

Full Length Research Paper

Determination of effective organic baiting technique for harvesting of termites (*Macrotermes Bellicosus*) for use as alternative protein for poultry

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Experiments at Mbaga hills of Siaya County in Kenya were aimed to determine the most effective organic baiting technique for mass harvesting of *Macrotermes bellicosus*. Around two separate mounds, 5 treatments replicated 3 times, using earthen pot and plastic containers with maize stocks, eucalyptus stems, lantana camara twigs, Napier grass and rice husks, were set up. Termite counts, at 6.00 am and 6.00 pm, and data on temperature and humidity, from a Hobo data logger were collected over the 21 days period. The data were analyzed using Analysis of Variance (ANOVA) at ($p=0.05$) and Least Significance Difference (LSD) tests. Substrate preference differed significantly ($p < 0.05$) with highest being maize (2,919). Mean termite count differed significantly by containers ($p < 0.05$) with highest being earthen pots (1787). Termite count at 6.00 am (2,021) differed significantly ($p < 0.05$) with at 6.00 pm (1,952). The count further differed significantly by temperature at night ($22.1\text{ }^{\circ}\text{C}$) and day (30.2 ± 0.13). Finally, count differed by relative humidity ($p < 0.05$) at night (91.0 ± 0.10) and day (69.1 ± 0.50). Results on the effect of bait type, container type, humidity and temperature on count of termites may have practical, policy and theoretical implications for sustainable agriculture.

Key words: *Macrotermes bellicosus*, substrate preference, mass trapping.

INTRODUCTION

Termites are the largest group of insect detritivores comprising 90% of the insect biomass within tropical forest soils, making them fundamental in decomposition process (Nan-Yao, 2019). They are revered within rural communities due to their use in soil fertility improvement and as a food resource for both human and livestock (Mali et al., 2019). Studies have confirmed that insect entomophagy is practiced by about two billion people on earth (Van-Huis et al., 2013). In Africa, Termites are among the most consumed insects (Kinyuru et al., 2013).

In West African states like Togo, Ghana, and Burkina Faso they have traditionally been used to feed poultry (Sankara et al., 2018). This begs the research question "Can *Macrotermes bellicosus* be harvested in large quantities for use as a sustainable and cheaper alternative source of poultry proteins?" The current study aims to determine an environmentally sustainable technique for the mass harvesting of *Macrotermes bellicosus* for use as an alternative source of protein in the manufacture of poultry feeds.

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Feeding poultry is costly with the cost of commercial feeds accounting for >70% of the total production cost (Sankara et al., 2018). The high costs of poultry feeds have been a major constraint with most farmers opting for free range indigenous birds. Even so, they still suffer from quantitative and qualitative food shortages (Pousga et al., 2007a, 2007b). This has affected supply of chicken meat and eggs and consequently reducing family incomes. The problem of high cost of feeds may be addressed if alternative sources of cheaper protein, such as termites, are explored. However, researchers are yet to determine the most effective organic baiting technique for the large scale harvesting of termites. Research on termite use as a cheaper source of protein in manufacture of poultry feeds is still in its infancy. Currently, research is yet to determine an environmentally sustainable technique for the mass harvesting of termites. As it stands, the protein component in poultry feeds is costly resulting to unaffordability by poor farmers. The current study seeks to address this problem by determining the most effective termite harvesting technique which is environmentally sustainable.

The literature on substrate preference suggests the use of maize stalks, rice husks, eucalyptus, lantana camara and Napier grass as suitable substrates for mass trapping of termites. Termites are usually found at sites with plant debris or dead animals, and can be spotted through the characteristic soils associated with termite tubes. The traditional baiting technique involves scrapping the soil with a hoe and then placing a trap consisting of a container, overturned and filled with humid organic matter. The trap is placed in the morning (6–8 am) or in the evening (around 6-7 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 (Dao et al., 2020). A variant of the method consists of placing the organic matter, e.g. cow dung, without a container, on the termite nests and tubes, and collecting the matter with termites by hand. Also, farmers may obtain termites by the less environmentally sensitive method of breaking termite mounds.

The use of termite remains a challenge as the traditional technique is not only destructive but may not be suited when high quantities are needed to feed a larger flock or to increase the proportion of proteins in their feeds. Because of this, many farmers stop feeding their poultry with termites, without finding alternative protein sources (Farina et al., 1993).

Other reasons for reduced usage of termites is the lack of time and the lack of knowledge of trapping technique (Boafo et al., 2019a). The development of sustainable

methods to trap and harvest termites is important for its successful use as alternative protein source for poultry in the traditional poultry keeping systems without affecting the environment and local biodiversity (Dao et al., 2020). Thus, the development of sustainable methods to collect, harvest and store termites is needed to ensure that traditional poultry farmers can provide protein feed to their birds without affecting the environment and local biodiversity (Dao, 2016; Ouedraogo, 2016; Boafo et al., 2019). The current study sought to identify suitable organic forage material and the best technique for collecting large quantities of termites for use as an alternative source of poultry protein.

