet might assist lower the catabolism and requirement for dietary protein (amino acids). The term "protein-sparing effect of lipids" refers to this (Gatlin *et al*., 2007). The ratio of protein to usable energy should be taken into account, not the percentage of protein in the diet as a whole.

2.8.2. Lipids (Fats)

A wide range of different chemicals are included in lipids (fats). Lipids provide a variety of functions, including providing structure and acting as precursors to numerous reactive chemicals. Triglycerides, phospholipids, and occasionally wax esters are the most frequent lipids in the diet (Patrick, 2008). Three fatty acids are joined to a glycerol molecule to form a triglyceride. Only two fatty acids make up the glycerol molecule that also makes up phospholipids. A phosphoric acid and another sort of molecule (choline, inositol, etc.) are joined in place of a third fatty acid (Calder, 2012). Wax esters are a typical type of lipid storage and are formed of a fatty acid and a long chain alcohol. Triglycerides' primary function is to store lipids (fatty acids). The lipid bilayer that makes up cell membranes is made up of phospholipids. The primary functional elements of dietary lipids are fatty acids. Unsaturated fatty acids in the n-3 and n-6 positions cannot be produced by man, despite the fact that they are necessary for a variety of processes (Calder, 2012). Therefore, these two types of fatty acids must be provided in the diet as they are necessary for man.

A general consequence of an essential fatty acid deficit is a reduction in growth and a variety of deficiency symptoms, such as depigmentation, fin erosion, cardiac myopathy, fatty liver infiltration, and "shock syndrome" (a brief loss of consciousness after an extreme stress). Long chain polyunsaturated n-3 fatty acids (EPA (20:5 n-3) and DHA (22:6 n-3)) are needed in the diet of men in amounts ranging from 0.5 to 1%. Ingredients with marine origins, such as fish meal and fish oil, which are consistently present in substantial proportions in fish diets and termite food, can readily cover this amount(Igwe, 2011).

2.8.3 Carbohydrates

A very wide range of compounds are represented by carbohydrates. Starch, a glucose polymer, is the carbohydrate most frequently present in foods consumed by humans (Magallanes-Cruz et.al., 2017). Although there are ways to improve quality, man has a poor ability to use carbs. The raw forms of starch found in grains and other plant products are often poorly absorbed. However, the starch's digestibility is significantly enhanced by cooking it during pelleting or extrusion. Even though starch is a digestible substance, man only seems to be able to use a tiny amount of it efficiently. The majority of man's energy comes from sources other than carbohydrates (FAO, 2002). However, to produce the right physical characteristics of the food, a particular proportion of starch or other carbohydrates (for example, lactose, hemicellulose) is needed. In terms of energy generation, termites and tilapia fish are fairly comparable (Nyukuri, *et al*. 2014).

2.9 Food insecurity

According to FAO (1996), When everyone, at all times, has physical and financial access to enough safe and nourishing food to suit their dietary needs and food preferences for an active, healthy life, then there is food security. Programs to promote food security often focus on one or a combination of these three factors:

Food availability: When all citizens of a nation can consistently get enough food each year, whether it is produced domestically, imported commercially, or provided through food aid (FAO, 1996).

Food access: When everyone in a household has enough money to buy culturally appropriate food for a healthy diet; this depends on how much money is available to and allocated among family members as well as the cost of food in the area. (FAO, 1996).

Food utilization: When food is prepared and consumed to maximize its nutritional worth for the entire family, which depends on a household's understanding and actions about food storage and processing, fundamental nutrition concepts, and appropriate child care (FAO, 1996).

According to Tayler (Mohamed, 2017), There are three different types of food insecurity: cyclical or seasonal (occurring at certain times of the year), transitory or temporary (caused by shocks and natural catastrophes), and chronic (occurring on a regular and recurrent basis). In Kenya, poverty, poor agricultural production, conflict, HIV/AIDS, and sporadic natural catastrophes are the main causes of food insecurity (droughts ,floods)

(Nyaberi & Wandiga ,2001) Poor food usage, especially in relation to nutrition, is also a problem for food security. With the exception of natural disasters, all of these causes are persistent problems. Development solutions, not temporary food aid, are needed to solve the problems of chronic food insecurity. While food aid may be necessary to prevent famine, it primarily addresses the symptoms rather than the root reasons of food security.

According to rough calculations, basic food output per person is about 856 kg per person per year greater than the about 776 kg per person per year needed to make up the basic crop element of the food basket used to determine the food poverty level (FAO, 2001). The production of personal goods and livestock has increased over the past ten years, indicating that they are also sufficient to fill the remaining gap in the food basket (FAO, 2002). Generally speaking, Kenya produces enough food to meet its population's minimally calculated food and energy needs, though this cannot be said for all regions (Garnett, 2013). The central region produces the fewest basic food crops per capita yet, according to most reports, is the best fed. For the urban and international markets, the central region concentrates on cash crops and is expanding into high-value specialty crops. These enable the region's rural inhabitants to earn salaries that are 24% higher than the national average for rural populations and to have some degree of food security.

The majority of Kenya's poor people live in rural areas (Andersson & Gabrielsson, 2012). Only 10% of the urban population is considered to be poor, whereas 39% of the rural population is considered to be poor (KHDS, 2005). However, the percentage of rural residents living in poverty has decreased from 60% in 1992–1993 to 39% in 1999–2000. Poverty rates have decreased for cash crop farmers considerably more quickly than for non-crop (livestock) and food crop producers. Analysis by Waiyaki (2016), shows that economic expansion - more income - rather than the redistribution of existing income is to blame for the whole decrease in poverty in recent years. But maintaining the current goal of 7% annual GDP growth was challenging.

CHAPTER THREE: MATERIALS AND METHODS

3.1 Study area

3.1.1 Background and location

Trans Nzoia and West Pokot Counties were covered by this study, in Western Kenya (Figure 3.1). A county in Kenya's old Rift Valley Province, Trans-Nzoia County is situated 380 kilometers northwest of Nairobi between the Nzoia River and Mount Elgon. The county major town, Kitale, is located in the town's center. Nearly 4 million people have settled in the area due to employment opportunities, while others are there as a result of immigration. It has a diverse economy focused primarily on agriculture. The area is located at an elevation of 1,900 meters above sea level, latitude 1°1'8.72"N, longitude 35°0'8.3"E, while West Pokot county is located at an elevation of 1906 meters above sea level, respectively, latitude 1013'59.99"N and longitude 35°07'0.12"E. It is a County with a protracted dry season and little rainfall. Livestock production, particularly the raising of goats and sheep, is the principal economic activity Figure 3.1.3.1.2. Climate

Altitude and physical characteristics like escarpments and volcanic peaks, primarily from the Cherangani Hills and Mount Elgon, have a significant impact on the climate in the study area. The weather is often mild and warm. In Kitale, the rainfall is bimodal and averages 1097 mm, with precipitation occurring even in the driest month. The Köppen-Geiger classification of the climate is Cfb. 18.3 °C is the average annual temperature. The region's significant temperature variability, which ranges from 10.5 oC minimum to 25.5 oC maximum throughout the year, favors the development of agricultural crops there (KNBS, 2010).

3.1.3 Population and land tenure

There are slightly more than 1300000 people living in the Trans Nzoia and West Pokot Counties, with a population of roughly 310 people per square kilometer (KNBS, 2010). Approximately 822,850 households are located in the study region, according to the 2010 Census. Individuals and cooperatives both own land, as evidenced by the numerous forest farms that are dispersed throughout the region.

Figure 3.1: Location of the study region is indicated on a map of Kenya (Adapted and modified from Microsoft Encarta 2008)

3.1.4. Economic activities

The main human economic activity within the study area is agriculture through crop farming and livestock husbandry such as rearing of cattle, sheep, goats and pigs. The main farming activities within the entire district include cultivation of cereals such as maize.

Non-cereal crops cultivated include potatoes and a variety of crops in small plots. Horticulture, agro-forestry, forestry are also practiced.

3.2 General procedure

The termite mounds were selected randomly in the study region

Plate 3.1Termite mound for:*A. tenax*

1°1'8.72"N, longitude 35°0'8.3"E

Plate 3.2 *: Macrotermes jeannelli*

$1^0$13'59.99"N and 35°07'0.12"E

A quantitative experimental design was used to correlate the swarming behaviour, amino acid differences, and food preference and survival rates of the three termite species.

3.2.1 Abiotic factors affecting swarming behavior of termites

Abiotic factors affecting the swarming behaviour of the termite alates which include temperature, humidity and rainfall were recorded daily and at the time of swarming. This was done in the morning at 9.00am and evening at 4.00pm due to the varied times the three species swarm. The factors was evaluated independently for each of the three species. For swarming quantities three active termite mounds were identified for each species and then monitored for a period of one year for emergence of termite alates around Kitale and West Pokot -Nasukuta livestock farm. The sites were chosen basing on past history of swarming from the locals and stakeholders. The termite alates was collected using traditional methods (Bagine *et al*., 2014). The field experiment for *P. grandiceps* was located at Sikhendu, Trans- Nzoia County. The termite mound were identified only after the first swarming since this species is subterranean and has no epigeal mound. Therefore selection of the termite mound was random and situated on a community farm. The field operation for this species required at least two people to monitor and erect a traditional trap (Makila *et al*., 2018). This was done by first identifying the nests of this species randomly in the field. Termites' nests with more than five epigeal mounds were deemed mature and were selected for artificial inducement. Collected alates were weighed using an electronic scale. For purposes of obtaining swarming quantity, *A. tenax* the alates were collected using traditional methods during the dry season by artificial inducement (Bagine *et al*., 2014). During the study, six termite mounds of this species were prevented from direct rainfall by constructing a polythene structure around them while others were left open to directly receive rain. This was done to establish if rainfall has any effect on swarming of this species. This was done in advance before the onset of rainy season. Mature and active termite nests were determined by counting the number of epigeal mounds and observing fresh construction. Nests with more than five epigeal mounds of this species with fresh construction were deemed mature and active respectively. Samples of *M.jeanneli* were collected by digging a trench and placing a collecting container inside the trench and covering the top of the trench so that all emerging alates are directed into the trench (Bagine *et al*., 2014; Makila *et al*., 2018). The amount of alates from each mound was weighed in kilograms and recorded for each species. The mean weight of the three samples for every species was then determined. Information on swarming quantities was also obtained from respondents who harvest and sell the termite alates of the three species.

