Tanzania Journal of Science 50(5): 1016-1027, 2024
ISSN 0856-1761, e-ISSN 2507-7961

Effect of Alternative Rearing Substrates on the Growth, Reproduction and Nutritional Composition of the African Field Cricket *Gyrllus bimaculatus* (Orthoptera: Gryllidae)

Atujune Katabaro[1], Blanka Joseph[1] and Anitha Philbert[1]
[1]*Department of Zoology and Wildlife Conservation, University of Dar es Salaam, Dar es Salaam, Tanzania*
Email: philbert.anitha@udsm.ac.tz
https://dx.doi.org/10.4314/tjs.v50i5.10

Abstract

The increasing demand for animal protein to cater to the ever-growing human population has prompted the quest for alternative protein sources from insects. The field cricket *Gyrllus bimaculatus*, is one of the species of major interest, however, rearing of this species depends on the commercial chicken feed, which is expensive. This study explored the suitability of food remains in the rearing of this species. Three experimental food types were formulated from various food remains, and fed to crickets along with the commercial chicken feed for 14 weeks. Crickets that were fed on a combined diet of mixed food types performed better in terms of growth, biomass, and survivorship than their counterparts. Food types had a significant effect on the growth rate of the crickets, crickets that were fed on combined diet of mixed food types had the highest average weight of 405.70 ± 1.71 mg, whereas, crickets that were fed on the control diet had an average weight of 284.7±5.03 mg. Analysis of the nutritional composition of the harvested crickets yielded similar results of crude protein contents for crickets that were fed on control diet and combined diet with 54.70% and 50.70 % crude protein contents, respectively. Since the performance of crickets that were reared on locally available food remains was similar to the ones that were fed on a standard commercial diet, this simple diet presents a potential substrate for mass rearing of crickets which is cost-effective.

Key words: *Gyrllus bimaculatus*; crickets; animal protein; insect rearing; food remains

Introduction

The global human population is rapidly increasing and is expected to surpass 9 billion people in 2050 (Bawa et al. 2020). To meet the global food requirements, FAO estimates indicate that the global food production will need to expand by 60% from current levels in 2050 (Hanboonsong et al. 2013). The rapid human population increase has generated a rise in livestock production to meet the protein requirements of animal origin including meat, eggs, milk, etc (Finley 2020). The main ingredients of livestock feeds are usually corn, wheat, soybean and fish meals (van Huis et al. 2013). Similarly, human beings depend on the same source of food hence creating competition with animal feed production sector. This competition, coupled with global increasing demand of these raw materials has led to the expansion of livestock production and aquaculture to feed the growing human population (Oonincx and De Boer 2012). To meet the growing food demand, more land has been cleared, natural resources such as fish and other edible biodiversity have been over exploited and the price of animal feed for aquaculture and livestock production has increased dramatically. It is reported that feed costs alone account for 60% of the total production cost of livestock protein (Hanboonsong et al. 2013). Insects offer an alternative source of protein for animal feeds which is affordable and sustainable.

Insect rearing is attracting attention as a novel way to produce feed because of its environmental benefits. The rearing of crickets for example, seems to be more eco-friendly because of their low emission of greenhouse gases, low water and feed intake, and the small land requirement for their production (Abbasi and Abbasi 2016). House crickets are generally easy to cultivate, cricket farming has been possible to upscale from small-scale farming systems to large-scale farms (Durst and Hanboonsong 2015). The two common species that are widely cultivated are *G. bimaculatus* and *A. domesticus* but many farmers prefer *G. bimaculatus* over *A. domesticus* because they develop faster and are larger in size with higher food conversion ratio (Orinda et al. 2017, Ngonga et al. 2020). Being omnivores, crickets can utilize both animal and plant based food sources, hence can be fed on various types of feeds thus easy to rear in large scale (Ayieko et al. 2016). The ongoing debates on insect farming in relation to energy consumption and feeding on agricultural products that could be fed directly to animals, indeed calls for exploration of alternative rearing substrates. To avoid competition, reared insects can be fed on wastes and other products that are not suitable for human or animal consumption and convert them into protein. When compared to livestock, insects have shown higher feed conversion efficiency (Shah and Wanapat 2021).