MATERIALS AND METHODS

Study area

This study was carried out in Mbagha hills area in Hono sub location of Siaya County, Kenya. The County lies between latitude 0° 26' to 0° 28' North and longitude 33° 58' East and 34° 33' West with a total land surface area of 1520 Km². The county has six sub-counties namely; Ugunja, Yala, Ugenya, Siaya, Bondo and Rarieda. The 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. The study site has an altitude range from 1140 M to 1200 M above sea level, with equatorial climate. An average temperature range of 17°C at night to 28°C at day time with a relative humidity of 24% day time and 81% at night (MOA, 2018). The site was chosen as a study area since it had few farmers already involved in termite trapping but using traditional baiting techniques.

Experimental design

A random block experiment comprising of five organic baits (decaying logs of *Eucalyptus* tree, dry maize straws, dried *Lantana* twigs, dried remains of Napier grass and dried rice husks). Each experiment was carried out in 3 replicates and lasted for a period of 21 days. In both the control and experimental groups, termite bait stations were placed around 2 randomly selected active *Macrotermes bellicosus* mounds found within the same plot. Each mound was surrounded by 5 bait stations placed in a circle following Mali et al. (2019). Each experimental units involved hoe-dug circular holes of diameter 30 cm and 25 cm deep. These specifications take into account earlier findings by the researcher, during the preliminary study that most termites are found within a depth of 25cm below the ground.

Baits were uniformly prepared, chopped and packed in plastic containers as illustrated in Figure 1, and then put inside the 25 cm deep pits at uniform depths.

The baits packed in the plastic containers were covered lightly with top soil in the control group experiment 1. This was to provide a dark environment inside and ensure that the termites attracted to the baits are not exposed to 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 influence those in next hole to disappear into their tunnels. In experiment 2, which was the treatment group, equal amounts of the baits were packed in round earthen pots as illustrated in Figure 2.

The pots were also laid inside the holes in an inverted position to guard external weather factors of rainfall and direct sunlight from



Figure 1. Organic baits packed in plastic containers (Control group).
Source: Authors



Figure 2. Organic Baits packed in earthen pots.
Source: Authors

influencing termites' interactions with baits. The arrangements thus involved 2 plots (separate farm lands) with 5 treatments replicated 3 times within a block as shown in Figure 3.

Data collection

Termites were collected daily early in the morning (6 am) and late in the evening (6 pm) from the earthen pots and plastic containers.

Number of termites in each container was counted and recorded to give the count of termites attracted to each bait, for the control and treatment group experiments. The data collected was used to compute the average count of termites collected for determining the effect of container type on the count of termites. Temperature and humidity data were taken using Hobo data logger (HOBO ware 3.7.22) at hourly intervals for both day and night. An average and standard deviation of the temperature and relative humidity collected was computed to assess the effect of environmental

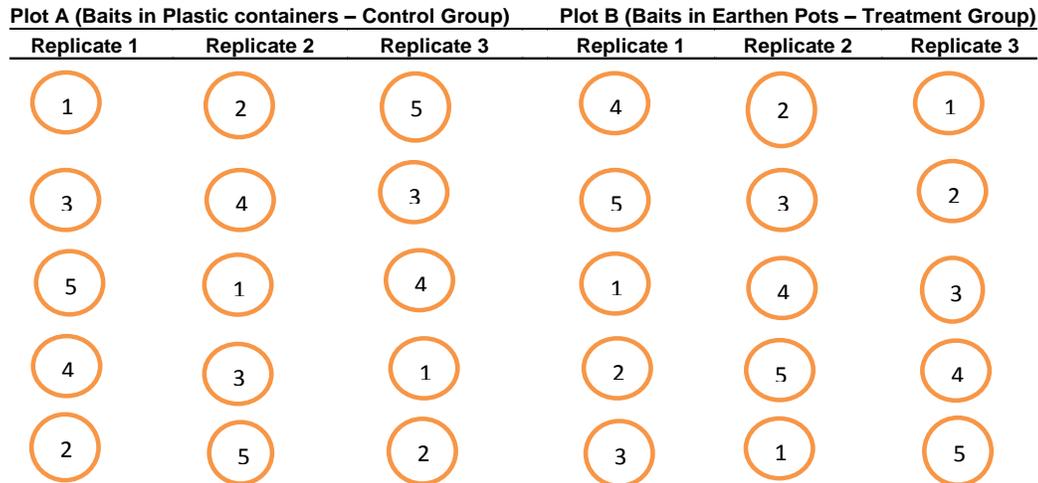


Figure 3. Arrangement of the control and treatment experiments across the plots. Cycle in plot A represent dug pits fitted with plastic containers while those in plot B represent dug holes fitted with earthen pots all containing baits numbered 1-5. 1, Log of *Eucalyptus* tree 2. Dry maize straws 3, Dried *Lantana camara* twigs 4. Dried remains of Napier grass 5. Dry Rice husks. Source: Authors

factors on the number of termites harvested.