3.2.2 Amino acid analysis

During prolonged rains, when they were anticipated to be available, termite alates were collected from the Kitale and West Pokot Nasukuta region. 50% of the colonies were resampled whenever they were available after having been identified and mapped. The selection of the sampling locations was informed by prior experience and by interviews with many stakeholders who are knowledgeable about locating places where termite alate predominates. The termite alates were collected by Utilizing traps set on the termite mound. By using destructive sampling, termite workers were collected by opening the termite mounds. The samples were put in collecting jars and transported to the laboratory for analysis and assays. A few of the alates, along with several small and big soldiers and workers, were preserved (in 70–80% ethanol) and transferred to the National Museums of Kenya for identification. Approximately 2000 live individuals from each colony were collected. Small, large, or soldiers and workers were all treated equally in collections.

Termite alates were collected, and their proximate amino acid content was determined using the procedures described in AOAC (2000). After hydrolyzing the sample for 24 hours with 6 M HCl at 110 C, the amino acid contents of the termite alates were assessed using an automated amino acid analyser. Before acid hydrolysis, performic acid was used to oxidize an amino acid that included sulfur. A portion of the evaporated hydrolysate was diluted with sodium citrate buffer and its PH was raised to 2.20 using sodium hydroxide. The aliquot was diluted with water before being utilized with neutralized hydrolysates. then put into an auto sampler tube, through a filter device, and then injected into an analyzer. Norleucine-containing solution from the amino acid standard kit was used to calibrate the amino acid analyser. To guarantee baseline separation of the peak, the analyzer conditions were changed. Minimum resolution between two peaks was 90%. Response factor RF_{aa} for each amino acid was calculated as follows:

$$RF_{aa} = \frac{P_n \times W_{aa}}{P_{aa} \times W_n}$$

Where P_{aa}= peak area of amino acid; P_n= peak area of norleucine W_{aa}= weight of amino acid, mg; W_n =weight of norleucine, mg.

Internal standard factor was calculated as follows:

$IS = W_n \times 2 \times 10^{-2}$ Where mg, norleucine = norleucine content in 20ml norleucine standard

Amino acid content of the test sample was calculated as follows:

$$AA, \% = \frac{P_{aa} \times RF_{aa} \times IS \times 100}{P_n \times W_s}$$

Where P_{aa}=peak area of amino acid, P_n=peak area of norleucine; W_s =weight of test portion, mg; RF_{aa}=amino acid response factor; IS = internal standard factor. The termite subsamples were subjected to all analyses in triplicate.

3.2.3 Survival rates during laboratory Studies

Research has been done to determine whether substrate is appropriate for use in lab tests for additional Reticulitermes species (*R. flavipes Kollar and R. virginicus* Banks) by Haverty (1979). However, studies examining survival rates for *P. grandiceps, M. jeanelli,* and *A. tenax* are lacking.. The experiments involved testing survival rates on : 1) maize cob husks on loam soil, 2) maize stalk on loam soil, 3) *Eucalyptus* wood on loam soil, 4) wheat straw on loam soil, 5) pine wood on loam soil and lastly 6) loam soil alone as a substrate. The loam soil was put in an incinerator for 24hours to remove any organic matter present in the soil. Termites were collected in May 2017 from termite mounds in Kitale and West Pokot-Nasukuta, Kenya. The samples were then brought in open collection jars to the lab. The termites were physically removed after they arrived. Since earlier studies have indicated that workers below the third stage had a low survival rate under the identical laboratory settings, the insects used in these trials were at least third-stage workers (Haverty, 1979,).

To ascertain survival rates, two experiments were conducted (Haverty, 1979). 15 rearing pots with dimensions of 18x15x7 cm were utilized for each experiment. These containers matched an experimental design with three treatments (each lasting two, four, or six weeks) and five replicates.

The water/substrate ratios employed in these studies were 1 volume of water to 4 volumes of each substrate due to how crucial humidity is to these insects' survival (Nobre *et al*., 2007; Munizaga, 2007; Munizaga *et al*., 2008; Arinana *et al*., 2012; EN 118, 2013). Pine wood is thought to be the best material for laboratory experiments with *P. millitaris.* (Smythe & Carter, 1970; Perkins, 2012).

Each container included 150 termite workers and alates, which were randomly chosen and kept in a rearing chamber in complete darkness at a constant temperature of 24 oC and at a humidity level of 85% relative humidity. The samples were taken out of the rearing chamber after 2, 4, and 6 weeks, and the number of surviving termites was counted. The survival rate was calculated as a percentage of workers who were still alive after receiving each treatment. For the substrates under test (T1, T2, and T3), the durations were 2, 4, and 6 weeks, respectively.

3.2.4 Food preference during laboratory Studies

The experiments involved testing food preference using : 1) maize cob husks on loam soil, 2) maize stalk on loam soil, 3) *Eucalyptus* wood on loam soil, 4) wheat straw on loam soil, 5) pine wood on loam soil and lastly 6) loam soil alone as a food substrate. The loam soil was put in an incinerator for 24hours to remove any organic matter present in the soil. Termites used on this study were collected in July 2017 from termite mounds in Kitale and West Pokot-Nasukuta, Kenya. The samples were then be transported to the laboratory in open collecting jars. Once there, the termites were manually and carefully extracted. The insects used in these experiments were workers of at least the third stage larvae (Ho & Kirton2007,).

Two experiments were performed to determine survival rates (Haverty, 1979; Ho & Kirton, 2007). For each experiment, 15 rearing containers measuring 18x15x7 cm were used. These containers corresponded to an experimental design with three treatments (of 2, 4 and 6 weeks duration) with 5 replicates each.

Since humidity is such an important factor in these insects' survival, the water/substrate proportions used in these experiments were 1 volume of water to 4 volumes of each substrate (Nobre *et al*., 2007; Munizaga, 2007; Munizaga *et al*., 2008; Arinana *et al*., 2012; EN 118, 2013).

A total of 150 termite workers and alates randomly selected were introduced into each container, which were kept in a rearing chamber in permanent darkness at a constant temperature of 24±2 ºC and at 80±5% relative humidity. After 2, 4 and 6 weeks, the samples were removed from the rearing chamber and the surviving termites were counted. The rearing chamber with the most surviving workers was deemed the most preferred food substrate for the particular species. The survival rate was estimated as percentage of surviving workers found for each treatment of the substrates tested.

3.3 Collection of white ant samples

During extended rainy periods, when they were anticipated to be available, termite alates were gathered from numerous locations in Western Kenya, including Kitale, Sikhendu, and Nasukuta livestock farm. Colonies were identified and mapped, and 50% of the colonies underwent a second sampling whenever termite alates were present. The selection of the sampling locations was informed by prior experience and by interviews with numerous regional stakeholders who are knowledgeable about locating places where termite alate predominates. Utilizing traps set on the termite mound to catch the alates, the termite alates were collected. By using destructive sampling, termite workers were gathered. The termite mound was cracked open to collect termites. Plastic bags containing the collected samples were used to transport them to the lab for analysis and experimental tests. The National Museums of Kenya preserved some of the alates together with a number of minor or large soldiers and workers for morphological identification.

From each colony, about 2000 live individuals were gathered. There was no distinction made in collections between little and large laborers or warriors. Since we had already conducted interviews with the locals regarding termite usage and trapping in our earlier work, none were conducted this time (Bagine, *et al.,* 2014).

3.4 Data analysis

The data was analyzed as follows: variables on swarming behavior and differences in amino acid profiles for the three different termite species was done using Chi-square test. While the relationship between times versus the various substrates and survival rates was done using ANOVA. Mean separation was done using Fishers LSD test. The analysis program SAS 9.1 Copyright (c) 2002-2003 by SAS Institute Inc., Cary, North Carolina, USA was used to conduct all statistical analyses. After analysis, data was presented using tables and bar graphs.

CHAPTER FOUR: RESULTS

4.1 Introduction

The study's findings are presented in this chapter in relation to its goals and working hypothesis. There are sections within the chapter. Information about abiotic factors influencing the three termites' swarming behavior is provided in Section 4.2. Section 4.3 provides analyzed information on amino acid profiles of the three termite species while section 4.4 provides information on survival rates of the three termite species. 4.5 provides information on food preference of the three termite species.

