DETERMINATION OF AN EFFECTIVE ORGANIC BAITING TECHNIQUE IN HARVESTING OF TERMITES (*MACROTERMES BELLICOSUS*) FOR USE AS ALTERNATIVE SOURCE OF PROTEIN FOR POULTRY.

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A THESIS SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE AWARD OF THE DEGREE OF MASTER OF SCIENCE IN FOOD SECURITY AND SUSTAINABLE AGRICULTURE, IN THE DEPARTMENT OF BIOLOGICAL SCIENCES, FACULTY OF SCIENCES, JARAMOGI OGINGA ODINGA UNIVERSITY OF SCIENCE AND TECHNOLOGY

OCTOBER, 2022

DECLARATION AND APPROVAL

Declaration

This thesis is my original work and has not been submitted for the award of any degree in any University.

Sign……………………………… Date……………………………………………

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(Reg. A451/4260/2018)

Approval

This thesis has been submitted for examination with our approval as the university supervisors.

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DECDICATION

I dedicate this work to my wife Agnes and children for their unending moral support and encouragement during the MSc degree research project.

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ABSTRACT

The aim of this study was to determine the most effective organic baiting technique for the mass harvesting of *Macrotermes bellicosus*. Existing traditional baiting techniques are neither environmentally sustainable nor suitable for trapping of large quantities of *Macrotermes bellicosus*. The objective was to determine an optimal technique by experimenting on effects of organic baits and environmental factors on the count of *Macrotermes bellicosus*. Around two separate mounds, 5 treatments replicated 3 times using earthen pot and plastic containers of maize stocks, eucalyptus stems, lantana camara twigs, Napier grass and rice husks, were set up. A Hobo data logger recorded temperature and humidity on an hourly basis and a count of termites harvested at 6 am and 6 pm over the 21 period was taken. Analysis of Variance (ANOVA) test at $p = 0.05$ and the Least Significant Difference (LSD) technique were used to test the research hypothesis. The effects of organic baits on termite counts differed significantly ($p < 0.05$) and maize straws emerged as the most effective bait. Further, environmental factors had a statistically significant effect ($p < 0.05$) on the mean count of termites. The ideal environmental conditions of high humidity (91.0 %) and low temperatures (22.1 ^{0} C) occur at night and collection at 6.00 am led to the highest mean termite count (2,021). Earthen pots mimicked the ideal environmental conditions for termites with higher mean termite counts (1,987) than plastic containers (774). From the findings the optimal termite baiting technique needs to incorporate both bait preference and environmental factors. Earthen pots with maize straws placed overnight around mounds and emptied at 6 am is the recommended organic baiting technique for the mass harvesting of *Macrotermes bellicosus*. These findings may have practical, policy and theoretical implications for research on the role of termites in sustainable agriculture.

Key words:

Bait preference, mass trapping, *Macrotermes bellicosus*

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CHAPTER ONE

INTRODUCTION

1.1 Introduction

This chapter establishes a background to the study, by focusing on the importance of termites as an alternative source of proteins, and the need for mass harvesting techniques. Included in the background are the importance of termites as an alternative source of proteins for poultry, the traditional methods of harvesting termites and the suitability of various types of baits and containers and the need to evaluate the effect of environmental factors, like temperature and humidity on the mass harvesting of termites. It also states the research problem, the objectives of the study, the research questions posed, the research hypothesis and justification for the study.

1.2 Background to the Study

The focus of the current study was on determining the effectiveness of baits used to harvest termites for use as an alternative source of proteins in commercial poultry farming. Termites have the potential of being an alternative source of proteins in manufacture of poultry feeds (FAO, 2018). However, while their use depends on the ability to harvest termites in large quantities, research is yet to establish the most suitable organic baits for commercial harvesting of termites. However, it is acknowledged that traditional methods of baiting may not provide adequate supplies for use as substitutes in preparation of poultry feeds. Thus a need exists to determine the effectiveness of organic baits in mass harvesting of *Macrotermes bellicosus* for use as an alternative source of proteins in manufacturing of poultry feeds.

Sustainable mass harvesting of termites is an important research theme owing to the importance of termites, as a source of proteins and their role in ecosystem. Termites are the largest group of insect detrivores comprising 90% of the 100 gm3 insect biomass within tropical forest soils, making them fundamental in decomposition process (Nan-Yao, 2019). They are revered within rural communities for their role in soil fertility improvement and as a food resource for both humans and livestock (Mali et al., 2019). Studies have confirmed that insect entomophagy is practiced among about two billion people on earth (Van-Huis et al., 2013). Termites are among the most consumed insects in Africa (Kinyuru et al., 2013).

They are also traditionally used to feed poultry in many West African countries such as Togo, Ghana, and Burkina Faso among other nations (Sankara et al., 2018). Traditionally, Macrotermes are collected by making holes in the lateral part of the mound and inserting baits such as plant branches and leaves in the hole before pulling three to four hours later with termites on them for feeding poultry (Dao et al., 2020). In the traditional trapping methods, signs of termites such as mud sheathing and runways are usually found at sites with plant debris or dead animals, and can be spotted through the characteristic soils associated with termite tubes. The soil is then scraped with a hoe and a trap consisting of a container, overturned and filled with humid organic matter is used (Kenis et al., 2014). The trap is placed in the morning (6–8 am) or in the evening (around 6 pm) and covered with foliage or pieces of fabric to protect it against the sun. Termites are collected the following morning (6-7 am) or two days later.

The organic matter, full of termites, is placed in another container and brought to the farm. If the pot is small and the quantity of organic matter is limited, the collection has to be made the following day otherwise termites will eat the whole content and leave the container. Larger containers can remain for two or more days (Dao et al., 2020). A variant of the method consists in placing the organic matter, such as cow dung, without container, on the termite nests and tubes, and collect the matter with termites by hand. Termites have been trapped by introducing leafy tree branches into the mound (Khan and Ahmad, 2018).

In Kenya, using inverted pots with organic baits such as grass is common. Others prefer beating ground or objects close to the termite mounds (Ayieko et al., 2010). This is meant to provoke the termites to come out. Winged ones are consumed by the farmer whereas the worker and soldier termites are collected and taken to birds. Similarly, digging of the termite mound and excavates to obtain the termites and the white part of the nest is practiced (Fiaboe and Nakimbugwe, 2017). Dry leaves can also be heaped along the fence where the chickens go to hunt for themselves. These traditional methods are deemed to be less environmentally sustainable, as they entail destruction of termite mounds yet these insects have an important role to play in the ecosystem. Thus it is important to establish a better technique that can be used for the mass harvesting of termites.

In particular, little evidence exists of the most potent organic baits for the mass trapping of termites. Previous studies, however suggest that types of organic baits and environmental factors may affect the count of termites harvested (Verelas et al., 2017). The current study was motivated by the lack of empirical evidence on the most effective baiting technique for the sustainable mass harvesting of termites. Lack of empirical knowledge on the effect of locally available organic baits and local environmental conditions has made it difficult to trap adequate quantities of termites for use in feeding poultry and other livestock among rural farmers.

Feeding poultry is costly and commercial feeds could account in excess of 70% of the total production cost (Sankara et al., 2018). This is relatively high and constrains the poultry industry, with majority of farming communities resorting to use free range and indigenous breeds of chicken, with occasional or routine supplementation. Even so, they still suffer from quantitative and qualitative food shortages (Pousga et al., 2007a, 2007b), which affects production of chicken and eggs consequently reducing family incomes.

The protein component in poultry feeds is costly, resulting in high cost of feeds. Fish meal and soya bean are the conventional protein sources. As Van-Huis et al., (2013) notes, these also form part of human diet leading to an indirect conflict between humans and livestock. As a result, overfishing has been observed owing to the high demand and raising environmental concerns on fish species extinction and sustainability. With heightened concerns for sustainable ecologies, concerns have been voiced for investigations into the most effective and sustainable baiting technique. However, traditional methods of harvesting termites for use as alternative protein sources are still popular (Van huis, 2017).

In the traditional trapping method, the first step is to search for signs of termites such as mud sheathing and runways on the ground. These are usually found at sites with plant debris or dead animals, and can be spotted through the characteristic soils associated with termite tubes. The soil is then scraped with a hoe and a trap is placed of the soil. The trap consists of a container, overturned and filled with humid organic matter (Kenis et al., 2014).The trap is placed in the morning (6–8 am) or in the evening (around 6 pm) and covered with foliage or pieces of fabric to protect it against the sun. Termites are collected the following morning (6-7 am) or two days later.

The organic matter, full of termites, is placed in another container and brought to the farm. If the pot is small and the quantity of organic matter is limited, the collection has to be made the following day otherwise termites will eat the whole content and leave the container. Larger containers can remain for two or more days (Dao et al., 2020). A variant of the method consists in placing the organic matter, e.g. cow dung, without container, on the termite nests and tubes, and collect the matter with termites by hand. The limiting part in quality feed access partly explains the low performance seen in indigenous poultry farming in Kenya (Kingori et al., 2003) Termites have been trapped by introducing leafy tree branches into the mound (Khan and Ahmad, 2018).

In Kenya, using inverted pots for utilization becomes challenging when high quantities are needed to feed a larger flock or to increase the proportion of protein feed in the livestock diet. Because of this, many farmers stop feeding their poultry with termites, without finding alternative protein sources (Farina et al., 1993; Kenis et al., 2014; Sankara et al., 2018). Other reasons for reduced usage of termites is the lack of time and the lack of knowledge of trapping technique (Boafo et al., 2019a). Studies in Kisii, Nakuru and Kirinyaga reveals use of organic substrates mainly grass for trapping termites. Others prefer beating ground or objects close to the termite mounds (Ayieko et al., 2010). This is meant to provoke the termites to come out. Winged ones are consumed by the farmer whereas the worker and soldier termites are collected and taken to poultry. Studies of termites in Kenya shows that more women are involved in utilization of termites and other insects for feeding local birds than men (Waithanji et al., 2019). For this reason, the development of sustainable methods to collect, harvest and store termites is important so that traditional poultry farmers can provide protein feed to their birds without affecting the environment and local biodiversity (Dao et al., 2020).

Environmentally friendly efforts by communities to keep termite population in check such as use of resistant tree species, mound excavation to retrieve the queen and biological control using indigenous chicken have been attempted (Loise and Nan, 2017). Use of organic baits to trap termites for feeding birds has therefore been considered environmentally friendly and sustainable manner of controlling termite population.

However, there is no readily available effective tested organic bait known. Few studies have suggested bait preference for termite trapping. However, none has conclusively confirmed organic bait for termite that would result to mass trapping (Mali et al., 2019). The current study thus sought to investigate the effect of bait types, collection time, and container type on the count of termites harvested.

1.3 Statement of the Problem

The current study sought to determine the effectiveness of organic baits in harvesting of termites for use as an alternative source of proteins in manufacturing poultry feeds. The problem is that majority of protein sources used by feed manufacturing industries are expensive hence making poultry feeds unaffordable. Feeds account for over 70 percent of poultry production costs and to keep the costs low there is need for alternative sources of proteins. Insects, particularly termites, have a huge potential as alternative protein source for poultry. However, there have been challenges on what bait should be used for trapping termites in quantities required to make them a viable source of protein for commercial feed manufacturing (Mali et al., 2019). This thesis sought to solve the problem by establishing an effective technique of trapping large amounts of termites for use in making feeds for poultry in Kenya.