The growth of insects is determined by factors like temperature, humidity, level of crowding, underlying genetic variation, etc. Crickets for example are known to survive at 28°C- 30°C and a relative humidity of 40%-70%. Nevertheless, when all these conditions are kept constant the type of diet that a cricket is fed to has a great effect in growth and development (Hanboonsong and Durst 2020). In rearing insects, diet is an important component, various studies have indicated the influence of diet on the survival rate, fecundity, development time and nutritional profile of crickets (Oonincx et al. 2015, Orinda et al. 2017, Dobermann et al. 2019). Crickets are omnivorous, can consume a wide array of organic materials, encompassing plant matter, fungi, small insects, and even carrion, and some species also feed on decomposing organic matter (Potapov et al. 2022). Elsewhere, studies have been conducted in finding local available feeds for cricket rearing. In Kenya, Orinda et al. (2017) explored the use of agro by -products feed in rearing crickets and the body weight was proven to be high when the rice bran blood meal was used. In Thailand, house crickets thrived very well when fed on 20–30% protein from formulated local diets (Bawa et al. 2020). Insect farming would promote sustainable food systems since insects can be fed on ingredients that are not suitable for human and livestock thus reducing the feed-food competition. The development of insect-based feed holds promise of high productivity for the livestock industry given its lower production costs using locally available substrates such as food wastes. This study, therefore, was designed to explore the suitability of using food waste in rearing the African field crickets for feed production. Utilization of wastes for crickets rearing supports circular economy (recycle, reuse and reduce the wastes) thus promoting environmental management in food production systems.

Materials and Methods

Study area

This study was conducted within the Mwalimu Nyerere campus located between 6.7792° S, 39.2043° E of the University of Dar es salaam, Tanzania. Adult wild African field crickets were collected from the surroundings and rearing was conducted in the Kihansi Spray Toad (KST) captive breeding facility. The facility was established in 2010 with toads translocated from Bronx and Toledo zoos. The captive facility building comprises of seven compartments which include a housed generator, an entrance veranda for propagating insects for toads' food, a culture room for fruit flies which is the major food of the toads, biosecurity shower room, the toad breeding preparatory room which is furnished with water filtration system, storage tanks and mist pumps for spraying water into the transparent containers of KST, and two rooms for breeding.

Collection of field crickets parent stock

The African field crickets were collected from the wild in various habitats, the selection of this species was prompted by their availability in the environment. Cricket's habitats sampled included: grasslands, shrub lands and open areas using sweep nets and hand-picking methods. A total of 500 adult crickets were collected, sorted and placed in a 6 litres rearing container with a 1 litre egg laying container filled with sterilized sand in a 60% -70% controlled humidity for egg laying. Eggs laid were collected after 3 days, incubated for 14 days at 30.5 ºC to obtain nymphs. The hatched nymphs were kept in a 60 litre rearing plastic cage covered with a sliding netted top for 1 day and were supplied with a standard chicken grower's mash, pumpkin leaves, carrots and water for acclimatization as previously described in Ayieko et al. (2016). Rearing of the field crickets was conducted in a biosecurity shower room for consecutive 14 weeks, from January –April 2023.

Preparation of experimental feed types

Food remains were collected separately from various cafeterias at the campus, they were dried under the sun for three days, and then grinded using a blender to obtain pelleted and powdered food which were fed to each experimental field crickets following the procedure of Collavo et al. (2005). Chicken growers mash was bought from animal feed sellers and used as the control food type. The summary of food formulations used in this study is presented in Table 1.

Table 1: Four different combination of food wastes used for rearing African wild crickets

Food type	Food Composition
1-Control	Maize, broken rice, extracted oil, rice bran, fish meal and soy beans.
2	Remains of cooked Ugali (corn flour meal), rice, peas, meat, fish, beans, cabbages and spinach.
3	Remains of cooked banana, dough, spaghetti, anchovies and fruits (watermelon, pineapples and oranges).
4	Food type 2&3 combined.