4.2 Abiotic factors affecting swarming behavior of termites

Temperature, humidity and rainfall were evaluated simultaneously to determine at what temperature, humidity and rainfall each of the three related termites emerged. This was done with an aim of possibly using the values to induce swarming in future. The three species showed variations in their requirements for swarming. Time of swarming varied from one species to another. *Pseudocanthotermes grandiceps* emerged from termite mounds between 1.00 pm to 3.00 pm while *Macrotermes jeanneli* emerged between 9.00 am to11.00 am. *Allodontermes tenax* showed a variation from the two species since it emerged at any time with or without rain when induced.

Emergence of *M. jeanneli* was between April and May just at the onset of long rain season while *P. grandiceps* emerged between august and October at the onset of short rains.

The three termite species were observed to swarm at varied temperatures and humidity. Each species had different swarming times like *P. grandiceps* were observed to emerge at 25 ^{0}C and relative humidity of 56%, *M.jeanneli* emerged at 22.8 ^{0}C and humidity of 67% and *A.tenax* emerged at 20^{0}C and humidity of 80%. All the three species emerged during the rainy season. Only *A.tenax* had a possibility of being induced to swarm during the dry season.

Table 4.1 Temperatures in 2018.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Minimum Temp.	11.2	12.0	13.6	14.6	14.0	13.0	12.4	12.8	11.4	12.8	11.8	12.2
Mean Temp.	19.8	21.4	19.8	19.6	19.7	18.9	18.4	19.2	19.0	19.7	19.6	19.7
Maximum Temp.	28.4	30.8	25.9	24.7	25.5	24.7	24.4	25.6	26.6	26.6	27.3	27.1

Mean temperatures ranged between 18.4 – 21.4^{0}C throughout the year. This temperatures favoured the emergence of the three termites. Their emergence temperatures ranged between 20^{0}C to 25^{0}C. From Table 4.1 and Figure 4.1 the maximum temperatures ranged from 24.4-30.8^{0}C.

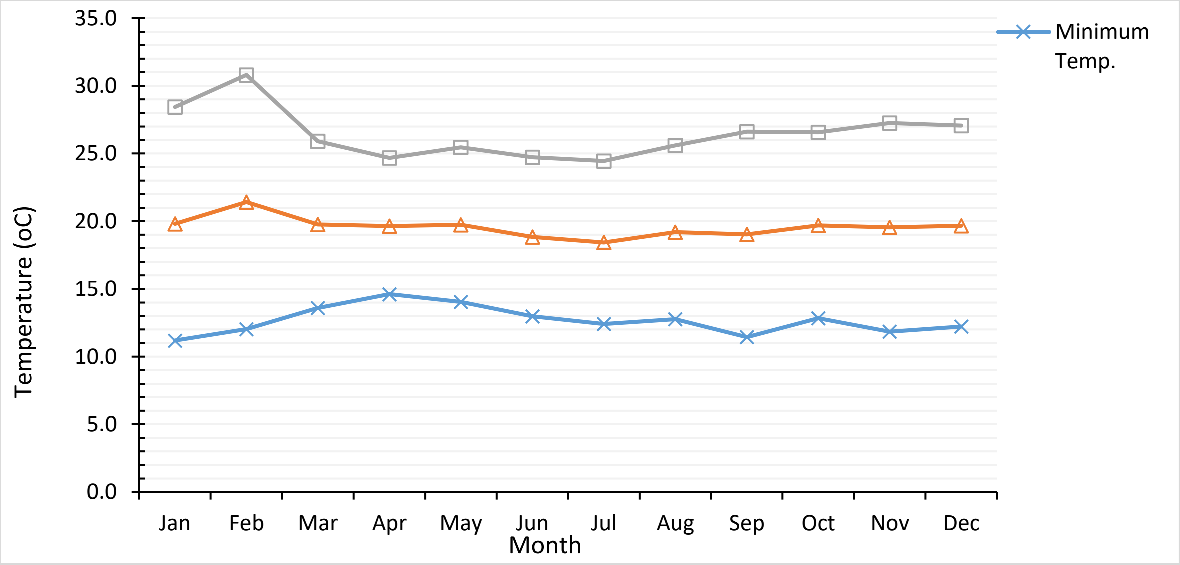

Figure 4.1 Temperatures (^{0}C) in 2018.

Table 4.2 Rainfall (mm) from January to December in 2018

Month	Jan	Feb	March	April	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Rainfall	1.2	0.3	0.9	11.1	5.8	1.2	4.2	4.5	3.1	6.2	3.0	8.3

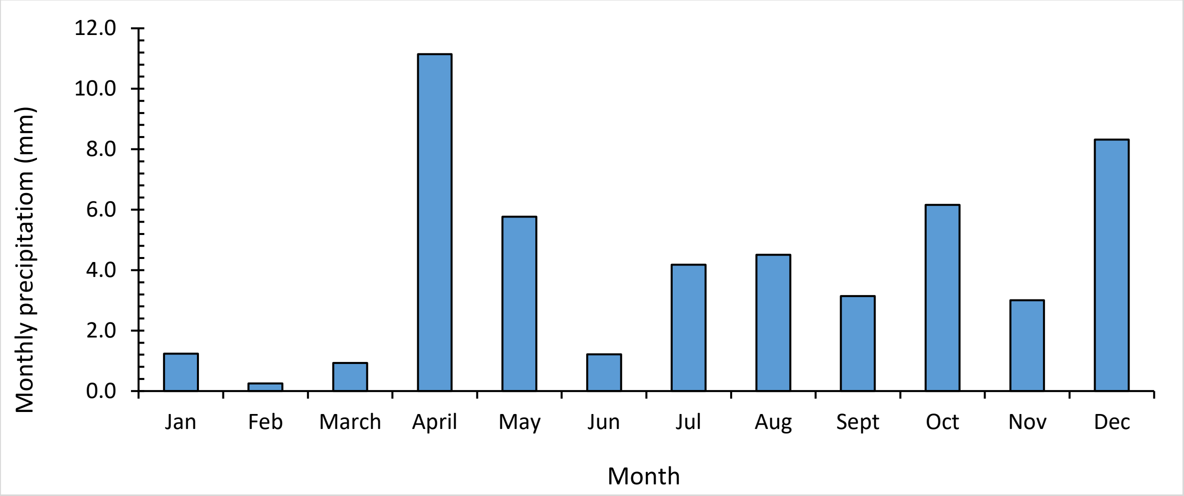

Figure 4.2 Rainfall (mm) from January to December in 2018

Table 4.2 and Figure 4.2 show rainfall in mm from January to December 2018. January and March experienced little rainfall as compared to the other months of the year. The highest amount of rainfall was experienced in April (11.1mm). Two species of termites' *M.jeanneli* and *P. grandiceps* only swarmed during the rainy season in April and May and August to October respectively. This shows that they depended on rainfall for them to swarm.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec

RH (9.00am)	73.2	63.3	86.2	90.6	91.5	92.8	91.5	88.4	80.3	74.7	71.0	75.1
RH (3.00pm)	31.5	27.1	53.5	70.3	64.7	61.5	61.3	59.2	54.2	56.9	48.9	47.9

Table 4.3 Relative Humidity (%) from January to December in 2018

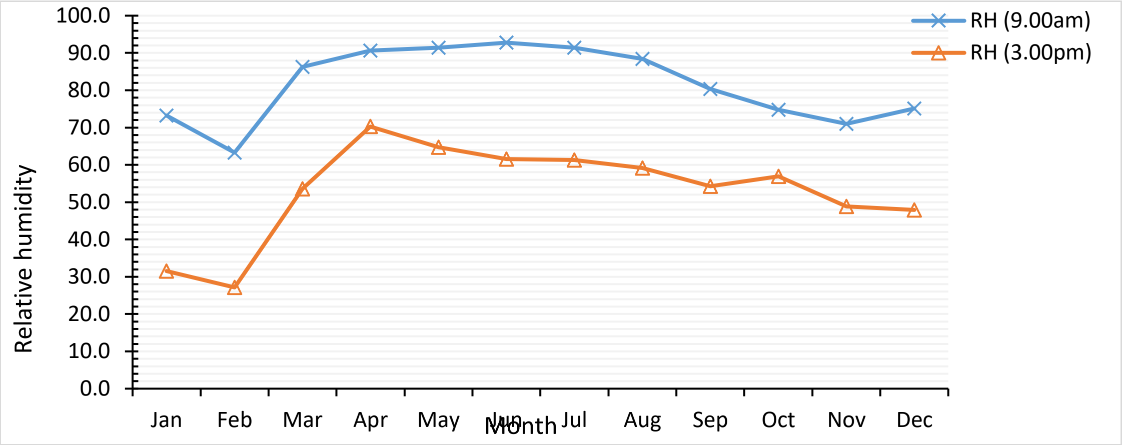

Figure 4.3 Relative Humidity (%) from January to December in 2018

Table 4.3 and Figure 4.3 show relative humidity for January - December 2018 at 9.00AM and 3.00PM. The lowest Relative Humidity recorded at 9.00AM ranged between 63.3% - 92.8% while at 3.00pm, it ranged between 27.1% -70.3%. It was observed that *P. grandiceps* emerged at a relative humidity of 56% in August to October. *M.jeanneli* emerged at 67% in April and May and *A.tenax* emerged at humidity of 80% during the rainy season and also when induced to swarm.