Data analysis

The data analysis was done using R statistical software (R v4.0.2). Descriptive statistics consisting of mean and standard error were computed to facilitate tests of the hypothesis. Analysis of variance (ANOVA) was done to compare how the various baits performed in attracting termites. Mean separation between the baits used was done using least significant difference (LSD), for counts of termites collected in earthen pots and plastic containers. In all tests, the computed p value was compared with the critical p value to establish the statistical significance of the effects of bait type, container type, collection period, humidity and temperature, on the count of termites harvested. Where the computed p value was compared to the critical p value of 0.05 to test the hypothesis.

RESULTS AND DISCUSSION

Results

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 was no statistically significant difference in attraction of *Macrotermes bellicosus* to different organic baits. Table 1 presents the results of the Least Significance Difference Test for the mean count of termites collected using earthen pots and plastic containers.

Effect of type of organic bait on the count of termites

The results of the Least Difference (LSD) Test, presented

in Table 2, 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 1, the differences were still significant irrespective of the type of container used to collect the termites. As shown in Table 1, the maximum harvest of termites 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 1, 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 1 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 2.

The last column of Table 2 labeled *p* shows the significance of the statistical test applied to the hypothesis. To reject or not reject a hypothesis, the *p* value in Table 2 is compared to the critical value of $p = 0.05$. The universal rule in all statistical tests is that, the

Table 1. Mean significance difference in attraction of *Macrotermes bellicosus* to different organic baits.

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

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

Source: Authors

Table 2. Analysis of variance on the effect of organic baits on the count of *Macrotermes bellicosus* harvested.

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.

Source: Authors

Table 3. Summary statistics on the effect of environmental factors and the count of termites harvested.

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

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

Source: Authors

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 2, the p -value associated with the first source of variation, namely the organic baits used in trapping of termites was 2^{-16} and less than the decision value of 0.05. This is interpreted to mean 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 2, 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 2, that the various organic baits differed significantly in their ability to trap termites. In particular, as indicated in Table 1, the most preferred organic bait by termites, as determined by the highest mean count

(2,919) was dried maize straw.

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 3 provides the summary statistics of the effect of environmental factors on the count of termites harvested.

As Table 3 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 $^{\circ}$ C and highest mean relative humidity of 91.1 %. From Table 3, the effects of temperature, relative humidity and plastic

Table 4. Analysis of variance (ANOVA) on the effects of environmental factors on the count of *Macrotermes bellicosus* harvested.

	Variation	DF	SS	MSS	F - value	P - value
Earthen pots containers	Collection Period	1	201	57201	0.7526	0.002116*
	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		

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.
 Source: Authors

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 3 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 4 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.

As evident in Table 4, 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.

Summary of results of hypothesis testing

The first null hypothesis (H_1) states 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.

DISCUSSIONS

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

Termite preference for organic-based baits can be identified through their presence and activity within biomass litter. 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 has 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 (Brune, 2014). Foods rich in sugars such as glucose are a preference to termites (Abushama and

Kambal, 1977; 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.

Wood such as Eucalyptus and Lantana which have higher indigestible components including lignin (Curtis, 2004) can prevent digestion hence reduced feeding rate or preference. 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 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.

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 environments 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 (Swoboda, 2004). 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 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 Bofo et al. (2019b) that termites require moist environments, for forming mud tubes that bridge the distance between their tunnels and their food. Zukowski 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 Swoboda (2004) established that soil chemical composition, moisture and humidity dictate 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 was obtained at Mbagha 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.

Conclusion

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 *Macrotermes bellicosus* should be collected very early at 6 am when it is still humid this is an important consideration in deciding on the optimal organic baiting technique for the mass harvesting of *M. 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 termites harvested, an optimal technique for the mass harvesting of *M. 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 than plastic container for the mass trapping of termites.

In a nutshell, 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 mass harvesting of *Macrotermes bellicosus* for use as an alternative protein for poultry. More significantly, it answers the call for further research and innovations on methods of collecting termites among poultry farmers by Van-Huis et al. (2013).

RECOMMENDATIONS

Practical and policy 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 *Macrotermes bellicosus*. The first practical recommendations are 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. It is therefore important that poultry farmers acquire huge stocks of dry maize straws that should then be used to continually bait termites 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 termite 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 fewer termites would have been trapped during the day.

Policy recommendations

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 organic baits for the mass trapping of termites. The ministry of agriculture can consider enhancing the sustainable harvesting of *Macrotermes bellicosus* through encouraging use of maize stalks as a policy. In particular, the policy can target the setting up of agricultural extension services, at National and County levels, 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 will be important for the ministry of agriculture to develop a policy on harvesting *Macrotermes bellicosus* using a more effective and sustainable technique for baiting and harvesting. This will involve the use of earthen pots and the trapping of termites over night to be collected in the morning.

Recommendations for further study

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 are 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. Also, 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 for different livestock species.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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