Experimental design

Experiments were conducted using the 14-days old nymphs (F1) of field crickets. For each food type (1-4), a total of 300 nymphs were allocated, 100 nymphs for each replicate making a total of 3 replicates. Nymphs were reared in a 60 litres plastic container with a netted lid to avoid predators, allow ventilation, and prevent crickets from escaping. The total number of nymphs used for experimentation was 1200. Nymphs were fed with growers strata mash, using a 6 cm feeding tray, pumpkin leaves, and hydrated cotton wool were used to provide water for the first 14 days to ensure accurate experimental conditions and attainment of a uniform metabolic capacity to all experimental field crickets before the start of the feeding experiment (Ayieko et al. 2016).

Drinking water was provided ad libitum in a sauce of 6 cm diameter with a moist cotton wool, which was changed every after one day. To prevent anxiety, egg trays (29 cm x 29.5 cm) were placed vertically in each rearing container to act as hide-outs and 100 g of each experimental food type were placed in an experimental rearing container using a 6 cm feeding tray. Experimental food and water were also provided ad-libitum for 14 weeks, old food was removed daily to prevent fungal growth and diseases invasion as previously described in Orinda et al. (2017). Temperature and relative humidity were maintained at 28 °C ± 2° C and 60%-70%, respectively.

Determination of growth parameters

Weight measurements of the crickets were taken on a weekly basis, for each replicate, a batch of all field crickets were collected in a dell cup of 22.4 g and weighed using analytical balance. The measurements were taken consistently for 14 weeks until crickets attained maturity. At maturity, between the 10^{th} -14^{th} week depending on the diet treatment, crickets were sorted as female and male in a ratio of 3:1 respectively. The growth parameters of field crickets were determined in terms of weight gain and survivorship rate (equations 1 and 2). Mortalities were recorded and dead crickets were removed from each cage on daily basis.

$$\text{Survivorship rate} = \frac{\text{Number of crickets stocked} - \text{Number of crickets died}}{\text{Number of crickets stocked}} \times 100 \quad (1)$$

$$\text{Weight gain} = \text{Final body weight (g)} - \text{Initial body weight (g)} \quad (2)$$

$$\text{Growth rate (mg)} = \frac{\text{Weight at maturity} - \text{Original weight}}{\text{Original weight}} \times 100 \quad (3)$$

Nutritional content analysis of the crickets harvested

Sample preparation

All crickets were harvested in the 15th week after oviposition, prior to harvesting they were starved for 8 h to empty their gut and denied access to drinking water for 4 hours (Bawa et al. 2020). The samples were then sun dried for 3 days, and thereafter blended using an electrical blender to produce powder materials. The specimen for each treatment category and a control were kept in polyethylene zip bags well tight to prevent exposure to moisture and air. Each bag was stocked with 250 g of the powder and for each treatment category the analysis was done in triplicates.

Proximate Analysis of the experimental food and harvested crickets

The proximate composition of the different experimental diet for the crickets was determined following the 2016 standard and procedure of the Association of Official Analytical Chemist (AOAC) methods. Ash content was determined by AOAC (method 923.03), crude protein content by Kjeldahl method with N × 6.25 (method 992.15), crude fiber (method 985.29), and moisture content (method 925.10) (AOAC 2016).

Data Analysis

Normality test was conducted using the D'Agostino & Pearson test. All data sets passed the normality test (alpha = 0.05) and thus warranting the use of parametric tests. Two-way ANOVA was used to determine the effect of time and the food type on growth and survivorship of the wild cricket as well as to test for any significant difference between the different treatments (food types) and between the chemical and nutritional composition of experimental and harvested crickets respectively. Post hoc Tukey tests were conducted to evaluate differences among means for data that were normally distributed and had equal variances. The software used was GraphPad Prism 10 and significant values were determined at 95 % CI.