Previous research such as that by Varelas & Langton (2017) have identified organic wastes, being made of cellulose, as a potential substrates for feeding termites. Nevertheless, as Varelas & Langton (2017) laments, there is limited evidence that identifies the specific plant species that may be useful as the preferred baits in the commercial harvesting of termites. Further, it is not clear as to whether plastic or earthen containers are most suited for collection of termites. Also, previous research is not conclusive on the effect of environmental factors, such as humidity and temperature as well as the time of collection on the harvesting of termites (Van huis, 2017).

This study therefore investigated suitable baits for trapping more termites for utilization as protein source in poultry feeds among the rural farmers in Siaya County. The study also compared two trapping techniques that are commonly used by the local community and recommended the most suitable method to be used. The findings of this study contribute to continuous efforts for sustainable harvesting of termites for feeding indigenous birds.

1.4 Objectives of the Study

1.4.1 Overall Objective

To determine effective organic baiting technique for the mass harvesting of termites *(Macrotermes Bellicosus)* for use as an alternative source of protein for poultry.

1.4.2 Specific objectives

1. To determine the effect of various types of organic baits on the count of *Macrotermes bellicosus* harvested.
2. To assess the effects of environmental factors on the count of *Macrotermes bellicosus* Harvested.

1.5 Research Hypothesis

H_1: There is no statistically significant difference in the count of *Macrotermes bellicosus* harvested using the different organic baits.

H_2: Environmental factors have no statistically significant effect on the count of *Macrotermes bellicosus* harvested

1.6 Justification

The current study is justified by the practical, policy and theoretical implications of its findings on the effectiveness of various organic baits and techniques in the harvesting of *Macrotermes bellicosus*. The identification of the preferred organic bait will enable poultry feed manufacturers to trap commercially viable amounts of termites. An assessment of the effect of environmental factors will provide insight into the appropriate techniques, including the type of collection containers, temperature and humidity conditions optimal for the harvest of termites. Thus by conceptualizing the set of environmental factors to include the local environments created, by types of containers used and time of collection, more insight will be shed on the effect of environmental factors on techniques for the mass trapping of termites.

From an empirical point of view, the results are a useful addition to the empirical body of literature on harvesting of termites for production of poultry feeds. Van-Huis et al., (2013) suggests that the development of sustainable methods to collect, harvest and store termites are important. They recommend termites as an alternative source of protein that has little effect on the environment and local biodiversity.

Environmentally friendly efforts to control termites including the use of resistant tree species, mound excavation and biological control by indigenous chicken have been attempted (Loise and Nan, 2017). Use of organic baits to trap termites is considered an environmentally friendly and sustainable approach. Thus establishing the techniques and procedures to be deployed in harvesting of termites addresses concerns raised in the literature by Mali et al., (2018) and Boafo et al., (2019).

In respect of policy regarding sustainable use of termites, findings on the effectiveness of various baits and procedures will inform relevant arms of government on their formulation of policies on feed manufacturing. In particular, it will form a basis on the issuance of policies to guide in the use of alternative naturally occurring and sustainable sources of proteins such as termites. Thus the study is justified as a useful addition to the empirical evidence on techniques and procedures of harvesting termites for use as an alternative source of proteins in poultry feed manufacturing.

1.7 Ethical considerations

All ethical issues were taken into considerations including refilling dug pits around mounds after the studies. Ethical review license application was successfully deposited with Jaramogi Oginga Odinga University of Science and Technology Ethics Review Committee.

1.8 Conceptual framework

A conceptual framework comprises a researcher’s thoughts on identification of the research topic, the problem to be investigated, the questions to be asked, the literature to be reviewed, the theories to be applied, the methodology to use, the methods, procedures and instruments, the data analysis and interpretation of findings, recommendations and conclusions to make (Ravitch & Riggan, 2017). It is the total, logical orientation and associations of anything and everything that forms the underlying thinking, structures, plans and practices and implementation of entire research project. It explains the relationship of the key decision variables that are deemed potent in solving a research problem (Kivunja, 2018). The literature reporting the likely variables explaining the effect of various organic baits on the count of termites harvested is distilled and presented in Figure 1 to guide the rest of the study. The conceptual framework, which guides the rest of the study is shown in Figure 1

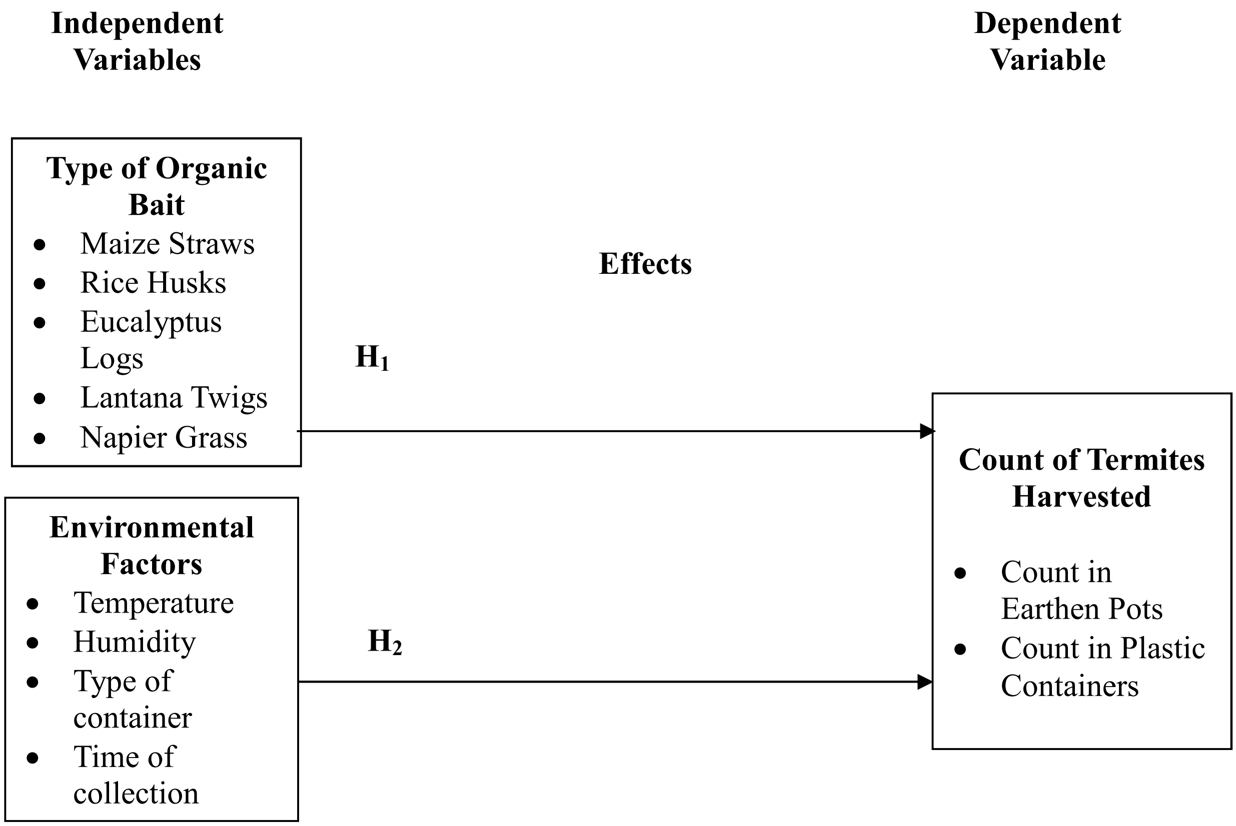


Figure 1: Conceptual framework on effective organic baits in harvesting of Macrotermes bellicosus

The conceptual framework in Figure 1 shows that the count of termites harvested is influenced by the type of organic baits and environmental factors. In particular, environmental factors such as humidity and temperatures, as well as in the types of containers used, and time of collection, drive the count of termites harvested. As depicted in Figure 1, the termite count is influenced by the effectiveness of the type of organic baits used in the traps. In particular, Figure 1 shows that rice husks, maize straws, eucalyptus logs, lantana twigs and Napier grass may have the potential to act as baits in the mass harvesting of termites. Further, the type of container used to collect the trapped termites is also a possible effect on the count of termites as they impact on the level of moisture, as measured by relative humidity and temperatures. Thus the current study conceptualizes the effectiveness of baits to be contingent on the micro climate created, through the use of containers and the effect of temperatures and humidity during the day and night.

Thus, as depicted in the conceptual framework (Figure 1), to ensure optimal harvest of termites' poultry farmers ought to pay attention to the type of baits as well as the techniques of collection, including the type of containers and time of collection, all of which mirror environmental factors. The conceptual framework hypothesizes that determining the effective organic baits requires a consideration of more than just the bait employed. Accordingly to optimize the count of termites harvested requires an understanding of the effect of related environmental factors. These include humidity and temperature, the techniques of collection and times of collection. Thus the framework suggests that successful mass harvesting of termites in equatorial climatic conditions requires a consideration of the type of optimal organic baits used, in addition to environmental related factors.

Chapter 1 presented an introduction to the rest of the study. It sets out the background, emphasizes the need to determine the most effective baits and techniques for sustainable trapping of termites. The research problem, its hypothesis and objectives as well as the value of the study were outlined in the current chapter. Chapter 2 presents a review of literature related to the research themes considered in the current study.

CHAPTER TWO
LITERATURE REVIEW

2.1 Introduction

The current chapter presents a critical review of literature pertinent to the research themes considered in the study. Included in the review are sections on the preferred organic bait for the optimal harvesting of Macrotermes bellicosus, the effect of environmental conditions, such as temperature, humidity, and related techniques for collection, on the harvesting of *Macrotermes bellicosus.*

2.2 Effect of the types of organic baits on the count of *Macrotermes bellicosus* harvested

Related studies that focus on the determination of effective organic baits for the mass harvesting of termites, while scant are yet to focus on the likely effect of various bait types in equatorial climate. For instance, a recent study carried out in India sought to examine the link between the quality of litter and the functional impact of termite feeding preferences on soil properties and soil hydraulic conductivity in a deciduous forest in southern India. It established that organic resources attracted termites differently. When elephant dung: "ED", elephant grass: "EG", acacia leaves: "AL" and layers of cardboard: "CB" were applied on repacked soil cores, ED appeared to be the most attractive resource to termites leading to a larger amount of soil sheathing (Cheik et al., 2019). Organic wastes such as plant tissues and timber waste such as saw dusts and wood shavings are also potential substrates for feeding termites since they both contain cellulose (Varelas and Langton, 2017).

In addition, baiting termites for chicken consumption is an environmentally friendly and sustainable method for controlling termite population (Mali et al., 2019). Despite all these, there is limited evidence on which plant is most preferred by termites. To fill this gap the current study investigates the most potent bait by experimenting with five forms of organic wastes. The current study extends earlier work suggesting that different organic baits attract termites differently. For instance, elephant dung: "ED", elephant grass: "EG", acacia leaves: "AL" and layers of cardboard: "CB" were investigated as suitability organic baits in a study at a deciduous forest in southern India by Cheik et al., (2019). The study sought to establish the link between the quality of litter and the functional impact of termite feeding preferences on soil properties and soil hydraulic conductivity.

The study by Cheik et al., (2019) found that ED appeared to be the most attractive bait for termites as it lead to a larger amount of soil sheathing on the repacked soil cores. Other studies, done on suitability of baits, within the tropics have suggested the appropriateness of cellulose organic wastes. For instance, Varelas & Langton (2017) investigated the potential of plant tissues, timber waste, saw dusts, and wood shavings as suitable substrates for feeding termites. The study established preference for organic baits with cellulose. Mali et al., (2019), Peden et al., (2013), and Wang & Henderson (2012) also concur with the observations that Termites prefer food with high levels of cellulose. Mali et al., (2019) demonstrated termite preference to maize in laboratory and field experiments. Their study suggested that termites had high affinity to maize due to high presence of organic carbon and simple sugars. Abushama & Kambal (1977), Deborah, Waller & Curtis (2003) also established that foods rich in sugars, such as glucose, are preferred by termites. Castillo et al., (2013) demonstrated that addition of sugars to a bait enhanced termite presence in those baits. In particular, as Waller et al., (1990) suggests, the amount of cellulose per unit area ought to be considered in a substrate selection study with termites.