Table 4.4 swarming quantities of three related termites

Species	weight 1 (kg)	weight 2(kg)	χ^2
P. grandiceps	13.2	11.1	3.227766
M.jeanneli	14.2	44.2	3.786857

A. tenax	6.4	3.2	3.745817

Total χ^2 CALC 10.76044 χ^2Tab 5.991
***P* = 0.05**

Amino Acid	*P.grandiceps* (g/100g)	*M.jeanelli* (g/100g)	*A.tenax* (g/100g)	Mean	SD	CV%	χ2
Lysine	6.44	7.8	4.16	6.13	1.84	30	0.607532
Threonine	4.36	3.91	3.2	3.82	0.58	15.3	0.044325
Valine	4.6	3.98	4.09	4.22	0.33	7.8	0.077451
Methionine	0.88	2.48	6.86	3.41	3.09	90.8	7.145698
Isoleucine	4.22	4.96	3.3	4.16	0.83	20	0.133807
Leucine	7.72	7.48	5.51	6.9	1.21	17.6	4.053052
Phenylalanine	4.58	3.36	2.54	3.49	1.02	29.4	0.355341
Tryptophan	2.47	1.7	6.43	3.53	2.54	71.9	4.888299
Histidine	3.09	2.15	2.09	2.44	0.56	23	0.174922
Arginine	6.9	6.6	4.15	5.88	1.51	25.7	0.343642
Aspartic acid	6.71	7.87	4.96	6.51	1.46	22.5	0.287363
Serine	5.39	4.06	4.14	4.53	0.75	16.5	0.183868
Glutamic acid	14.7	15.5	8.43	12.5	3.67	29.4	1.123141
Proline	6.7	4.01	4.05	4.58	0.96	21.1	0.29152
Glycine	6.09	5.76	3.25	5.03	1.55	30.9	0.50788
Alanine	6.86	6.97	5.79	6.21	0.66	10.7	0.111876
Cysteine	0.6	1.89	3.92	2.14	1.67	78.2	3.37496

Tyrosine	4.8	3.33	3.05	3.72	0.94	25.3	0.30558
Total				24.01026		***P* = 0.05**	**$\chi2$=43.773**

There was a significant difference, χ ^{2}CALC (10.76044) > χ ^{2}Tab (5.991), in the quantities collected among the three related termite species. The highest quantity collected was *M. jeaneli* and the least was *A.tenax.*

Table 4.5 amino acid content

4.3 Amino Acid Content

4.3.1 Amino Acid Content

Table 4.5 shows amino acid content of the samples obtained from the three termite species in (g/100g).SD = standard deviation, CV% = coefficient of variation percent, $\chi2$ = Chi-square, $\alpha = 0.05$.

Protein content of the three termite species are as shown in Table 4.5. The protein content obtained from whole termite showed *P. grandiceps* had the highest 94.11g/100g while *A. tenax* had the lowest at 79.92/100g. From the results, protein was the major nutrient component of the three termite species that were analyzed. Glutamic acid was the most abundant in the three species. It ranged between 8.43g/100g to 15.5g/100g of the total amino acids that were analyzed. The lowest concentrated amino acid was cysteine with values ranging between 0.60g/100g and 3.92g/100g. Leucine was found to be most highly concentrated essential amino acid. It was 7.72g/100g crude protein in *P. grandiceps*, 7.48g/100g in *M. jeanelli* and 5.51g/100g in *A. tenax*. Methionine was the lowest essential amino acid in *P. grandiceps* at 0.88g/100g crude protein. Methionine is important in synthesis of choline among other substances. Histidine was the lowest essential amino acid in both *M. jeanelli* and *A. tenax* at 2.15g/100g and 2.09g/100g respectively. Lysine was also relatively high ranging from 4.16g/100g to 7.80g/100g. Tryptophan was found to be available in considerable amounts of 1.70g/100 to 6.43g/100g, an amino acid absent in most of other protein foods (DeFoliart, 1991). A summary of essential amino acids is shown on figure 2. The most abundant essential amino acid in *P. grandiceps* was Leucine at 7.72g/100g, in *M. jeanelli* was lysine at 7.80g/100g and *A. tenax* was methionine at 6.86g/100g. According to FAO(1985), preschool children aged below 5 years require Leu (6.6 g/100g), Ile (2.8 g/100g), Lys (5.8 g/100g), Met + Cys (2.5 g/100g) and His (1.9g/100g). From the results obtained, the three termite species have the potential to provide the required amino acid and even exceed the requirements when compared to FAO,(1985) requirements. There was no significant difference in amino acid content of the three termite samples.

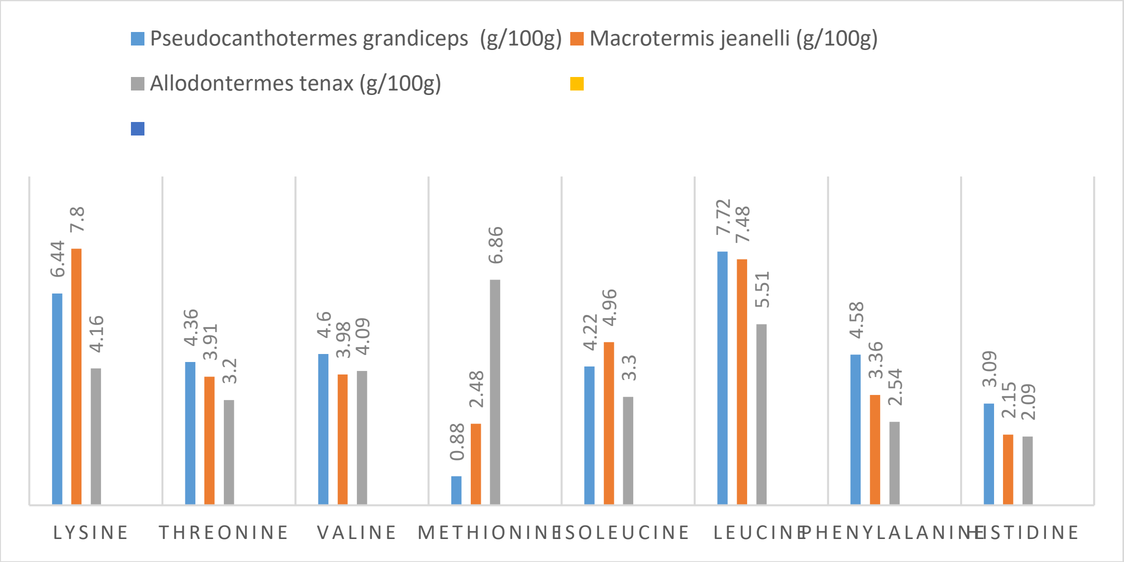

Figure 4.4: Essential amino acids for the three termite species

Leucine was the most highly concentrated essential amino acid at 7.72g/100g crude protein in *P. grandiceps*, 7.48g/100g in *M. jeanelli* and 5.51g/100g in *A. tenax*. Methionine was the lowest essential amino acid in *P. grandiceps* at 0.88g/100g crude protein. Histidine was the lowest essential amino acid in both *M. jeanelli* and *A. tenax* at 2.15g/100g and 2.09g/100g respectively

4.3.2. Amino Acid Classification

Table 4.6. Amino Acid Classification (g/100g Crude Protein) of the Termite species and their Percentages

Amino Acid	*P.grandiceps* (g/100g)	*M. jeanelli* (g/100g)	*A. tenax* (g/100g)	Mean	SD	CV%	χ2
TAA	94.11	93.81	79.92	89.28	8.12	9.1	0.240886
TEAA With His	35.89	36.12	31.75	34.59	2.46	7.1	0.017995
No His %TEAA	32.8	33.97	29.66	32.14	2.23	6.9	0.011351
With His	38.1	38.5	39.7	38.7	0.83	2.6	0.482691
No His	34.9	36.2	37.1	36.1	1.11	3.1	0.49989
TNEAA	31.66	34.4	23.32	29.8	5.77	19.4	1.141375
%TNEAA	33.6	36.7	29.2	33.2	3.77	11.4	0.237791
TAAA	20.41	23.37	13.39	19.1	5.13	26.8	1.758641
%TAAA	21.7	24.9	16.8	21.1	4.08	19.3	0.81495
TBAA	16.43	16.55	10.4	14.46	3.56	24.3	1.044602
%TBAA	17.5	17.6	13	16	2.63	16.4	0.384109
TNAA	57.27	53.89	56.13	55.8	1.72	3.1	0.619503
%TNAA	60.9	57.4	70.2	62.97	6.84	10.9	3.419493
TCEAA	24.09	21.59	18.42	23.4	2.84	12.1	0.370757

%TCEAA	25.6	25.6	23	24.7	1.5	6.1	0.00561
TEAlAA	28.1	27.4	22.74	26.1	2.91	11.2	0.187885
%TEAlAA	29.9	29.2	28.5	29.2	0.7	2.4	0.104163
TSAA	1.48	4.37	10.78	5.54	4.76	85.9	9.489002
%Cys/TSAA	40.5	43.2	36.4	40	3.42	8.6	0.0838
Leu/Ile ratio	1.83	1.51	1.67	1.67	0.16	9.6	0.04701
Lys/Trp	2.6	4.59	0.65	2.61	1.97	75.5	2.594804
Met/Trp	0.36	1.46	1.07	0.96	0.56	58.1	0.635441
TOTAL						***P* = 0.05,**	24.19175 **$\chi 2$= 55.758**

Table 4.6 shows classification of amino acids into Total essential amino acid (TEAA); Total conditionally essential amino acid (TCEA); Total nonessential amino acid (TNEAA); Total amino acid (TAA); Total acidic amino acids (TAAA); Total basic amino acids (TBAA); Total neutral amino acids (TNAA); Total essential aliphatic amino acids (TEAlAA) and (TSAA).