Results

Composition of experimental food types

Data from the proximate analysis of the experimental food is presented in Table 2. The experimental food type differed significantly in crude protein, crude fiber, crude ash, fats and other minerals combined (Table 2). The control food type 1 had high crude protein content (61.68%) and the lowest value of 1.68% crude protein was recorded from experimental food type 3. Generally, all the experimental food types 2-4 had low values of crude protein contents. The experimental food type 4 recorded the highest values of crude ash as well as fats and other minerals with 5.00% and 76.25% respectively. There was no significant difference ($F_{3, 11} = 57.607$, $P > 0.05$) between the nutritional contents of the experimental food types. Further analysis of each parameter (dry mass, moisture content, crude protein, ash, crude fiber, fats and minerals) revealed a significant difference for each group: Dry mass ($F_{3, 11}=2289$, $P < 0.0001$); Moisture content ($F_{3, 11}=2747$, $P < 0.0001$); Ash ($F_{3, 11}=624.2$, $P < 0.0001$); Crude fiber ($F_{3, 11}=276.0$, $P<0.0001$); Fats and other minerals ($F_{3, 11}=358465$; $P < 0.0001$).

Table 2: Chemical composition of the control and experimental food types fed to African field crickets during experimentation

Food type	Dry mass (DM)%	Moisture content (MC)%	Crude Protein (CP)%	Ash (%)	Crude Fiber (%)	Fats and other minerals (%)
1-Control	95.18 ± 1.50	4.82 ± 0.06	61.68 ± 0.10	3.27± 0.45	1.68 ± 0.06	28.55 ± 0.24
2	87.21 ± 0.21	12.79 ± 1.13	2.34 ± 0.17	5.40 ± 0.28	3.66 ± 0.85	75.81 ± 0.30
3	86.47 ± 0.69	13.53 ± 0.98	1.68 ± 0.25	4.32 ± 0.34	3.43 ± 0.64	63.51 ± 0.47
4	88.45 ± 0.01	11.55 ± 0.45	3.83 ± 0.43	5.00 ± 0.41	3.38 ± 0.27	76.25 ± 0.44

Effect of different food types on growth of African field crickets

A similar quantity of food regardless of diet composition was consumed across all the experimental diets. The effect of diet on the growth rate of wild crickets for the 14 weeks is presented in Figure 1. Analysis to establish the influence of food on the growth rate of the crickets shows there is a significant difference between the experimental food types ($F_{(3, 39)} = 4.64$, $P=0.007$). Similarly, rearing time significantly influenced the growth rate of the crickets ($F_{(13, 39)} = 32.58$, $P<0.0001$).

Nevertheless, during rearing, there was no significant weight increase in the crickets for all the diets in the first 3 weeks, but the overall results show an increasing trend of the weight of the crickets fed on the four experimental food types from the fourth week (Figure 1). There was a sharp increase in crickets' weight from week 8 to week 11 for all the experimental diets. Further analysis indicated that the weight of crickets which were fed on food type 4 (combination of food type 2 and 3) increased more rapidly resulting in the highest adult cricket mean weight (405.70± 1.71 mg) at the age of 14 weeks and food type 3 resulted into the lowest mean weight of crickets at maturity (284.70 ±5.03 mg). However, the weight of the crickets began to decrease in week 12 for the crickets that were fed on food type 3 and 4 and this coincided with onset of oviposition.

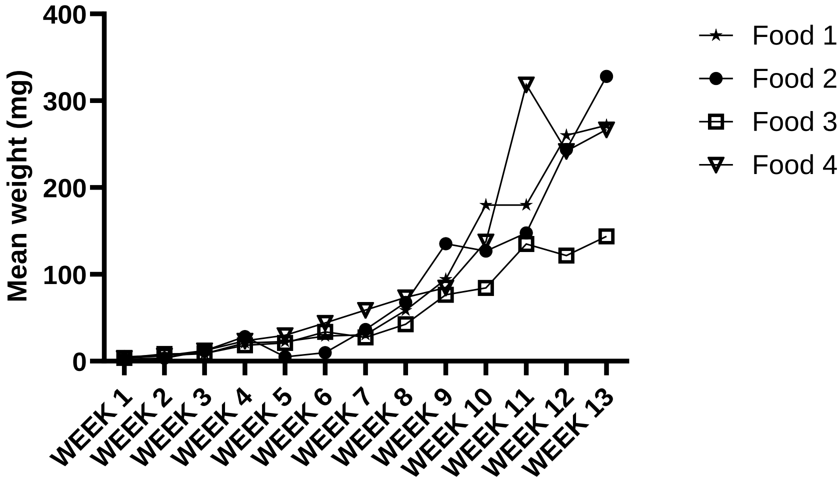

Figure 1: Showing the effect of different food formulations on growth of the reared African field crickets