Lignin is less preferred since it's harder to digest (Judd and Corbin, 2009). Wood such as Eucalyptus and Lantana which have higher indigestible components including lignin (Deborah A. Waller and Curtis, 2003) which may prevent digestion. Eucalyptus and Lantana are known for allelopathy, which is the occurrence of toxic substance in tissues which repels termites (Mali et al., 2019). The allelochemicals released from chopped Eucalyptus logs may led to less preference of the substrate. Mali et al., (2019) further notes that tree species produce allelochemicals to naturally deter insect feeding. Studies by Ayieko et al., (2010), Fiaboe and Nakimbugwe (2017) also explained use of different substrates to trap termites for poultry feeding.

From the literature it is evident that previous studies suggest that various kinds of organic substrates can be used to bait termites. However, there is limited evidence to pinpoint specific plant species as preferred baits. Following suggestions of the potential that organic substrates may have in the mass harvesting of termites, the current study aims to replicate these findings in Kenya.

In particular, it seeks to determine the specific organic bait, which may optimize the trapping of *Macrotermes bellicosus* inhabiting equatorial rain forests of Siaya County in Kenya. In addition to widely available substrates such as maize stalks, rice husks, eucalyptus logs, lantana twigs and Napier grass have been considered as suitable organic baits. To determine the most effective organic bait, the current study hypothesized that there is no statistically significant difference in attraction of *Macrotermes bellicosus* to different organic baits.

2.3 Effect of environmental factors on the count of *Macrotermes bellicosus* harvested

The effect of environmental factors on the count of termites harvested is a poorly investigated issue. In particular, few researches have focused on the effect of temperature and humidity, either directly or indirectly, through the microclimate created at particular time periods and type of container used. While collection of termites for poultry feeding is an ancestral practice (Sankara et al., 2018), few studies have focused on the effect of environmental factors on the techniques of collection, including the type of containers and time of collection.

Studies however, show that farmers in Africa have collected termites from the wild since time immemorial (Kenis et al., 2014). For instance, Van Huis et al. (2013) report that termites are traditionally used to feed poultry in many West African countries, including Togo, Ghana, and Burkina Faso. Unfortunately, few studies have however focused on the collection of termites in East African countries, in particular with regard to the effect of collection time on their mass harvesting. The time at which termites are collected is often determined by the method of trapping termites. For instance where termites are collected using the traditional method involving the making of holes, in the lateral part of the mound and inserting baits, they are often collected by pulling the plant branches and leaves three to four hours later. A variation to this method is to partially destroy the mounds by digging them early in the morning, between 6 and 9 am (Dao et al., 2020).

Another variation to the traditional methods of making holes and partial destruction of moulds is to scrap the soil with a hoe and place a trap consisting of a container, overturned and filled with humid organic matter (Kenis et al., 2014). The trap is placed in the morning (6–8 am) or in the evening (around 6 pm) and covered with foliage or pieces of fabric to protect it against the sun.

Termites are collected the following morning (6-7 am) or two days later. The organic matter, full of termites, is placed in another container and brought to the farm. If the pot is small and the quantity of organic matter is limited, the collection has to be made the following day otherwise termites will eat the whole content and leave the container. Larger containers can remain for two or more days (Dao et al., 2020).

Previous studies on the effect of containers used for mass harvesting of termites have identified the potential effect of various container attributes. In particular, past studies suggest that quantities of termites trapped depends on size of vessels used (Boafo et al., 2019a). In studies on how to use containers, recommendations have been made to use different sizes of containers depending on the size and age of flock. In Togo, farmers use an old canary (plastered water-storage pot) with dry cereal stems, stones and some moist soil is placed upside down over a mound entrance hole. Termites can then be harvested in 2-4 weeks when the amounts of termites inside is considered favorable (Farina et al., 1993). Related studies on the effect of environmental conditions by Zukowski & Su (2017) also show that survival of termites (Isoptera) is related to their exposure to various levels of relative humidity (RH) and water availability.

In Burkina Faso for example, farmers harvest termites using calabashes filled with moist old dung and organic material placed underground. The calabashes are emptied few days later and the contents containing termites given to poultry (Aïchatou Nadia Christelle Dao et al., 2020). In Togo, farmers use an old canary (plastered water-storage pot) with dry cereal stems, stones and some moist soil is placed upside down over a mound entrance hole. Termites can then be harvested in 2-4 weeks when the amounts of termites inside is considered favorable (Farina et al., 1993). In Kenya, using inverted earthen pots with organic substrates such as grass is common (Ayieko et al., 2010). Trapping termites using containers is one of the traditional methods of obtaining termites. Another traditional approach is the digging of the termite mound and excavating it to obtain the termites and the white part of the nest (Fiaboe and Nakimbugwe, 2017). Often, this involves the use of dry leaves that is heaped around the destroyed mound to attract the termites as chickens hunt for themselves. While these traditional methods involve the use of various kinds of containers, it's not clear whether plastic or earthen port containers are most preferred as a collection container.

In the current study the effectiveness of plastic containers and earthen ports was investigated in order to ascertain the most potent container for collecting termites. In Kenya, using inverted pots with organic substrates such as grass is common. Others prefer beating ground or objects close to the termite mounds (Ayieko et al., 2010). This is meant to provoke the termites to come out. Winged ones are consumed by the farmer whereas the worker and soldier termites are collected and taken to poultry. Similarly, digging of the termite mound and excavates to obtain the termites and the white part of the nest is practiced (Fiaboe and Nakimbugwe, 2017). In all these methods, the termites are collected at varying times, including after a few hours or a few days. Dao et al., (2020) suggest that where termites are trapped in containers after partial destruction of their mounds early collection is required. They explain that this is as a result of termites being sensitive to temperatures, driving deep in the subterranean part of the nest, when it is sunny in the day.

Despite research on the harvesting of termites, it is not clear as to whether the time of collection would affect the count of termites, where a more environmentally sustainable method is utilized. In the current study, a more environmentally sustainable method is adopted to determine the most potent organic bait for trapping of termites as well as the optimal time. Previous research is not conclusive on whether, the time of collection has a statistically significant effect where earthen pots or plastic containers filled with organic baits is used. To determine the effect of the time at which *Macrotermes bellicosus* are collected the current study collected termites at six in the morning and six in the evening.

Previous research suggest that environmental conditions determine the distribution of various termite species. In particular, researchers have suggested that their preference for moist conditions determine their distribution. For instance, Boafo et al., (2019a) explain that termites require moisture in forming mud tubes that bridge the distance between their mounds and their food. Loise & Nan (2017) have also suggested that humidity, soil chemical characteristics and moisture contents dictate termite distribution and availability. In Burkina Faso for example, farmers harvest termites using calabashes filled with moist old dung and organic material placed underground. The calabashes are emptied few days later and the contents containing termites given to poultry (Dao et al., 2020).

While previous studies suggest that the conditions in the environment may affect the distribution of termites, the evidence remains speculative. In particular, they may not fully explain the effect of temperature and humidity in the mass harvesting of *Macrotermes bellicosus* in equatorial climates. Further, earlier work has concentrated in preference for relative humidity (Zukowski and Su (2017) or termite distribution and availability (Loise and Nan (2017).

The lack of studies on the effect of environmental conditions makes it difficult to develop optimal technique for the mass harvesting of Macrotermes bellicosus. The current study fills this empirical and conceptual gap by investigating the effect of temperature and relative humidity on the mass harvesting of *Macrotermes bellicosus* in equatorial climatic conditions. To examine the effect of environmental conditions, the current study hypothesizes that temperature and relative humidity do not have a statistically significant effect on the count of termites harvested.

2.4 Summary of literature and research gaps

Related literature on the main themes in this study suggests empirical, contextual, methodological and conceptual gaps that need to be filled. Past studies on the use of termites have left several empirical gaps that make it difficult to recommend that most suitable organic substrates for the mass harvesting of termites. In particular, there is need to test the previous suggestions that organic baits may provide a sustainable technique for the mass harvesting of termites. Previous research, conducted in the context of other environmental conditions cannot be expected to offer a conclusive answer to the question of which organic substrates is most effective. This arises from the nature of organic baits used in these studies, conducted in the tropics, which are different from those used in the context of equatorial climates.

The methodologies adopted in previous studies on harvesting termites also offer several opportunities to study the sustainability of methods for trapping termites. Related research have tended to focus on laboratory experiments and may not offer results that inform the most suited techniques for the environmentally sustainable harvesting of termites. The current study extends such work by the use of field experiments, over a period of 21 days, thereby bridging the methodology gaps. Finally, several studies on the harvesting of termites have pointed at conceptual gaps that inform the current study. The related literature may not be fully relied on to explain the possible factors that may explain how mass harvesting of termites could be achieved.

Thus without a re-conceptualization of the antecedents of sustainable harvesting of termites, it may not be possible to utilize termites as a commercially viable alternative source of proteins in the mass harvesting of termites. While the literature suggests that termites are a potential source of alternative proteins in the manufacture of poultry feeds more work is required to derive practical techniques for the mass harvesting of termites.

The literature suggests that organic baits are more sustainable, and that the types of containers used, the time of collection and environmental conditions may be key in the mass harvesting of termites. The current study seeks to establish the most preferred organic baits, for the mass harvesting of termites and the effect of container types, time of collection and temperature as well as humidity. It seeks to enhance empirical knowledge, contextual relevance, methodological insights as well as a re-conceptualization of drivers that leads to sustainable mass harvesting of termites for use as an alternative source of proteins for poultry.

The current chapter provided a review of literature pertinent to the objective of the study. In particular, it focused on a review of the related research on the themes of types of organic baits and effects of environments on the count of termites harvested. The extant literature was summarized and research gaps identified. The next chapter presents the methods and materials used by the researcher to collect data to be analyzed in response to the research questions implied by the objectives of the study.

CHAPTER THREE
MATERIALS AND METHODS

3.1 Introduction

The current chapter details the materials and methods used to obtain data in answer to the research questions. Included is the study area, experimental design, data collection procedures and the methods of data analysis.

3.2 Study Area

The location of the experimental sites around Mbaga hills, on the outskirts of Siaya Town off Siaya - Ndere Road, at Hono Sublocation is shown in Figure 1.

Figure 2. Location of the experimental sites
Source: IEBC Kenya - Map of Alego Usonga constituency

The experimental site is shown in Figure 1. The site was in Hono Sub-location in Alego Usonga, in Siaya County, Kenya. Siaya was chosen as a study area as most farmers were using traditional methods of harvesting termites. Further, Siaya Sub -County has the requisite environmental conditions for termites to thrive as evident from several termite mounds around Mbaga hills.

Siaya County lies between latitude 0^{o} 26’ to 0^{o} 28’ North and longitude 33^{o} 58’ East and 34^{o} 33’ West, and has a total land surface area of 1520 Km^2. Siaya County consists of Ugunja, Yala, Ugenya, Siaya, Bondo and Rarieda sub counties. Siaya County borders Busia County to the north, Kakamega County to the north eastern, Vihiga County to the east, Kisumu County to south east, with Lake Victoria to the south and west. In terms of climatic conditions, the County has an equatorial climate with an elevation of ranging from 1140 m to 1200 m above sea level. Siaya has a temperature range of 170C at night and 280C at day time. The relative humidity is 24% day time and 81% at night (MOA, 2018).