Total essential amino acids (TEAA) with His ranged between 31.75g/100g to 36.12g/100g; without His it ranged between 29.66 g/100g to 33.97 g/100g.WHO requirements for essential amino acids (EAA) with His is as follows: Baby: 46.0 g/100 g; preschooler: 33.9 g/100 g; schoolchild: 24.1 g/100 g; and adult: 12.7 g/100 g. Without His: newborn 43.4 g/100 g; toddler to preschooler 2-5 g/100 g; schoolchild 10–12 g/100 g; and adult 11.1 g/100 g. The three termite species contain the EAA in the required proportions to supply human diet satisfactorily to all age groups except in infants. Percentage TEAA was considerably higher with Histidine 38.1-39.7g/100g; without Histidine 34.9 - 37.1g/100g as compared to percentage TNEAA 29.2 - 36.7g/100g in the three termite species; similarly the TAAA were higher 13.39 - 23.37g/100g as compared to TBAA 10.4-16.55g/100g. TNAA range was 57.4 – 70.2g/100g showing that they formed the bulk of all the amino acids. TCEAA ranged between 18.42 to 24.0g/100g while Cys/TSAA content ranged from 36.4 to 43.2g/100g. Leu/Ile ratios ranged from 1.51 to 1.83 g/100 g, which was less than the 2.36 g/100 g necessary. This study also showed that Lys/Trp ranged between 0.65 to 4.59g/100g while Met/Trp range was 0.36 to 1.46g/100g. The termites' amino acids classes did not differ significantly in all the three termite species.

4.3.3. Amino Acid Groups of the Termite Species

Amino groups are shown in Table 4.3.3. Group I includes aliphatic amino acids (Gly, Ala, Val, Leu, and Ile); Group II includes amino acids with OH groups (Ser and Thr); Group III includes amino acids with sulfur atoms (Cys and Met); Group IV includes amino acids with acidic groups or their amides (Asp and Glu); Group V includes amino acids with basic groups (Lys, His, and Arg); Group VI includes amino acids with aromatic ring

Table 4.7. Amino acid groups of the termite species.

Groups	*P.grandiceps* (g/100g)	*M.jeanelli* (g/100g)	*A. tenax* (g/100g)	Mean	SD	CV%	χ^2
I	28.49	29.15	21.94	26.53	3.99	15	0.208774
II	9.75	7.97	7.34	8.35	1.25	15	0.160994
III	1.48	4.37	10.78	5.54	4.76	85.9	10.48238
IV	20.41	23.37	13.39	19.1	5.13	26.8	1.37478
V	16.43	16.55	10.4	14.46	3.52	24.3	0.708189
VI	14.94	10.54	14.11	13.2	5.64	42.8	1.290547
VII	5.7	4.01	4.05	4.59	0.96	21	0.275194

TOTAL	14.50086	***P* = 0.05, χ2= 21.026**

Group I ranged between 21.94- 29.15g/100g; group II, 7.34- 9.75g/100g; group III, 1.48- 10.78g/100g; group IV, 13.39 – 23.37g/100g; group V, 10.4- 16.55g/100g; group VI, 10.54 – 14.94g/100g and group VII, 4.01-5.70. The three termite species' amino acid groups did not significantly differ from one another.

Table 4.8. Summary of the amino acid content

Groups	*Pseudocanthotermes grandiceps* (g/100g)	*Macrotermis jeanelli* (g/100g)	*Allodontermes tenax* (g/100g)	χ^2
Total essential amino acids	32.8	33.97	29.66	0.247638
Total non-essential amino acids	31.66	34.4	23.32	0.267171
Total			**P=0.05,** χ^2=5.991	0.51481

Table 4.8 gives a summary of amino acid content. Total essential amino acids and total non-essential amino acids were not significantly different in the three termite species.

4.4 Survival rates laboratory studies

4.4.1 Survival rates laboratory studies of *Allodontermes tenax*

Treatment	Maize cob husks and loam	Maize stalk and loam	*Eucalyptus* wood and loam	Wheat straw and loam	Pinewood and loam	Loam soil alone

Replicates						
R1(2WEEKS)	70.9±9.28a	78.5±5.99a	75.9±5.09a	92.2±2.54a	48±6.56a	6.8±1.97a
R2(4WEEKS)	52.3±3.90a	70.0±12.22a	71.3±8.97a	87.1±3.94a	56.5±8.15a	0.8±0.49b
R3(6WEEKS)	49.3±7.14a	42.9±6.79a	38.9±4.73b	67.5±6.17b	38.7±6.78a	0.0±0.00b

Table 4.9: Average percentage survival rates of *Allodontermes tenax* ± SEM

The means in the rows with the same letters do not significantly differ from one another ($P > 0.05$). The unit of survivorship was 2 weeks, 4 weeks and 6 weeks respectively. The rate of survival was highest in wheat straw and loam at a grand average of 82.26% followed by maize stalk and loam at 63.82%. Apart from the control experiment, the lowest survival rates were observed in pinewood at 47.72%. This show that wheat straw enhanced the survival of *A. tenax*

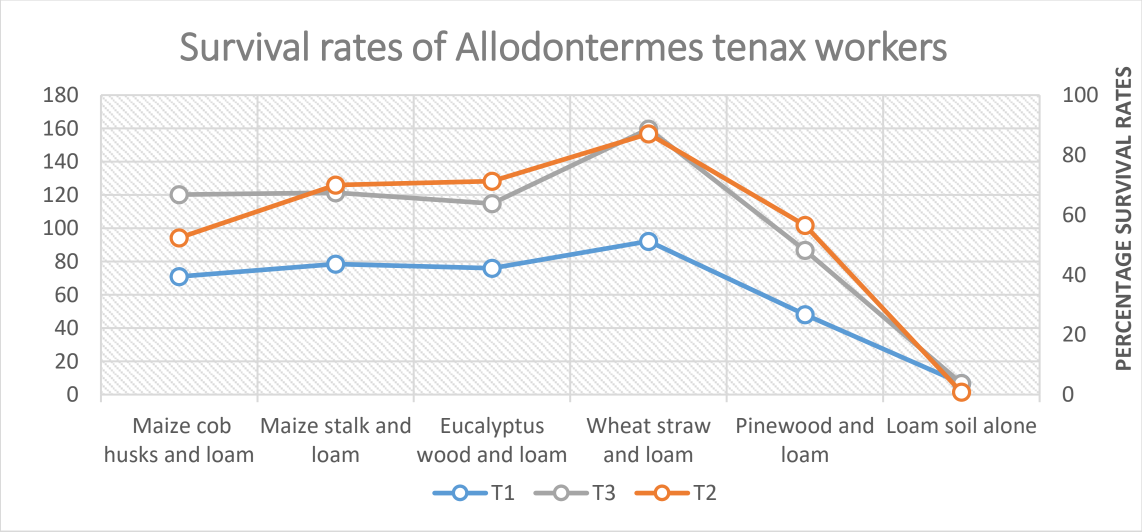

Figure 4.5 Average percentage survival rates of *Allodontermes tenax*

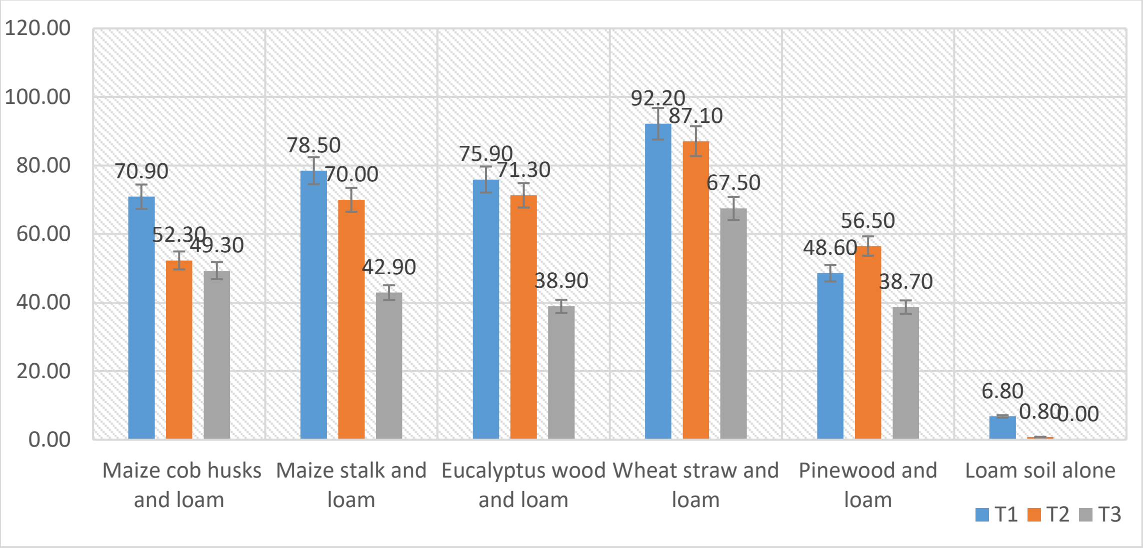

Figure 4.6. Survival rates of *Allodontermes tenax* workers

From figure 4.4.1 the rates of survival were highest during the first two weeks then started to decline from the fourth (4th) week up to the sixth (6th) week across all the food substances that were provided for the termite workers.