Effect of different food formulations on the survivorship of wild crickets

The survivorship rates of crickets that were fed on experimental food type 2 and 3 were relatively low, recording high mortality rate of up to 50% for the first 5 weeks (Figure 2). Whereas, crickets reared on the experimental food type 4 had a significant higher survivorship rate (*P*<0.0001). The survivorship rate of crickets that were fed on experimental food type 4 was not significantly different from the control diet food type 1 (*P*>0.05). Between the 6th -10th week, the survivorship rate of crickets were almost constant across all the treatments and decreased again during the 11-14th week. In general, both the experimental food types ($F_{3, 39}$=22.69, *P*<0.0001) and time ($F_{13, 39}$=79.11, *P*<0.0001) showed a significant difference in the survivorship of crickets.

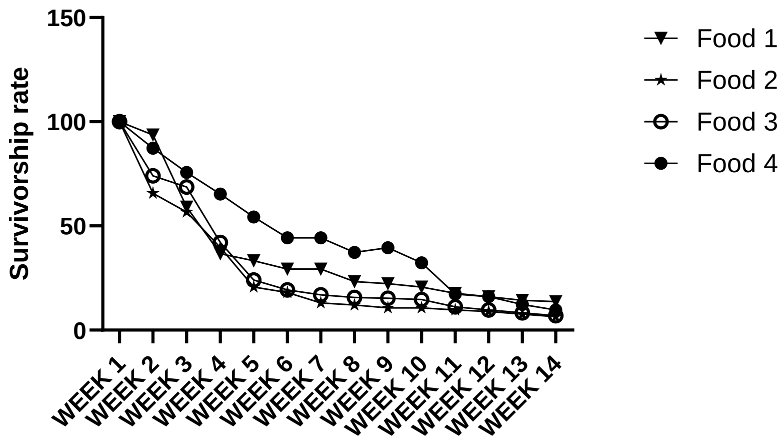

Figure 2: Showing the effect of different food formulations on the survivorship of reared African Field Crickets

Nutritional composition of crickets

Nutritional composition of the harvested crickets was significantly influenced by the experimental food treatments (Table 3). Higher quantity of crude protein was recorded from crickets that were fed on the control commercial food type 1 (54.70%) which was comparable to the values obtained from the crickets that were fed on the combined diet of mixed food types- food type 4 (50.70%), the lowest crude protein content was recorded from crickets that were fed on experimental food type 2 (38.57%). The same trend was observed for all the parameters (crude ash, crude fiber, and fats and other minerals combined).

Effect of different food treatment on reproduction performance of crickets

Information on reproduction performance of the crickets is presented in Table 4. Diet influenced reproduction parameters such as age at attaining sexual maturity, age at onset of oviposition, egg batch size and hatch ability rate. Crickets that were fed on experimental food type 4 attained sexual maturity earlier (at the age of 10 weeks) than crickets that were fed on other experimental food types. In all the treatment groups, age of attaining sexual maturity was between the 10^{th} -14^{th} weeks. The corresponding age at the onset of oviposition was between the 12^{th} -15^{th} weeks with crickets that were fed on experimental food types 2 and 3 recording a delayed process. The egg batch size was highest for the crickets that were fed on the control commercial diet food type 1(100 eggs/crickets/week) and was least in the crickets that were fed on experimental food type 4 (69 eggs/crickets/week). Similary, the highest hatch rate (81%) was recorded for the eggs obtained from crickets that were fed on experimental food type 2 and lowest (67.5%) for crickets that were fed on experimental food type 4.