3.3 Experimental Design

The study aimed at determining the most suitable organic baits in trapping of termites. To determine the baits that termites preferred two sets of experiments were designed. The design involved experimenting with five different types of organic termite baits placed in two types of containers over a period of 21 days.

Experiment 1 - Baits in Plastic Containers

In the first experiment, plastic containers were used for collection of termites baited using five different kinds of baits placed in five bait stations. The plastic containers were put inside hoe-dug holes of diameter 0.3 m and 0.3 m deep as termites are found within a depth of 0.25 m below the ground. To test the first hypothesis on the preferred organic baits the researcher staffed five different baits types in the plastic containers. The five baits packed in plastic containers, shown in Figure 3, were dry logs of Eucalyptus tree, dry maize straws, dried Lantana twigs, dried remains of Napier grass and dried rice husks.

Figure 3

Organic baits packed in plastic containers

The bait stations, in 3 replicates, were placed around 2 randomly selected active *Macrotermes bellicosus* mounds in the same piece of land. Each mound was surrounded by 5 bait stations placed in a circle as described by Mali *et al,.* (2018). Baits were uniformly prepared, chopped and individually packed inside the 0.3 m deep pits at uniform depths. The pits were fitted with shallow plastic containers which were meant to guard the termites from disappearing into their tunnels during harvesting. The baits were then lightly covered with top soil. Covering the baits with soil was to provide dark environment inside and also to guard the termite attracted to the baits against external weather factors such as rainfall and direct sunlight. An all-round 1.5 m distance was maintained between and within individual holes so that harvesting the termites in one hole does not affect those in next hole to disappear into their tunnels.

Experiment 2 -Baits in Earthen Pots

In the second experiment, equal amounts of the five types of organic baits which were uniformly prepared, chopped and individually packed inside the earthen round pots as shown in Figure 4.

Figure 4

Organic baits packed in earthen pot containers

The pots were laid inside the 0.3 m deep holes, in an inverted position. This procedure ensured that rain or direct sunlight does not influence termites' interactions with baits. An all-round 1.5 m distance was maintained between and within individual holes so that harvesting the termites in one hole does not influence those in next hole to disappear into their tunnels. The two experiments were conducted on two separate plots, with 5 treatments replicated 3 times within a block, as shown in Table 1.

Table 1

Arrangement of the experimental design across the plots

Plot A (Baits placed in plastic containers)			Plot B (Baits placed in earthen pots)		
Replicate 1	Replicate 2	Replicate 3	Replicate 1	Replicate 2	Replicate 3
1	2	5	4	2	1
3	4	3	5	3	2
5	1	4	1	4	3
4	3	1	2	5	4
2	5	2	3	1	5

Key: Cycle in Experiment1 represent dug pits while those in 2 represent dug holes with pots all containing baits numbered 1-5.

1) Stocks of dry Eucalyptus tree stem 2) Dried maize straws 3) Dried Lantana camara twigs 4) Dried remains of Napier grass 5) Dried Rice husks.

3.4 Data collection

The current study sought to determine the preferred organic baits in harvesting of *Macrotermes bellicosus* and the best technique for sustainable harvesting. Data was collected in order to test two hypotheses on the most suitable organic baits, the effect of container types, the effect of time of harvesting, and that of environmental conditions. The data collected included the number of termites collected, the humidity and temperature at specific times, in a period of 21 days. The data on the number of termites were collected two times in a day. The first collection was made at 6 am in the morning and the second one at 6 pm in the evening. To collect the termites from the first experiment, plastic containers were removed, and termites collected and preserved in bags. On the other hand, to collect the termites in the second experiment, the pots were removed from holes and substrate mixed with termites placed in tight bags to avoid escape.

For each experiment, the containers were carefully labeled and the number of termites in each container was counted and recorded to help establish preferred organic baits, and the effect of environmental conditions, including microclimate created by use of different containers and time of collection on termite counts. To gather data on the direct effect of environmental conditions, readings for temperature and humidity were taken using a Hobo data logger (HOBO ware 3.7.22 version). This was installed within the dugout pits for trapping the termites. The data logger was set to record the temperature and humidity on hourly basis across the day and the night. An average of the temperature and relative humidity collected across the various hours of the day (dawn to dusk) was computed to obtain the average day temperature and humidity.

3.5 Data Analysis

The analysis of data on number of termites collected, types of containers used, times of collection and environmental conditions was done using version 4.0.2 of the R statistical software. The tests on the effect of type of baits, collection times and environmental conditions on harvesting of termites were based on average values. Thus the mean number of termites per earthen pots emptied and plastic containers was obtained. Also, the temperature and relative humidity was averaged to obtain the average day temperature, average day Relative Humidity (RH), average night temperature and average night humidity (RH). Analysis of variance (ANOVA) was conducted to compare different baits on their effectiveness to attract termites. Mean separation between the baits used was done using least significant difference (LSD). In all tests, the computed value of $p \leq 0.05$, thereby confirming the significance.

The data, on the number of termites collected was further analyzed to test the effect of container types used and environmental conditions on the number of termites trapped. To assess the effect of temperature and moisture content on the availability of termites, a generalized additive model (GAM) was used to build up a mixed effects regression model. The model is superior as it makes an adjustment for the model assumptions in the traditional regression models. The model specification was as follows:

$$TC = \alpha + \beta_1 \, BT + \beta_2 \, EF + \varepsilon$$

Where:

TC is the termite count (per earthen pot container or plastic container in pits)

$\beta_1 + \beta_2$, are the regression parameter to be estimated (intercept and slope that indicate how Yi varies with a corresponding change in predictor variables)

BT = Bait Type

EF = Environmental Factors

The current chapter presented the materials and methods that were used to collect and analyze data in answer to the research questions posed in this study. The next chapter presents the results of the study that are discussed in the subsequent chapter.

CHAPTER FOUR
RESULTS

4.1 Introduction

The current chapter presents results of two sets of experiments designed to establish the optimal conditions for the mass harvesting of termites. The focus of the current study was on determining the effect of various organic baits and environmental factors on the count of termites' harvested. The data collected is presented using tools of descriptive and inferential statistical data analysis.

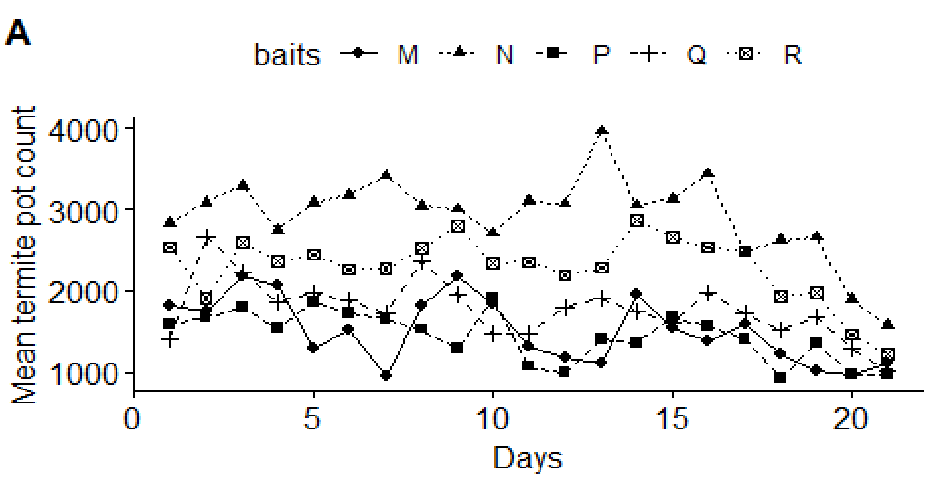
4.2 Descriptive statistical analysis

4.2.1 Effect of the type of organic baits on the count of *Macrotermes bellicosus* harvested

To test the hypothesis that count of termites harvested did not depend on the type of organic baits used the mean count of termites per container types and bait types was computed. Data showing the mean termite counts per the type of baits for termites collected using pots over the 21 days period is presented using line graphs, as Figure 5 and 6.

Figure 5

Effect of the type of organic bait on the count of termites from earthen pots

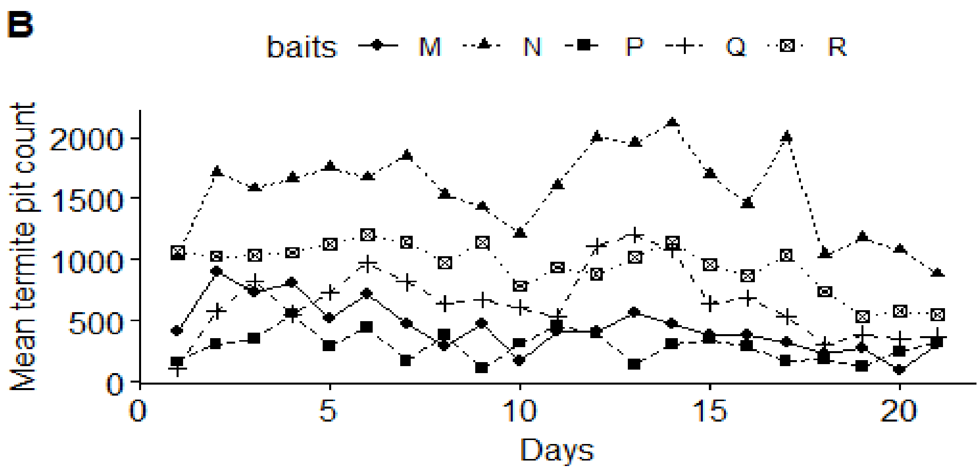


Key:
Type of Organic Baits
Decaying Eucalyptus log (M)
Dry maize straws (N)
Dried Lantana twigs (P)
Dried Napier grass (Q)
Dry rice husks(R)

Figure 5 provides a visual display of the effect of type of organic baits used by showing the mean number of termites collected using earthen pots, over the 21 days period. As evident from Figure 5, dry maize straws (N) was the most preferred organic substrate for the mass trapping of termites, while dry rice husks were the least preferred.

Figure 6

Effect of the type of organic bait on the count of termites from plastic containers



Source: Field data (2022)
Key:
Type of Organic Baits
Decaying Eucalyptus log (M)
Dry maize straws (N)
Dried Lantana twigs (P)
Dried Napier grass (Q)
Dry rice husks(R)

Figure 6 provides a visual display of the effect of type of organic baits used by showing the mean number of termites collected using earthen pots, over the 21 days period. As evident from Figure 6, dry maize straws (N) was the most preferred organic bait for the mass trapping of termites, while lantana twigs were the least preferred.

The results in Figure 5 and 6 suggest that irrespective of the type of container used for the collection of termites. Table 2 and 3 presents the data using a table of mean counts of termites collected using earthen pots and plastic containers

Table 2

Effect of the type of organic bait on the count of termites from earthen pots

Type of Organic Bait	Mean Count of Termites	Standard Deviation	Standard Error
Dry maize straws (N)	2,919	879	6.97
Dry rice husks(R)	2,286	647	5.13
Dried Napier grass (Q)	1,775	574	4.55
Decaying Eucalyptus Log (M)	1,513	591	4.69
Dried Lantana twigs (P)	1,440	476	3.78

Source: Field data (2022)

As evident from Table 2, the most preferred organic bait for the mass harvesting of termites was dry maize straws (N) which had a mean termite count of 2,919 termites. On the other hand, the least preferred organic bait was dried Lantana twigs (P) which had a mean termite count of 1,440 termites.