Results also show that maize cob husks and loam soil did not significantly $P > 0.05$ impact the termite workers' survival. Similarly, maize stalk and loam soil; pine wood and loam did not significantly affect survival of termite workers of *A. tenax* $P > 0.05$. However *Eucalyptus* wood and loam; wheat straw and loam; loam soil alone significantly affected the survival of *A. tenax* workers $P < 0.05$. The workers survived more on wheat straw while more deaths were found on loam soil alone

4.4.2 Survival rates of *Pseudocanthotermes grandiceps* during laboratory study

The highest percentage survival rates were observed in maize stalk and loam at 78.5% followed by wheat straw and loam at 71.6%. The lowest percentage survival rates were observed in pinewood and loam at 45.9%. Figure 4.4.3 shows the distribution of values in all treatments. There was a general decline in numbers from week four to week six.

There was no discernible difference between the treatments in maize cob husks and loam, wheat straw and loam, or pine wood and loam. T1, T2 and T3, $P > 0.05$. However, maize stalk and loam, *Eucalyptus* wood and loam, loam soil alone showed significant difference among the treatments $P < 0.05$. The highest survival rates were observed in maize stalk and loam in all the treatments while the least observed in loam soil alone across all the treatments.

Table 4.10: Average percentage survival rates of *Pseudocanthotermes grandiceps* ±SEM

Treatment / Replicates	Maize cob husks and loam	Maize stalk and loam	*Eucalyptus* wood and loam	Wheat straw and loam	Pinewood and loam	Loam soil alone
R1(2WEEKS)	66.4±8.75a	86.1±2.38a	71.2±4.82a	76.4±4.57a	45.1±6.06a	9.9±1.33a
R2(4WEEKS)	65.8±11.64a	84.6±3.41a	67.2±8.49a	73.6±4.78a	54.7±7.35a	1.7±0.35b
R3(6WEEKS)	46.2±6.77a	64.8±6.67b	36.7±4.51b	64.9±5.34a	38.0±6.03a	0.0±0.00b

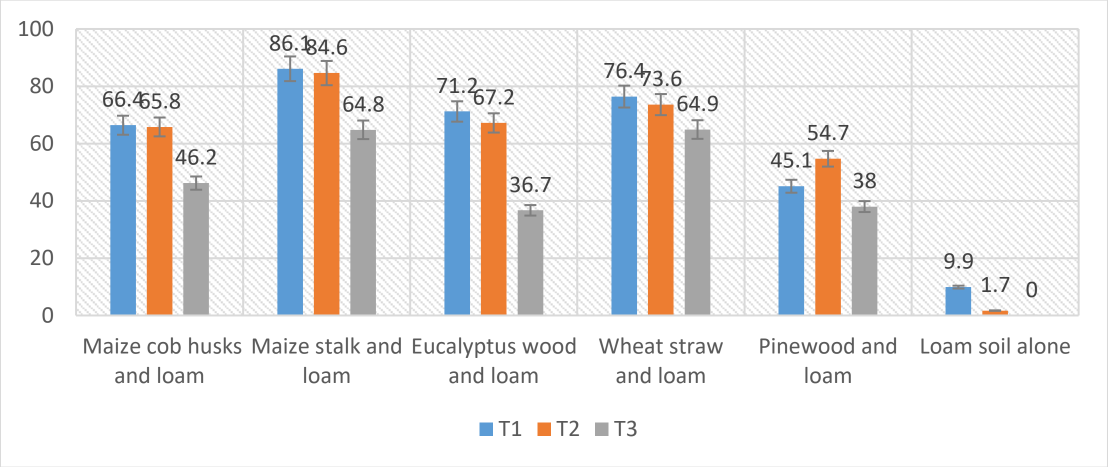

Figure 4.7 Average percentage survival rates of *Pseudocanthotermes grandiceps*

Maize stalk and loam had the highest survival rates with the least observed in loam soil alone.

4.4.3 Survival rates of *Macrotermes jeanneli* during laboratory study

Generally the survival rate of *M.jeanneli* was the lowest when compared with the *A. tenax* and *P. grandiceps*. There was a general decline in the survival rates of termite workers among the food items with least survival rates seen in pine wood and loam and loam soil alone. The food substance that caused the workers of this species to survive longer than the rest was wheat straw and loam at 71.1% and the lowest was 43.6% in pinewood and loam. Table 4.11 and The distribution of percentage survival rates for the various dietary categories is shown in Figure 4.8 below.

Table 4.11 Survival rates of *Macrotermes jeanneli*

Treatment / Replicates	Maize cob husks and loam	Maize stalk and loam	*Eucalyptus* wood and loam	Wheat straw and loam	Pinewood and loam	Loam soil alone
R1(2WEEKS)	62.0±8.19a	68.8±4.50a	64.3±3.65a	76.3±3.36a	43.6±5.41a	2.8±0.65a
R2(4WEEKS)	58.5±9.14a	47.1±2.73b	59.9±7.33a	76.8±3.65a	52.3±6.44a	0.9±0.40b
R3(6WEEKS)	43.3±6.11a	37.4±5.38b	35.6±3.68b	60.1±5.59b	34.8±5.71a	0.3±0.26b

Figure 4.8 Average percentage survival rates of *Macrotermes jeanneli*

Pine wood and loam, as well as maize cob husks and loam, did not differ from one another significantly ($P > 0.05$). On the other hand maize stalk and loam, *Eucalyptus* wood and loam, wheat straw and loam showed a significant difference among the treatments $P < 0.05$. Hence the time duration affected the survival of the termite workers of this species**.**

4.5 Food Preference of termites under laboratory study

4.5.1 Food preference of *Allodontermes tenax*

Table 4.12: Average percentage food preference of *Allodontermes tenax* ± SEM

Treatment / Replicates	Maize cob husks and loam	Maize stalk and loam	*Eucalyptus* wood and loam	Wheat straw and loam	Pinewood and loam	Loam soil alone
R1(2WEEKS)	70.9±9.28a	78.5±5.99a	75.9±5.09a	92.2±2.54a	48±6.56a	6.8±1.97a
R2(4WEEKS)	52.3±3.90a	70.0±12.22a	71.3±8.97a	87.1±3.94a	56.5±8.15a	0.8±0.49b
R3(6WEEKS)	49.3±7.14a	42.9±6.79a	38.9±4.73b	67.5±6.17b	38.7±6.78a	0.0±0.00b

The mean values in each row with a common letter do not differ from one another significantly (P > 0.05). Food preference was highest in wheat straw and loam at a grand average of 82.26% followed by maize stalk and loam at 63.82%. Apart from the control experiment, the least preferred food was pinewood at 47.72%. This show that wheat straw is the most preferred food for *A. tenax*. There was a lot of activity and tunnel construction around wheat straws than any other food substrate in the experiment.

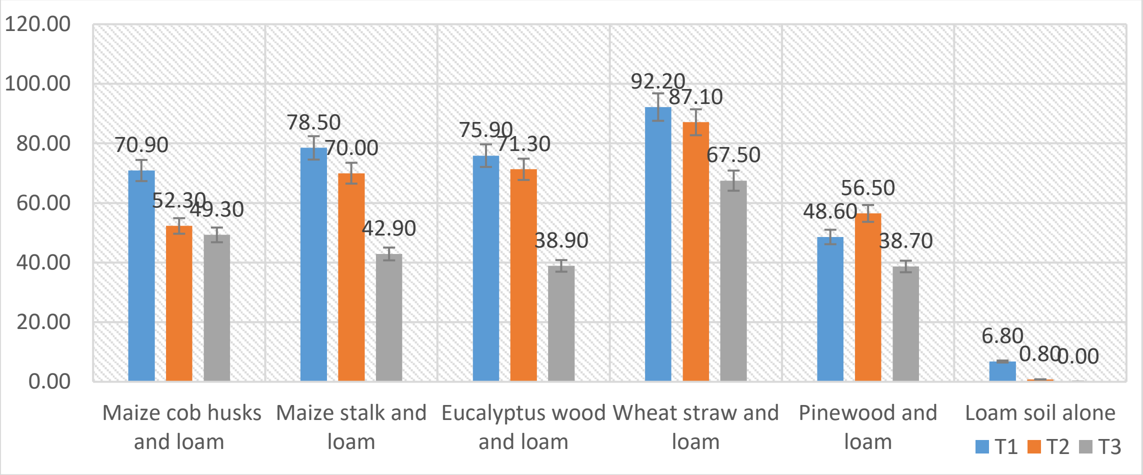

Figure 4.9 Food preference of *Allodontermes tenax* workers

From figure 4.9 the termite worker numbers were high during the first two weeks then started to decline from the fourth (4th) week up to the sixth (6th) week across all the food substances that were provided. There was competition and depletion of the most preferred food leading to accumulation of wastes hence the decline in numbers. The least preferred food substrate was the least consumed hence starvation and death of termite workers.

The findings demonstrate that neither the loam soil nor the maize cob husks substantially (P > 0.05) influenced the termite workers' selection for food. Similarly, maize stalk and loam soil; pine wood and loam did not significantly affect food preference of termite workers of *A. tenax* P > 0.05. However *Eucalyptus* wood and loam; wheat straw and loam; loam soil alone significantly affected food preference of *A. tenax* workers P < 0.05. The workers fed more on wheat straw hence a higher rate of survival while little feeding was found on loam soil alone hence the highest death within a short time.