The effect of the type of organic bait on the count of termites from plastic containers is presented in Table 3.

Table 3

Effect of the type of organic bait on the count of termites from plastic Containers

Type of Organic Bait	Mean Count of Termites	Standard Deviation	Standard Error
Dry maize straws (N)	1,543	503	3.99
Dry rice husks(R)	943	378	3.00
Dried Napier grass (Q)	653	378	3.00
Decaying Eucalyptus Log (M)	444	591	4.69
Dried Lantana twigs (P)	287	329	2.61

Source: Field data (2022)

As evident from Table 3, the most preferred organic bait for the mass harvesting of termites was dry maize straws (N) which had a mean termite count of 1,543 termites. On the other hand, the least preferred organic bait was dried Lantana twigs (P) which had a mean termite count of 287 termites.

4.2.2 Effect of environmental factors on the count of *Macrotermes bellicosus* harvested

The effect of environmental factors was investigated by examining the technique of collection taking into account humidity and temperatures. The effect of different types of collection containers and times of collection provided an operational measure of environmental conditions for the trapping of termites.

4.2.2.1 Effect of type of containers on the count of *Macrotermes bellicosus* harvested

The descriptive results of the effects of the types of containers used is presented in Table 4 showing the mean count of termites collected using earthen pots and plastic containers.

Table 4

The effect of type of containers on the count of termites harvested

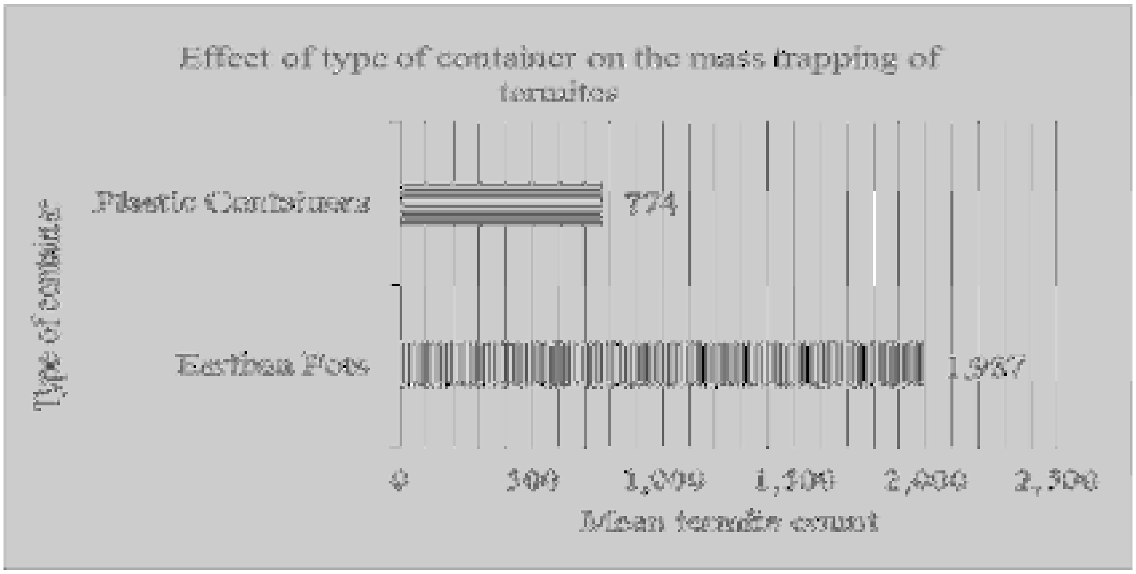
Type of Organic Bait	Mean Count of Termites		Difference
	Earthen Pots	**Plastic Containers**	
Dry maize straws (N)	2,919	1,543	1,376
Dry rice husks(R)	2,286	943	1,343
Dried Napier grass (Q)	1,775	653	1,122
Decaying Eucalyptus Log (M)	1,513	444	1,069
Dried Lantana twigs (P)	1,440	287	1,153
Overall Mean	1,987	774	1,213

Source: Field data (2022)

As evident from Table 4, the mean count of termites collected using earthen ponds was higher than that for those collected using plastic containers by a mean differnce of 1,213. Table 4 shows that earthen pots may be the best type of container to use for the sustainable mass trapping of termites. The data in Table 4 is presented using a line graph to provide a visual picture of the effect of type of container used on the count of termites collected.

Figure 7

Effect of type of container on the count of termites harvested



Source: Field data (2022)

As Figure 7 shows, the use of earthen pots for the mass collection of termites leads to a higher count of termites collected, suggesting that the creation of a micro environment suitable to termite activities inproves the count harvested. The effect of environmental factors was also investigated by operationalizing environmental factors as the timming of termite collection.

4.2.2.1 Effect of the time of collection on the mass harvesting of Macrotermes bellicosus

The effect of environmental contitions, such as temperature and humidity was also investigated by establishing the effect of the time at which termites were collected on their count.

Data on the effect of the time of collection of termites using earthen ponds is presented in Table 5.

Table 5

The effect of time of collection using earthen ponds on the mean count of termites harvested

Time of collection	Mean Count of Termites
Night time (6.00 am)	2,021
Day time (6.00 pm)	1,952

Source: Field data (2022)

As evident from the table the collection of termites during the night results in a higher termite count then picked up at 6.00 am in the morning.

To provide a visual picture of the effect of time of collection on the count of termites collected in earthen pots, the data in Table 5 is presented using a line graph in Figure 8.

Figure 8

Effect of the time of collection on the count of termites from earthen pots

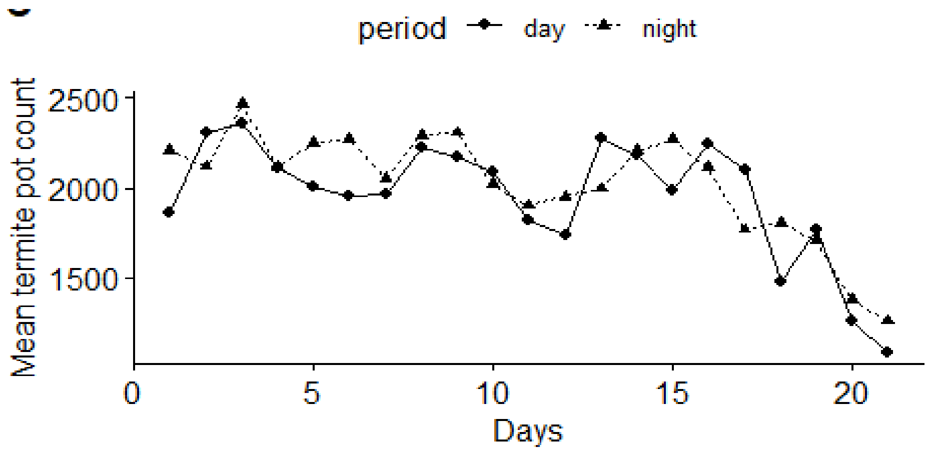


Figure 8 provides a visual display of the effect of time of collection by showing the mean count of termites collected in earthen pots, over the 21 days period. As evident from Figure 8, night time was the most preferred period for the mass trapping of termites, which were then collected at 6.00 am in the morning.

Termites were also collected using plastic containers, used as surrogates to higher temperatures and lower relative humidity. Data on the effect of time of collecting termites trapped using plastic containers on the count of termites harvested is presented in Table 6.

Table 6

The effect of collection time using plastic containers on count of termites harvested

Time of collection	Mean Count of Termites
Night time (6.00 am)	806
Day time (6.00 pm)	742

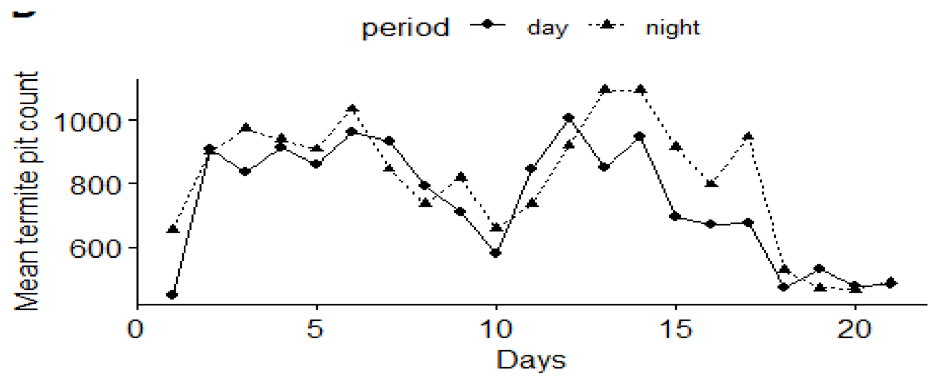
Source: Field data (2022)

Table 6 shows that collecting termites at night yields a higher count thatn if they are collected during the day. The data in Table 6 is presented using a line graph in Figure 9.

Figure 9 provides a visual picture of the effect of time of collection on the count of termites, collected in plastic containers, as Figure 9.

Figure 9

Effect of the time of collection on the count of termites from plastic containers



Source: Field data (2022)

As evident from Figure 9, night time was the most preferred period for the mass trapping of termites, in plastic containers, for collection in the morning at 6.00 am. It's worth noting that count of termites trapped in earthen pots is higher than those trapped using plastic containers.

4.2.2.3 Effect of temperature and humidity on the count of *Macrotermes bellicosus* harvested

The current study considered the effect of environmental conditions on the count of termites harvested by examining the effect of temperature and humidity on the count of termites. Data on the effects of environmental conditions, collected using a Hobo data logger (HOBO ware 3.7.22 version), on the temperature and humidity reported hourly is presented in Table 7.

Table 7

Effect of temperature and humidity on the count of Macrotermes bellicosus

Collection time	Earthen Pot Mean	Plastic Container Mean	Mean Temp (0C)	Mean RH (%)
Day	1,952±16.1	742±8.82b	30.2±0.13	69.1±0.50
Night	2,021±14.5	806±9.49a	22.1±0.04	91.0±0.10

NS=Not significant; *implies significant at 5% level of significance

The data in Table 7 shows that low temperatures (22.1 0 C) and higher relative humidity (91.0 %) resulted in the highest mean count of *Macrotermes bellicosus* harvested (2,021).

The findings in Table 7 on the effect of these environmental factors shows that termites thrive where the environment is characterized by low temperatures and higher humidity at night. Further, daytime is a less suitable time to collect termites as temperatures are high and humidity is low.

The results of descriptive statistical analysis formed the basis of interferential statistical analysis required to test the researcher's beliefs about the effect of types of baits and environmental conditions.

4.3 Regression analysis and hypothesis testing

Regression analysis is used to determine the relationship between variables and measures the strength of association between two or more variables (Kothari, 2004). The current study hypothesized a relationship between the type of organic baits used and environmental conditions on the count of *Macrotermes bellicosus* harvested.

To test the two hypotheses considered in the current study means and standard deviations of the count of termites harvested were used to conduct ANOVA tests. First, regression analysis enabled the researcher to test the difference in the effects of the five types of organic baits on the count of termites collected. Second, it facilitated testing of the difference in the effect of temperature and humidity, and use of earthen pots or plastic containers at night or in the day on the count of termites collected.

4.3.1 Effect of organic baits on the count of *Macrotermes bellicosus* harvested

The first objective in this study was to identify the preferred organic bait for the mass harvesting of *Macrotermes bellicosus*. To determine the preferred organic bait the study tested the hypothesis that there is no statistically significant difference in attraction of *Macrotermes bellicosus* to different organic baits. Table 8 presents the results of the Least Significance Difference Test for the mean count of termites collected using earthen pots and plastic containers.

Table 8

Mean significance difference in attraction to different organic baits.

	Type of Container	
	Earthen Pot	**Plastic Container**
Baits	**Mean count ± SE**	**Mean count ± SE**
Dry maize straws	2,919 ± 6.97^{a}	1,543 ± 3.99^{a}
Dry rice husks	2,286 ± 5.13^{b}	943 ± 3.00^{b}
Dried Napier grass	1,775 ± 4.55^{c}	653 ± 3.97^{c}
Decaying log *Eucalyptus*	1,513 ± 4.69^{d}	444 ± 3.76^{d}
Dried *Lantana* twigs	1,440 ± 3.78^{d}	287 ± 2.61^{e}

Mean values in a column followed by unlike letter (s) are significantly different at 5% level using LSD test.

Source: Field experiment data (2022)

The results of the Least Difference (LSD) Test, presented in Table 8, shows that at a 5% level of significance there were significant differences in the mean count of termites trapped using the five different types of organic baits.

Further, as evident from Table 8, the differences were still significant irrespective of the type of container used to collect the termites. As shown in Table 8, the maximum harvest of termites was obtained from the use of maize straws, of 2,919 in earthen pots and 1,543 in plastic containers were statistically different ($p<0.05$) with all the other treatment. Also, the mean count of termites for Rice husks, Napier, *Eucalyptus* log and Lantana twigs were statistically different ($p<0.05$) with each other in both experiments, except in one case.

This exception, is evident in Table 8, from the similarity of superscripts following the mean counts for eucalyptus and lantana twigs, in which there wasn't a statistically significant difference ($p<0.05$). Further, Table 8 shows that *Lantana* twigs had the least ($p<0.05$) number of termite-catch in both setups. This was unique in the experiment where termites were trapped in plastic containers but did not differ significantly ($p>0.05$) with those attracted by *Eucalyptus* logs where termites were attracted using earthen pots.

An ANOVA test was carried out to the hypothesis that there is no statistically significant difference in attraction of *Macrotermes bellicosus* to the five organic baits. The result of the test of overall statistical significance in the difference of termite counts for the five types of baits is presented in Table 9.

Table 9

ANOVA on the effect of organic bait type on the count of Macrotermes bellicosus

Variation	DF	Sum of squares	Mean sum of squares	F-value	P-value
Baits	4	192,269,283	48,067,321	114.844	2e-16 *
Period	1	760,174	760,174	1.816	0.178
Residuals	624	261,171,756	418,544		

* Implies significance at 5% level of significance

The last column of Table 9 labeled *p* shows the significance of the statistical test applied to the hypothesis. To reject or accept a hypothesis, the *p* value in Table 9 is compared to the critical value of p =0.05. The universal rule in all statistical tests is that, the decision about significance is made by checking if the computed value of *p* is smaller than the significant alpha level of 0.05. In Table 9, the *p*-value associated with the first source of variation, namely the organic baits used in trapping of termites was 2^{e-16} and less than the decision value of 0.05. This is interpreted to mean that that there is a statistically significant difference in the effectiveness of the various types of organic baits on the count of termites harvested. Accordingly, based on the ANOVA results in Table 9, the null hypothesis that there is no statistically significant difference in effectiveness of organic baits for the mass trapping of termites is rejected.

It can therefore be concluded, from the ANOVA test results in Table 9, that the various organic baits differed significantly in their ability to trap termites. In particular, as indicated in Table 8, the most preferred organic bait by termites, as determined by the highest mean count (2,919) was dried maize straw.

4.3.2 Effect of environmental factors on *Macrotermes bellicosus* harvested

The second objective of the study was to determine the effect of environmental factors on the count of *Macrotermes bellicosus* harvested. Table 10 provides the summary statistics of the effect of environmental factors on the count of termites harvested.

Table 10

Effect of environmental factors on the count of termites harvested

Collection Period	Mean Temp (^{0}C)	Mean RH (%)	Mean Count from Earthen Pot Containers	Mean Count from Plastic Containers
Day	30.2±0.13	69.1±0.50	1,952±16.1	742±8.82b
Night	22.1±0.04	91.0±0.10	2,021±14.5	806±9.49a
	*	*	NS	*

NS=Not significant; *implies significant at 5% level of significance

As Table 10 shows, the mean count of termites harvested were highest (mean = 2021) when termites were collected overnight, in earthen pots. This coincided with the lowest mean temperatures of 22.1 ^{0}C and highest mean relative humidity of 69.1 %.

From Table 10, the effects of temperature, relative humidity and plastic containers had a statistically significant effect on the count of termites collected at the 5% level of significance. However, the effect of earthen pots did not have a statistically significant effect on the count of termites harvested.

The data in Table 10 was used to carry out an ANOVA of the effect of environmental factors on the count of termites harvested. The study tested the hypothesis that environmental factors do not have a statistically significant effect on the count of *Macrotermes bellicosus* harvested. Table 11 presents the results of ANOVA tests of the statistical significance of the effects of types of containers, time of collection, temperature and humidity on the count of termites harvested.

Table 11

ANOVA on the effects of environmental factors on the count of termites harvested

	Variation	DF	SS	MSS	F - value	P - value
	Collection Period	1	57,201	57201	0.7526	0.002116*
Earthen Pots Containers	s(avg_temp)	1	952,669	952,669	12.5343	0.001248 *
	s(avg_RH)	1	394781	394,781	5.1941	0.029475 *
	Residuals	32	2,432,203	76,005		
Plastic Containers	Collection Period	1	141,748	141,748	4.9468	0.0333188 *
	s(avg_temp)	1	543,961	543,961	18.9833	0.0001272 *
	s(avg_RH)	1	118	118	0.0041	0.0492459 *
	Residuals	32	916,966	916,966		

Note: s (avg_temp) is the smoothing function of the average temperature
s (avg_RH) is the smoothing function of the average relative humidity
*implies significant at 5% level of significance

As evident in Table 11, the ANOVA test shows that the effect of temperature (*p* = 0.001248, for collection in pots and *p* = 0.0001272 for collection in plastic containers) was less than the critical *p-value* of 0.05%. Also, it is evident that the effect of relative humidity (RH) (*p* = 0.029475, for collection in earthen pots and *p* = 0.0492459 for collection in plastic containers) was less than the critical *p-value* of 0.05%. Further, the effect of collection period (*p* = 0.002116, for collection in pots and *p* = 0.0333188 for collection in plastic containers) had a statistically significant effect on the count of termites harvested. Evidently, as the computed value of *p* was less than the critical value of *p* of 0.05.

4.4 Summary of results of hypothesis testing

The first null hypothesis (H_1) that there is no statistically significant difference in the count of *Macrotermes bellicosus* attracted to different organic baits was rejected. It was therefore concluded that there was a statistically significant difference in the count of termites attracted to the different organic baits. The second null hypothesis (H_2) that environmental factors have no statistically significant effect on the count of *Macrotermes bellicosus* harvested was rejected, hence environmental factors had a statistically significant effect on count of termites harvested.

CHAPTER FIVE
DISCUSSIONS

5.1 Introduction

The current chapter discusses the findings in chapter four in light of related studies reviewed in chapter two. The previous findings are discussed in light of the current findings on the most preferred organic bait, the effect of types of trapping containers as well as the time of collection and environmental conditions.

5.2 Effect of Organic Baits on the count of *Macrotermes bellicosus* harvested

Termite preferences for organic baits have been a subject of studies that were conducted in conditions that are dissimilar to those in equatorial Africa. This has made it difficult to identify an optimal bait type that may be used in the mass harvesting of termites. To fill this gap, the current study is designed to provide additional evidence on termite preference for organic baits that are abundant in equatorial climate. The current study provides empirical evidence that maize straw, which are abundant in the equatorial climate, in counties such as Siaya, is most preferred organic bait for mass trapping of Macrotermes bellicosus. The finding that maize straws were the preferred organic bait in the mass trapping of termites was evident when both types of containers were used in the mass trapping of Macrotermes bellicosus. In particular, the results of the two experiments of 2919 and 1543 termites harvested, were statistically different ($p<0.05$) with all the other treatment. This finding confirms previous research that have suggested that baits with cellulose may be the preferred bait for trapping termites, in equatorial Africa.

Research by Mali et al., (2019) suggested that termites prefer food with high levels of cellulose. On the other hand, since lignin is harder to digest termites do not like it compared to other baits (Judd and Corbin, 2009). Although there is no evidence to conclude that termites have cellulose receptors, it is thought that termites break down the cellulose in their guts and determine the sugar concentrations (Waller ***et. al.***, 2014).

Foods rich in sugars such as glucose are a preference to termites (Abushama and Kambal, 1977; Deborah, Waller and Curtis, 2003). Castillo et al., (2013) had demonstrated that addition of sugars to bait enhanced termite presence in those baits. Thus, the linkage of sugars with cellulose could be the answer to termite's preference of maize straws irrespective of the types of containers used to trap termites. The preference for foods with greater cellulose concentrations could also be adaptive for termites and their symbionts in that higher cellulose concentration would be more digestible (Paulo ***et. al.,.*** 2011).

Wood such as Eucalyptus and Lantana which have higher indigestible components including lignin can prevent digestion hence reduced feeding rate or preference (Deborah. Waller and Curtis, 2003). This is also in concurrence with Waller et al., (1990) who suggested that the amount of cellulose per unit area be considered in a bait selection study with termites. The termites could also have made their choices based on nutrient value such as levels of nitrogen, phosphates and micronutrients or proportions of digestible components in the food source. Preference of termites to maize of stalk is also in agreement with findings by both Peden et al., (2013) and Wang and Henderson (2012) demonstrating termite preference to maize in laboratory and field experiments respectively. Mali et al., (2019) also suggested that termites had high affinity to maize due to high presence of organic carbon and simple sugars.

Eucalyptus and Lantana are known for the toxic substance, known as allelopathy, which repels termites (Mali et al., 2019). The allelochemicals released from chopped Eucalyptus logs could thus have led to reduced liking compared with the rest of the diets. Mali et al., (2019) also observed that some tree species such as pine are repellants due to production of allelochemicals to naturally deter insect feeding. This property might have worked against Eucalyptus logs being preferred in the current study. It may be concluded that for the mass trapping of termites, in equatorial Africa, the widely available maize stalks ought to be used to optimize the count of termites.

5.3 Effect of environmental factors on the count of *Macrotermes bellicosus* harvested.

The current study sought to provide empirical evidence on the effect of the environmental factors on the count of termites harvested.

To establish the effect of environmental factors the study investigated the effect of temperature and humidity as key environmental factors that drive the count of termites harvested. Following previous studies, the research sought to determine if the use of natural or artificial containers for trapping of termites and the time of their collection, all environment related factors have on the count of termites harvested. From the results it is evident that environmental factors have an effect on the count of termites harvested. The study found out that the use of earthen pots would result in more termites in comparison with plastic containers. In particular, it was established that use of natural containers was more effective collection containers, as they mimicked the type of environmental conditions termites require to survive. In particular, it may be argued that use of earthen pots enabled the researcher to naturally control the effects of confounding factors, such as temperatures and relative humidity. Further, the use of plastic containers may have resulted in the suffocation of termites, as plastic containers trapped heat.

The explanation, in the current study of the effect of containers and collection times, as surrogates of environmental variables resonates with earlier findings that humidity and temperature determine the distribution and availability of termites (Loise and Nan, 2017). Further, the findings that the termite counts are higher, the higher the relative humidity and lower their temperatures, support assertions that termites love moist environments (Boafo et al., 2019b). Perhaps this is why in the current experiment, termites were less attracted to traps that consisted of a non-natural objects, such as plastics that may have instead acted as natural barriers rather than a preferred container for mass trapping of termites.