4.5.2 Food preference of Pseudocanthotermes grandiceps

Table 4.13: Average percentage food preference of *P. grandiceps* ±SEM

Treatment / Replicates	Maize cob husks and loam	Maize stalk and loam	*Eucalyptus* wood and loam	Wheat straw and loam	Pinewood and loam	Loam soil alone
R1(2WEEKS)	66.4±8.75a	86.1±2.38a	71.2±4.82a	76.4±4.57a	45.1±6.06a	9.9±1.33a
R2(4WEEKS)	65.8±11.64a	84.6±3.41a	67.2±8.49a	73.6±4.78a	54.7±7.35a	1.7±0.35b
R3(6WEEKS)	46.2±6.77a	64.8±6.67b	36.7±4.51b	64.9±5.34a	38.0±6.03a	0.0±0.00b

The highest food preference was observed in maize stalk and loam at 78.5% followed by wheat straw and loam at 71.6%. The lowest percentage food preference was observed in pinewood and loam at 45.9%. Table 4.13 and figure 4.10 shows the distribution of values in all treatments. In maize cob husks and loam; wheat straw and loam; pine wood and loam for the six weeks, there was no discernible difference between the treatments ($P > 0.05$). However, maize stalk and loam, *Eucalyptus* wood and loam, loam soil alone showed significant difference among the treatments for the six weeks $P < 0.05$. The highly preferred food in this species was maize stalk and loam. While the least preferred was loam soil alone across all the treatments. There was no significant difference for the first two weeks across all the six food substrates $P > 0.05$. However from 4th week to 6th week, there was significant difference across the six food substrates.

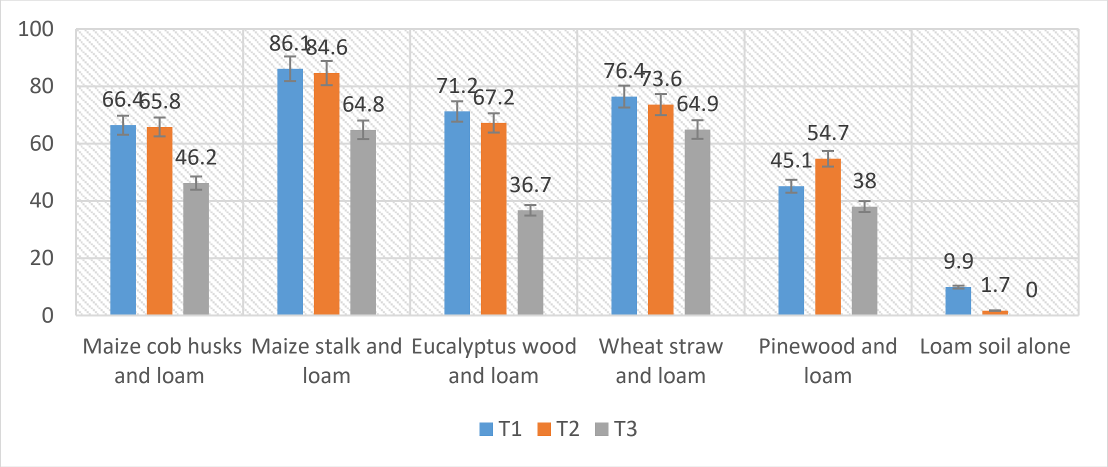

Figure 4.10 Average percentage food preference of *Pseudocanthotermes grandiceps*

Maize stalk and loam had the highest survival rates with the least observed in loam soil alone.

4.5.3 Food preference of *Macrotermes jeanneli*

Generally *M. jeanneli* showed the lowest preference across all the six food substrates provided when compared with the *A. tenax* and *P. grandiceps*. The least preferred food was pine wood with loam. The food substrate that was the most preferred in this species was wheat straw and loam at 71.1% and the lowest was 43.6% in pinewood and loam. Table 4.14 shows the distribution of percentage survival rates among the food items.

Table 4.14 Food preference of *Macrotermes jeanneli*

Treatment / Replicates	Maize cob husks and loam	Maize stalk and loam	*Eucalyptus* wood and loam	Wheat straw and loam	Pinewood and loam	Loam soil alone
R1(2WEEKS)	62.0±8.19a	68.8±4.50a	64.3±3.65a	76.3±3.36a	43.6±5.41a	2.8±0.65a
R2(4WEEKS)	58.5±9.14a	47.1±2.73b	59.9±7.33a	76.8±3.65a	52.3±6.44a	0.9±0.40b
R3(6WEEKS)	43.3±6.11a	37.4±5.38b	35.6±3.68b	60.1±5.59b	34.8±5.71a	0.3±0.26b

Pine wood and loam, as well as maize cob husks and loam, did not differ from one another significantly ($P > 0.05$). On the other hand maize stalk and loam, *Eucalyptus* wood and loam, wheat straw and loam revealed a significant difference among the treatments $P < 0.05$. Hence the type of food affected the survival of the termite workers of this species**.**

CHAPTER FIVE: DISCUSSION

5.1 Abiotic factors affecting swarming behavior of termites

Swarming greatly differ from one species to another as observed from the results. Swarming depended on temperature, humidity and only occurred during rainy season. It was observed that teach species had its own time, humidity and temperature of swarming. It was also noted that swarming only occurred during the rainy season. Temperature and humidity are the primary elements that influence termite swarming, with rainfall serving to provide the required humidity (Mitchell, 2008; Aihetasham & Akhtar, 2008; Sugio *et al*., 2020). Two species *A. tenax,* also *P. grandiceps* have been induced to swarm when there are no rains (Makila *et al*., 2018). Makila *et al*., (2018) notes that at the time of inducement, the weather should be sunny and calm. The alates only emerged when there was enough moisture either by pouring water directly in the emergence holes to naturally induce them to swarm or during rainy season (Makila *et al*., 2018; Harit *et al*., 2014; Nasir & Akhtar 2011). Temperatures above 22 ^{0}C and humidity above 70% was observed to stimulate emergence of termites (Sugio *et al*., 2020; Mitchell, 2008; Aihetasham & Akhtar, 2008). This was found to be true with the three species, *A tenax, P. grandiceps and M. jeanneli*. For example *P. grandiceps* were observed to emerge at 25^{0}C and relative humidity of 56%, *M. jeanneli* emerged at 22.8^{0}C and humidity of 67% while *A. tenax* emerged at 20^{0}C and humidity of 80%. Termites were seen to swarm only during the rainy season unless induced artificially but still the conditions for their swarming must be considered when inducing. Swarming quantities differed significantly among the three species with *M. jeanneli* producing the highest quantity of alates on average while the lowest quantity was seen in *A. tenax*. Termites of the family *Termitidae* are the ones known to swarm in large quantities, though the quantities vary from species to species (Tong, *et al.,* 2017; Majumder, 2022). These results coincide with the three species under this study that belong to family *Termitidae.*

5.2 Amino acid content

The three termite species contained essential amino acids in considerable amounts. Leucine was the highest among all the essential amino acids, followed closely with lysine. Leucine is important for general muscle health (Oliveira *et al*., 2018). It can stimulate protein synthesis and reduce muscle protein breakdown especially after injury (Brestensky *et al*., 2019). Additionally Leucine also raises insulin levels in the blood (Oliveira, *et al.,* 2018; Brestensky *et al.,* 2019) Leucine was the most abundant amino acid in the three termite species with *P. grandiceps* leading at 7.72g/100g crude protein and the lowest was observed in *A. tenax* 5.5g/100g crude protein. The three termite species therefore have the potential to provide the required 5.5g/100g daily intake (Borack &Volpi, 2016).

Lysine is an essential amino acid that can only be obtained from food (Goyal *et al*., 2017), it is important in normal growth and muscle turnover. It is also important in the formation of carnitine, a substance found in most cells of the body; it also transports fats across cells for energy production. Animal protein foods rich in lysine include; beef steak, 3.3g/100g; lean chicken breast, 3.08g/100g and lean pork, 2.76g/100g (Goyal, *et al*, 2017; Yang, 2017). Comparably *M. jeanelli* has the highest content of lysine at 7.8g/100g closely followed by *P. grandiceps* 6.44g/100g and *A. tenax* 4.16g/100g. The three termite species have more than what the conventional sources can provide therefore the insects' protein could be used as an alternative food source of protein especially to the malnourished households who cannot afford most of the other animal protein foods.

Arginine is a very important amino acid to the heart (Albaugh *et al*., 2017). It changes into nitric oxide a powerful neurotransmitter substance that relaxes the blood arteries, which increases blood circulation. When arteries relax and improves blood flow it may improve erectile dysfunction (McNeal, *et al.,* 2018). In addition arginine leads to wound healing, causes the kidneys to remove waste materials, maintains immune and hormone function (Albaugh, *et al.,* 2017; McNeal, *et al.,* 2018). Arginine was the highest amino acid in *P. grandiceps* at 6.90g/100g and the lowest in *A. tenax* at 4.15g/100g. Arginine daily requirement is 2 to 3g taken three times per day (McNeal, *et al.,* 2018).