The current study sought to find out if the time of collection was a significant effect on the count of termites harvested. In particular, it sought to establish whether the time of day or night at which the termites were collected influenced the count of termites collected. The finding that the time of collection was a significant determinant of the count of termites supports earlier findings by Dao et al., (2020) that termites are sensitive to temperatures and drive deep in the subterranean part of the nest during the day when the sun is shining. The findings in this study provide empirical support to the assertion that the maximum count can be obtained in the morning. The finding of a high termite count in the morning confirms earlier findings on the significance of collection times.

The time of collection was a statistically significant determinant of termite counts is in line with previous findings that termites drive deep in the subterranean part of the nest during the day when the sun is shining (Dao et al., 2020). While the time of collection and type of containers were used as indirect variables to capture the best techniques, regarding container types and collection times that suited the environment for termites. In addition, it sought to establish the effect of environmental factors, using the most often cited direct measures of environmental factors, namely temperatures and humidity. The results show that termites were less available in the day when temperatures were high and humidity was low. The findings confirm that termites were more available at night possibly as a result of lower temperatures and higher humidity at night. It was established that nights were relatively colder and more humid than days hence the higher number of termites lured to the baits at night.

The finding on the effect of temperature and relative humidity supports earlier findings by Boafo et al., (2019b) that termites require moist environments, to forming mud tubes that bridge the distance between their tunnels and their food. Zukuwuski and Su (2017) found that high relative humidity was preferred by most termite species when studying termite survival when exposed to different levels of relative humidity. A study by Loise and Nan (2017) established that soil chemical composition, moisture and humidity dictates the availability of the termites. They also established that cooler nights with less evaporative potentials saw more termite activity and less stress in burrowing and looking for organic baits in this experiment. It is clear that from the findings in this study that it would be more efficient to place baits overnight and collect termites in the morning rather than do it during the day albeit more pronounced in plastic container pits.

It may be concluded that findings in the current study amplify earlier work in the context of an equatorial environmental conditions, such as that which obtains at Mbaga hills, in Siaya County, Kenya. Like in previous studies the experiments, in the current study demonstrate the statistical significance of the type of organic bait and environmental conditions, on the count of termites trapped and collected.

The current chapter provided a discussion of the findings in light of the earlier work on the themes of termite harvesting, environmental conditions and techniques of harvesting, including the time of collection and type of container for collection of termites.

CHAPTER SIX
CONCLUSIONS AND RECOMMENDATIONS

6.1 Introduction

The study focused on the determination of effective organic baiting techniques for the mass harvesting of *Macrotermes bellicosus* for use as an alternative source of proteins for poultry. The current chapter draws conclusions and recommendations from the results of the study. Included are conclusions on the most suitable organic baits and techniques of collection, as suggested by the effect of temperature and moisture on their foraging behavior. Recommendations for the policy and practice of food security and sustainable agriculture are also adduced from the results of this study.

6.2 Conclusions

A number of conclusions can be drawn from the findings on the most suitable bait and choice of container and the time of collection. First, from the finding that the organic bait types used had significantly different effects on the count of termites collected, it may be concluded that maize straws are the most effective bait. Second, three conclusions may be drawn from the findings on the effects of environmental factors, namely humidity and temperature, collection containers and time of collection, on the count of *Macrotermes bellicosus* harvested.

The first conclusion, related to environmental factors, arises from the finding that the low temperatures at night had a statistically significant difference on the count of termites collected during the day and at night. It may be concluded that in considering the most suitable baiting technique, the influence of temperatures on the time of collection cannot be ignored. In particular, it may be concluded that the best technique of trapping termites of the *Macrotermes bellicosus* species ought to include the period of collection. Thus it can be concluded that collection of termites at night offers the most suitable period owing to the effect of lower night temperatures on the count of *Macrotermes bellicosus* harvested.

The second conclusion, related to the effect of environmental factors, derives from the effect of relative humidity on the count of *Macrotermes bellicosus* collected. It may be concluded that arising from the higher count of *Macrotermes bellicosus* collected at higher relative humidity at night, an optimal organic baiting technique ought to include the effect of relative humidity.

Thus it can be concluded that an optimal technique for collection ought to consider the influence of higher humid conditions occurring at night, hence collect *Macrotermes bellicosus* very early at 6 am when it is still humid is an important consideration in deciding on the optimal organic baiting technique for the mass harvesting of Macrotermes bellicosus.

The third conclusion, arising from the effect of environmental factors, derives from the effect of earthen containers on temperature and humidity in the bait stations. It may be concluded that since the type of containers used had a statistically significant difference on the count of *Macrotermes bellicosus* harvested, an optimal technique for the mass harvesting of *Macrotermes bellicosus* ought to consider the type of containers used. In particular, the use of natural earthen pots, owing to their effect of lowering temperatures and increasing humidity, are better that plastic containers for the mass trapping of Macrotermes bellicosus.

In a nutshell, it can be concluded that an optimal technique for the mass trapping of *Macrotermes bellicosus* ought to consider the effects of bait type, container type, and period of collection. From the findings in the experiments, the effective organic baiting technique ought to consider the type of organic bait used, type of container used and the time at which termites are collected.

Previous studies by Ayieko et al., (2010), and Fiaboe and Nakimbugwe (2017) explored the use of different baits to trap termites for poultry feeding. It can be concluded that the current study adds to this stream of research and has aided in the determination of effective organic baiting technique for the mass harvesting of *Macrotermes bellicosus* for use as an alternative source of protein for poultry. More significantly, the current study answers the call for further research and innovations on methods of collecting termites among poultry farmers by Van-Huis et al., (2013).

6.3 Recommendations

The finding from this study leads to a number of practical and policy recommendations in relation to the determination of an effective organic baiting technique for the mass harvesting of m Macrotermes bellicosus. The first practical recommendations is derived from the effect of type of organic baits used on the count of *Macrotermes bellicosus* harvested. To begin with, it was evident that the most effective organic bait is maize straws. Thus, it may be recommended that poultry farmers interested in mass harvesting of *Macrotermes bellicosus* ought to acquire huge stocks of dries maize straws that should then be used to continually bait *Macrotermes bellicosus* by setting traps around their mounds.

The second practical recommendation for farmers is derived from the effect of environmental factors on the count of *Macrotermes bellicosus* harvested. It can be recommended that farmers set up traps by placing inverted earthen pots filled with dried maize stalks in holes dug up around mounds of Macrotermes bellicosus. The use of earthen pots as opposed to plastic containers will ensure that farmers trap more termites in an environmentally sustainable manner. Earthen pot containers are natural and hence bio degradable, in addition to being able to create a conducive environment for the sustainable mass trapping of Macrotermes bellicosus. This recommendation on the use of earthen pots is a more environmentally sustainable practice as opposed to the traditional practice of destroying the *Macrotermes bellicosus* mounds. Another practical recommendation for farmers, deriving from environmental factors, is that termites ought to be trapped overnight as the environment is more humid and cooler than during the day. It may be recommended that traps be set up at night and termites collected in the morning at 6 am and not in the evening as less termites would have been trapped during the day.

In addition to the practical recommendations to farmers that derive from the findings of the current study, there are also important policy recommendations that may be made from the results of the study. The first policy recommendations derives from the finding that maize stalks are the optimal type of organic bait for the mass trapping of termites. The ministry of agriculture, can consider having a policy aimed at enhancing the sustainable harvesting of *Macrotermes bellicosus* through encouraging use of maize stalks. In particular, the policy can target the setting up of agricultural extension services, at County or National level, to train farmers on alternative and more sustainable approaches to sourcing protein for their poultry.

Currently, there is no policy framework that supports sustainable harvesting of termites in Kenya, and traditional approaches, involving the destruction of *Macrotermes bellicosus* mounds is common. Thus, it may be recommended that the ministry of agriculture ought to develop a policy on harvesting *Macrotermes bellicosus* that support the use of a more effective technique for baiting and harvesting termites involving the use of earthen pots and the collection of termites in the morning.

Recommendations on additional further research on the optimal baiting technique for the mass harvesting of *Macrotermes bellicosus* can be derived from the inherent limitations in the methods chosen to conduct the current research.

First, it may be recommended that laboratory experiments ought to be set up for a better control of the influence of bait type, container type and time of collection on the count of termites harvested. In particular, laboratory experiments would provide a more accurate set up to isolate the mediating effects of type of container and time of collection on the influence of temperature and humidity on the count of *Macrotermes bellicosus* harvested. Second, the experiments in the current study, were carried out in an area whose climatic conditions is equatorial. Thus it may be important to replicate the study in temperate or tropical environmental conditions. Also, future work could focus on determining the influence of other types of organic baits, in addition to the five considered in the current study.

Finally, as utilization of termites as a source of proteins for poultry will go a long way in bringing down the costs of poultry feeds, more studies are necessary to compare effectiveness of other types of baits and the baited container techniques. Perhaps experiments involving moist baits or adding of glucose to the bait may be more instructive of the techniques that may yield the highest count of termites harvested. Finally, there is strong need to carry out further research towards solving the food security challenges facing humanity world over, utilizing different species of insects as a source of proteins

The current study adds to the empirical studies on the use of insects as an alternative source of proteins for poultry. In particular, it has enhanced knowledge about the technique of using organic baits to trap termites using an environmentally sustainable approach. Arising from the findings it can be concluded that traditional methods of mound destruction are less sustainable and with an enabling policy, farmers can be trained on the more sustainable technique for the mass harvesting of Macrotermes bellicosus. Since the traditional destruction of mounds is not a sustainable technique for continual harvesting of termites, it should be discouraged. Thus instead of farmers destroying mounds in search of termites, they ought to set up traps, that simulate environmental conditions suitable for termites, for the continuous harvesting of termites. Thus the baited container technique is more recommended for the sustainable harvesting of termites for use as an alternative source of proteins for poultry.

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REFERENCES

Abushama, F. T., & Kambal, M. A. (1977). The role of sugars in the food-selection of the termite Microtermes traegardhi (Sjost.). Zeitschrift Für Angewandte Entomologie, 84(1–4), 250–255. https://doi.org/10.1111/j.1439-0418.1977.tb04285.x

Ayieko, M., Oriaro, V., & Nyambuga, I. . (2010). Processed products of termites and lake flies: improving entomophagy for food security within the lake Victoria region. African Journal of Food, Agriculture, Nutrition and Development, 10(2).

Banjo, A., Lawal, O., & Songonuga, E. (2006). The nutritional value of fourteen species of edible insects in southwestern Nigeria. African Journal of Biotechnology, 5(3).

Birech, E. (2002). Feed and Nutrient intake of free-ranging chickens in Nakuru District, Kenya.

Boafo, H. A., Affedzie-Obresi, S., Gbemavo, D. S. J. C., Clottey, V. A., Nkegbe, E., Adu-Aboagye, G., & Kenis, M. (2019b). Use of Termites by Farmers as Poultry Feed in Ghana. MDPI, 10(3). https://doi.org/https://doi.org/10.3390/insects10030069

Castillo, V. P, Sajap, A, & Sahari, M.H. (2013). Feeding Response of Subterranean Termites Coptotermes curvignathus and Coptotermes gestroi (Blattodea: Rhinotermitidae) to Baits Supplemented With Sugars, Amino Acids, and Cassava. Journal of Economic Entomology 106(4):1794-801. DOI:10.1603/EC12301

Cheik, S., Shanbhag, R. R., Harit, A., Bottinelli, N., Sukumar, R., & Jouquet, P. (2019). Linking Termite Feeding Preferences and Soil Physical Functioning in Southern-Indian Woodlands. MDPI, 10(1). https://doi.org/https://doi.org/10.3390/insects10010004

Dao, A. N. C., Sankara, F., Pousga, S., Coulibaly, K., Nacoulma, J. P., Ouedraogo, S., Kenis, M., & Somda, I. (2020). Traditional methods of harvesting termites used as poultry feed in Burkina Faso. International Journal of Tropical Insect Science, 40(1), 109–118. https://doi.org/10.1007/s42690-019-00059-w

Dao, Aïchatou Nadia Christelle, Sankara, F., Pousga, S., Coulibaly, K., Nacoulma, J. P., Ouedraogo, S., Kenis, M., & Somda, I. (2020). Traditional methods of harvesting termites used as poultry feed in Burkina Faso. International Journal of Tropical Insect Science, 40(1), 109–118. https://doi.org/10.1007/s42690-019-00059-w

FAO. (2018). Soil pollution: a hidden reality. In Food and Agriculture Organization.

Farina, L., Demey, F., & Hardouin, J. (1993). Termite production for traditional poultry breeding in Togo. In AGRIS, 9(4), 181–187.

Fiaboe, K., & Nakimbugwe, D. (2017). Integrating insects in poultry and fish feed in Kenya and Uganda.

Judd, T. M., & Corbin, C. C. (2009). Effect of Cellulose Concentration on the Feeding Preferences of the Termite Reticulitermes flavipes (Isoptera: Rhinotermitidae). Sociobiology, 775–784.

Kenis, M., Koné, N., Chrysostome, C., Devic, E., Koko, G., Clottey, V., Nacambo, S., & Mensah, G. (2014). Insects used for animal feed in West Africa. Entomologia, 2(2). https://doi.org/https://doi.org/10.4081/entomologia.2014.218

Khan, A., & Ahmad, W. (2018). Termites and Sustainable Management. Termites and Sustainable Management, March. https://doi.org/10.1007/978-3-319-72110-1

Kothari, C.R. (2004) Research Methodology: Methods and Techniques. 2nd Edition, New Age International Publishers, New Delhi.

Kingori, A., Tuitoek, J., Muiruri, H., & Wachira, A. (2003). Protein requirements of growing indigenous chickens during the 14-21 weeks growing period. South African Journal of Animal Science, 33(2). https://doi.org/10.4314/sajas.v33i2.3759

Kinyuru, J. N., Konyole, S. O., Roos, N., Onyango, C. A., Owino, V. O., Owuor, B. O., Estambale, B. B., Friis, H., Aagaard-Hansen, J., & Kenji, G. M. (2013). Nutrient composition of four species of winged termites consumed in western kenya. Journal of Food Composition and Analysis, 30(2), 120–124. https://doi.org/10.1016/j.jfca.2013.02.008

Kivunja, C. (2018) . Distinguishing between Theory, Theoretical Framework, and Conceptual Framework: A Systematic Review of Lessons from the Field. http://ijhe.sciedupress.com International Journal of Higher Education Vol. 7, No. 6; 2018

Loise N, Nan K, (2020). Moisture alone is sufficient to impart strength but not weathering resistance to termite mound soil. R Soc Open Sci. 2020 Aug; 7(8): 200485. Doi: 10.1098/rsos.200485

Mali, B., Okello, S., Ocaido, M., Nalule, A. S., & Celsus, S. (2019). Organic Baiting of Subterranean Termites. 12(9), 11–14. https://iosrjournals.org/iosr-javs/papers/Vol12-issue9/Series-2/C1209021114.pdf

MOA. (2018). Climate Risk Profile for Siaya County. Retrieved Jauary 2020. https://cgspace.cgiar.org/rest/bitstreams/119954/retrieve

MOLD. (2006). Animal Production Division, Kenya. Annual Report.

Munyuli Bin Mushambanyi, T., & Balezi, N. (2002). Use of cockroach and termites as potential substitutes of meal meat in broilers feeding in South-Kivu, Democratic Republic of Congo. In AGRIS, 20(1), 10–16.

Nan-Yao, S. (2019). Development of Baits for Population Management of Subterranean Termites. Annual Review of Entomology, 64, 115–130.
https://doi.org/https://doi.org/10.1146/annurev- ento-011118-112429

Ntukuyoh, A. I., Udiong, D. S., Ikpe, E., & Akpakpan, A. E. (2012a). Evaluation of Nutritional Value of Termites (Macrotermes bellicosus): Soldiers, Workers, and Queen in the Niger Delta Region of Nigeria. International Journal of Food Nutrition and Safety, 1(2), 60–65.

Ntukuyoh, Udiong, Ikpe, & Akpakpan. (2012b). Evaluation of Nutritional Value of Termites (*Macrotermes bellicosus*): Soldiers , Workers , and Queen in the Niger Delta Region of Nigeria. International Journal of Food Nutrition and Safety, 1(2), 60–65.

Oonincx, D. G. A. B. A. B., van Itterbeeck, J., Heetkamp, M. J. W. W., van den Brand, H., van Loon, J. J. A. A., & van Huis, A. (2010). An exploration on greenhouse gas and ammonia production by insect species suitable for animal or human consumption. PLoS ONE, 5(12), 1–7. https://doi.org/10.1371/journal.pone.0014445

Oyarzun, S. E., Crawshaw, G. J., & Vaides, E. V. (1996). Nutrition of the Tarnandua : 1 . Nutrient Composition of Termites (Nasutitermes spp .) and Stomach Contents From Wild Tamanduas (Tamandua tetradactyla). 524(1 996).

Paul, D., & Sudipta, D. (2011a). Assessment of the nutritive value of some wild edible insects of Meghalaya, North East India. Journal of Entomological Research, 35(4), 353–358.

Paul, D., & Sudipta, D. (2011b). Nutrient content of sexual and worker forms of the subterranean termite, Reticulitermes sp. Indian Journal of Traditional Knowledge (IJTK), 10(3), 505–
` 507. http://hdl.handle.net/123456789/12030

Peden, D., Swaans, K., Mpairwe, D., Geleta, N., Zziwa, E., Mugerwa, S., Taye, H., & Legesse, H. (2013). Improving agricultural water productivity through integrated termite management. IN: Wolde, M. (Ed). 2013, Rainwater Management for Resilient Livelihoods in Ethiopia: Proceedings of the Nile Basin Development Challenge Science Meeting, Addis Ababa, 9–10 July 2013. NBDC Technical Report 5. Nairobi, Kenya: ILRI.

Pousga, S., Boly, H., Lindberg, J. E., & Ogle, B. (2007a). Effect of supplements based on fishmeal or cottonseed cake and management system on the performance and economic efficiency of exotic hens in Burkina Faso. African Journal of Agricultural Research, 2(10), 496–504.

Pousga, S., Boly, H., Lindberg, J. E., & Ogle, B. (2007b). Evaluation of traditional sorghum (Sorghum bicolor) beer residue, shea-nut (Vitellaria paradoxa) cake and cottonseed (Gossypium Spp) cake for poultry in Burkina Faso: Availability and amino acid digestibility. International Journal of Poultry Science, 6(9), 666–672. https://doi.org/10.3923/ijps.2007.666.672

Ravitch, S. M. & Riggan, M. (2017). How conceptual frameworks guide research. 2 nd Edn. Los Angeles, CA: Sage.

Ravindran, V., & Blair, R. (1993). Feed resources for poultry production in Asia and the Pacific. III. Animal protein sources. World's Poultry Science Journal, 49(3), 219–235. https://doi.org/10.1079/WPS19930020

Sankara, F., Pousga, S., Dao, N. C. A., Gbemavo, D. S. J. C., Clottey, V. A., Coulibaly, K., Nacoulma, J. P., Ouedraogo, S., & Kenis, M. (2018). Indigenous knowledge and potential of termites as poultry feed in Burkina Faso. Journal of Insects as Food and Feed, 4(4), 211–218. https://doi.org/10.3920/JIFF2017.0070

Sogbesan, A. O., & Ugwumba, A. A. A. (2008). Nutritional Evaluation of Termite (Macrotermes subhyalinus) Meal as Animal Protein Supplements in the Diets of Heterobranchus longifilis (Valenciennes, 1840) Fingerlings. Turkish Journal of Fisheries and Aquatic Sciences, 8(1), 149–158.

Tacon, A. G. J., & Metian, M. (2008). Global overview on the use of fish meal and fish oil in industrially compounded aquafeeds: Trends and future prospects. Aquaculture, 285(1–4), 146–158. https://doi.org/10.1016/j.aquaculture.2008.08.015

Tschirner, M., & Simon, A. (2015). Influence of different growing substrates and processing on the nutrient composition of black soldier fly larvae destined for animal feed. Journal of Insects as Food and Feed, 1(4), 249–259. https://doi.org/10.3920/JIFF2014.0008

Van-Huis, A., Van-Itterbeeck, J., Klunder, H., Mertens, E., Halloran, A., Muir, G., & Vantomme, P. (2013). Edible insects. Future prospects for food and feed security. In Food and Agriculture Organization of the United Nations (Vol. 171).

Van Huis, A. (2017). Cultural significance of termites in sub-Saharan Africa. Journal of Ethnobiology and Ethnomedicine, 13(1), 1–12. https://doi.org/10.1186/s13002-017-0137-z

Varelas, V., & Langton, M. (2017). Forest biomass waste as a potential innovative source for Rearing edible insects for food and feed – A review. Science Direct; Elsevier, 41, 193–205. https://doi.org/https://doi.org/10.1016/j.ifset.2017.03.007

Waller, D. A., Jones, C. G., & La Fage, J. P. (1990). Measuring wood preference in termites. Entomologia Experimentalis et Applicata, 56(2), 117–123. https://doi.org/10.1111/j.1570-7458.1990.tb01388.x

Debora A., Waller A., & Curtis, A. D. (2003). Effects of sugar-treated foods on preference and nitrogen fixation in Reticulitermes flavipes (Kollar) and Reticulitermes virginicus (Banks) (Isoptera: Rhinotermitidae). Annals of the Entomological Society of America, 96(1), 81–85. https://doi.org/10.1603/0013-8746(2003)096[0081:EOSTFO]2.0.CO;2

Wang, C., & Henderson, G. (2012). Evaluation of Three Bait Materials and Their Food Transfer Efficiency in Formosan Subterranean Termites (Isoptera: Rhinotermitidae). Journal of Economic Entomology, 105(5), 1758–1765. https://doi.org/https://doi.org/10.1603/EC12201

Waithanji, E, Affognon, D, H, Kingori, S & Diiro, G (2019). Insects as feed: Gendered knowledge attitudes and practices among poultry and Pond Fish farmers in Kenya. NJAS: wageningen journal of life sciences 92(June):100312 DOI:10.1016/j.njas.2019.100312

Zukowski, J., & Su, N. Y. (2017). Survival of Termites (Isoptera) Exposed to Various Levels of Relative Humidity (RH) and Water Availability, and Their RH Preferences. Florida Entomologist, 100(3), 532–538. https://doi.org/10.1653/024.100.0307

Appendix 1: Researcher taking data on count of termites harvested

Source: Researcher

Appendix 2: Research assistants opening dug pits to remove termites

Source: Researcher

Appendix 3: Head of Macrotermes bellicosus.

Source (Dao et al., ***2019).***

Appendix 4: Mounds of Macrotermes bellicosus.

Source (Dao et al., ***2019).***

Appendix 4: Birds feeding on collected termites

Source: Researcher