Methionine is important in treatment of individuals who are undergoing depression, those who are recovering from alcoholism, allergies, asthma and Parkinson's disease. Methionine was highest in *A. tenax* at 6.86g/100g and lowest in *P. grandiceps* 0.88g/100g. Crickets have a methionine content of 2.29g/100g and moths have 0.62g/100g (Oibiokpa *et al.,* 2018).Therefore on average the three termite species had a higher content of methionine than the other insects analyzed as shown on Table 4.5

Tryptophan is a precursor in the synthesis of neurotransmitter substances like serotonin (Kaluzna-Czsplinska *et al*., 2019). It is an important amino acid that should be availed in the foods consumed. It is also important in the synthesis of anti-pellagra vitamin, nicotinic acid and melatonin (kaluzna-Czsplinska *et al.,* 2019). Tryptophan was found to be highest in *A. tenax* 6.43g/100g and lowest in *P. grandiceps* 2.47g/100g. *Macrotermis nigeriensis* have a tryptophan content of 2.36g/100g; *Cirina foda* contains 1.84g/100g, *Gryllus assimilis* 2.53g/100g and *Melanoplus foedus* 2.64g/100g (Oibiokpa *et al.,* 2018). Among the insects listed, *A. tenax* has the highest content of tryptophan.

By blocking protons to keep an acid-base balance in tissues and blood, histidine is in charge of maintaining a normal pH of 7 in the body(Kessler & Raja, 2019). It is also important to hemoglobin to shuttle oxygen around the body and a precursor of histamine among other important roles (Kessler & Raja, 2019). Histidine was found to be 3.09g/100g in *P.grandiceps*, 2.15g/100g in *M. jeanelli* and 2.09g/100g in *A. tenax*. The daily requirement of Histidine in human body is 1.2g/100g (Kessler & Raja, 2019) therefore the three termite species have the potential to provide the required histidine to humans.

Valine daily requirement is 2.6g/100g, Isoleucine 2.0g/100g, Phenylalanine and tyrosine 2.5g/100g, and Threonine is 1.5g/100g (Hoffer, 2016). From the results the three termite species have the potential to provide the daily requirement. The three termite species in particular should be encouraged for entomophagy because they are inexpensive sources of protein that can be found nearby when they swarm. The total essential amino acids (TEAA) are required in different proportions across the age groups according to FAO (1985). Infant requires 46.0g/100g His; pre-school 2-5years require 33.9g/100g; school child 10-12 years 24.1g/100g while adult needs 12.7g/100g. (Without Histidine (His) in g/100g): infant 43.4, pre-school 32.0, school child 22.2 and adult 11.1g/100g. From the results, it shows that all the three termite species have the required amount, 31.75g/100g – 35.89g/100g with His and 29.66 - 33.97g/100g without His, to supply the different age groups except for the infants who require a higher amount. Total acidic amino acids (TAAA) was found to be more abundant in the three termite samples (13.39g/100g - 23.37g/100g) as compared to total basic amino acids (TBAA) 10.4 – 16.55g/100g. The total Sulphur amino acids (TSAA) were also lower in the three termite samples 1.48 - 10.78g/100g as compared to total essential aliphatic amino acids (TEAlAA) 22.74 – 28.1g/100g. The daily TSAA requirement is 1.26- 2.1g/100g in young men (Zehra & Khan (2016).). From the results, the three termite species contain the required quantities of TSAA and therefore can be recommended to supply the nutrients to the populace. The same applies to total essential conditional amino acids (TECAA) which are amino acids that are not synthesized in the body under some pathophysiological conditions like prematurity in infants and individuals with severe catabolic distress (FAO/WHO, 1985).

They ranged between 18.42 – 24.09g/100g. Cys/TSAA content ranged from 36.4 to 43.2g/100g. Most animal proteins often have a low value for this ratio (Adeyeye & Kenni, 2008). Leucine to isoleucine (Leu/Ile) ratios ranged from 1.51 to 1.83 g/100 g, which was less than the 2.36 g/g needed. Pellagra illness can result from any Leu/Ile imbalance, particularly in nations like Kenya where maize is a major crop (Ekpa, 2020). This study has also show that lysine to tryptophan (Lys/Trp) ranged between 0.65 - 4.59g/100g while methionine to tryptophan (Met/Trp) range was 0.36 - 1.46g/100g.

5.3 Survival rates during laboratory Studies

Termites can survive up to two weeks without food, without water it takes a few days (Becker, 2012; Chouvenc, 2020). Termites in this experiment were subjected to three treatments with various cellulose rich foods available in their environment. The treatments involved rearing the termite workers in a controlled environment for two weeks, four weeks and six weeks consecutively. The experiment agrees with previous studies such that the workers which were reared on loam soil alone that had been incinerated for to remove all the organic matter, almost all survived for only two weeks mainly because of moisture content in the soil (Chouvenc, 2020). Choosing the foods substances to be used in rearing depended on a prior survey of the areas where the termites occur in abundance and the type of cash crop majorly grown in the area (Kooyman, 1987; Wanyonyi *et al*., 1984). Maize and wheat were the main crops grown in the area of study. From the survey, it was observed that *A. tenax* mounds were found in abundance in Eldoret, Kenya where wheat is majorly grown, while *P. grandiceps* mounds were majorly located in Trans - Nzoia County – Kitale area where maize is grown in abundance. *M.jeanneli* was majorly found in Arid and semi-arid parts of Kenya; West Pokot County. This show that distribution and abundance depends on type of crop as their major food. There was a general decline in numbers across all the food items used in rearing and treatments. Wheat straw was the most preferred food item for both *A. tenax* and *M.jeanneli.* Dried maize stalk was the second most preferred food for the two species. Termites differ in food requirement according to the species and where it is located, some species can do well on pine wood but most prefer apple, birch and some others prefer some tropical hardwoods (Becker, 2012). Wood of pine is the most preferred food item for Reticulitermes and Coptotermes species (Mannesmann, 1972; Ngee *et al*., 2004). The most preferred food for *P. grandiceps* was maize stalk on loam soil. Generally wheat straw and maize stalk showed more survival rates compared to the other food items used in this experiment and more tunnels were constructed in wheat straw than in other food items.

Food preference goes hand in hand with survival rates of termites workers (Meyer-Rochow *et al.,* 2021). As observed from the experiment, the most preferred food caused the termite workers to survive longer than the less preferred food item. Wheat straw and maize stalk are the most preferred food items and hence caused the termite workers to survive longer as compared to the other food items used.

On comparing the general survival rates of the three termite species, *A. tenax* had highest percentage survival rate followed by *P. grandiceps* Traditionally *A. tenax* has been harvested during the dry season for consumption by locals in the study area (Bagine *et al*., 2014). Therefore according to this experiment, it is the most preferred species for enhancing production. *M.jeanneli* had the lowest survival rates. The lowest survival rates of *M.jeanneli* is attributed to the type of food provided in this experiment. It shows that survival rates of termites is highly dependent on the type of food available in their locality

(Jacob *et al.,* 2022). It was noted that *M.jeanneli*, being an arid and semi-arid species, providing it with food substances not abundantly present in their locality greatly reduced their survival rates (Chouvenc, 2020; Jacob *et al.,* 2022).

5.4 Food preference during laboratory Studies

Food preference is highly correlated with the crop that's cultivated in the area (Richardson and sun, 2023). *Allodontermes tenax* had a higher preference for wheat straw than any other food substrate provided hence a higher percentage in survival of termite workers at 82.26%. There was a lot of activity and tunnel construction around wheat straw during the sixth week study period, most of the wheat straw had been consumed after the sixth week. The second most preferred food substrate was maize stalk at 63.82%. The numbers of termite workers declined with time across the six food substrates with the highest drastic decline observed in loam soil alone due to starvation and death after the second week. The numbers in wheat straw were high but there was a decline due to accumulation of wastes and exhausting of the food reserves leading to competition for the limited resources leading to death of termite workers. When the right and most preferred food is readily available, organisms' survival is enhanced as seen in wheat straw for this particular species (Makila, 2022).

A similar trend is observed in *Pseudocanthotermes grandiceps*. The most preferred food for this species is maize stalk and loam at 78.5% followed by wheat straw and loam at 71.6%. There was no significant difference in all the six food substrates since the termite workers were still adapting to the new environment. Termites can survive for two weeks without food when humidity is high (Wan *et al*., 2022). From the fourth week to the sixth week there was a significant difference across all the food substrates with the highest survival rate being recorded in maize stalk and loam, the most preferred food substrate. The percentage survival rate depended on the food preference with the most consumed causing more survival of the termite workers.

Macrotermes jeanneli showed the least survival rate in all the six food substrates provided. *M. jeanneli* is a species found in dry areas like West Pokot (Wanyonyi *et al*., 1984). The most preferred food substrate was wheat straw but with the lowest percentage survival of 71.1% and the least preferred food being pinewood at 43.6%.

CHAPTER SIX: CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Abiotic factors affect swarming of termite alates. And each termite species has its own time for swarming with a specific temperature and humidity during the rainy season.

The three termite species were found to have the required essential and nonessential amino acids enough to supply all human age groups except in infants who have a higher protein requirement. The three termite species are therefore recommended to alleviate malnutrition especially in low income households which use termites as food. The non-termite users are also encouraged to use due to their high nutritious value.

The most preferred food item that increased survival rates of the three species was wheat straw. While the least preferred was pine wood in all the three species.

Food preference was highly dependent on the locality in which the termite species was found in abundance and the percentage preference varied in the three termite species.

Generally the best termite species for mass production is *A. tenax* since it can be induced to swarm during the dry season and showed the highest survival percentage. The termite workers also showed more survival rates in a laboratory study

6.2 Recommendations

1. More studies should be done to rear the species and hence increase chances for inducement
2. More studies are required to determine amino acids of other species available in Western Kenya.
3. More studies are required to test more food items locally available in the areas where the termite species are found in abundance.

4. More studies are needed to establish the best form in which the food substrates should be fed to the termite workers.

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