Table 3: Nutritional composition of the African field crickets reared on different food types

Crickets	Dry mass (DM)%	Moisture content (MC)%	Crude Protein (CP)%	Ash (%)	Crude Fiber (%)	Fats and other minerals (%)
Fed on food type 1	97.97 ± 0.30	2.03 ± 0.28	54.70 ± 2.34	6.14 ± 0.18	4.73 ± 0.21	32.40 ± 0.31
Fed on food type 2	62.46 ± 1.16	37.54 ± 0.95	38.57 ± 2.43	4.24 ± 0.16	2.12 ± 0.10	17.53 ± 0.17
Fed on food type 3	67.89 ± 0.31	32.11 ± 0.10	40.67 ± 1.99	4.69 ± 0.08	3.13 ± 0.03	19.40 ± 0.28
Fed on food type 4	93.72 ± 0.17	6.28 ± 0.06	50.70 ±1.49	6.24 ± 0.23	6.11 ± 0.52	30.67 ± 1.14

Table 4: Showing the effect of different food substrates on reproductive performance of the reared African field crickets

Food type	Number of female individuals/100	Attainment of sexual maturity (in weeks)	Time for oviposition (in weeks)	Total number of Eggs laid/food type	Egg batch size	Average number of eggs/cricket/day	Total number of nymphs	Hatch rate (%)
1	41	11-13	13	3100	76 ± 1.14	7.6 ± 0.28	2170	70
2	23	12-14	15	2340	100.2 ± 1.77	14.3 ± 0.45	1890	81
3	21	12-14	15	1870	89 ± 7.07	12.7 ± 0.14	1400	75
4	29	10-12	12	2000	69 ± 5.66	9.9 ± 0.28	1350	67.5

Discussion

There is a growing interest for search of sustainable and alternatives livestock feed to replace fish and soybeans meals whose costs have dramatically increased thus increasing the cost of livestock production. Mass production of insects using local and readily available materials such as food wastes offers an alternative and cost-effective source of dietary protein. The performance of experimental food formulations was evaluated against the commercial food (chicken grower's mash) on the growth, reproduction and nutritional composition of the reared African field crickets.

A suitable diet is crucial for growth and development of crickets. This study has shown that different locally available feeds lead to varying weight gain and protein content in crickets. The study presents the pattern of growth of the field crickets reared under three experimental food formulations. All nymphs exhibited the same pattern of growth in the early weeks 1-7 of development. However, crickets that were fed on experimental food type 4 and 2 expressed superior growth rates compared to other treatment groups. Experimental foody type 4 had a relatively higher protein content (Table 2) compared to other treatment groups and this can attest for the stable growth pattern recorded for the crickets that were fed on this diet. These finding are in tandem with previous studies on various species of crickets which showed that these organisms thrive better when fed on diets with higher protein contents (Fuah et al. 2015, Orinda et al. 2017, Bawa et al. 2020). The growth performance of crickets that were fed on experimental food type 4 is comparable to crickets that were fed on the control commercial food type 1. These findings may be as a result of mixed content of different nutrients that constituted food type 4 such as: protein; from meat, legumes, fish and sea food; carbohydrates food such rice, seeds and nuts as well as vegetables and fruits. Combination of different food remains in a good proportion may increase the weight gain performance compared to selectively combined food with deficiency in some components. Therefore, combined food remains presents a potential for the highly nutritious yet affordable diet for crickets rearing alternative to the expensive chicken growers mash.

The study findings further demonstrate a significant impact of diet on the biomass production. The higher biomass yield observed in the crickets that were fed on food type 1 (control) compared to those that were fed on food types 2 and 3 can be attributed to the superior nutritional profile of the control diet. These findings are similar to the results previously report by Morales-Ramos et al. (2020) showing that the combined commercial diet resulted to higher biomass yield than using uncombine commercial feeds. It was interesting to observe that crickets that were fed on the mixed food type 4 were able to achieve a total biomass that was statistically similar to the control group. Combined diet has been reported to support robust growth and biomass accumulation in other species of crickets (Oonincx et al. 2015, Orinda et al. 2017) this, indicates the ability of crickets to efficiently convert the nutrients available in different substrates including food wastes into body mass.

Food plays essential role in survival of field crickets, however in all experimental food types, including the control food type 1, the survival rate was lower than 70% and continued to decrease throughout the entire period of the study. The observed survival rate is lower than values reported previously on other species of insects (Megido et al. 2016, Clifford and Woodring 1990), both studies reported the survivorship rate above 70%. The low survivorship rate of the same species (*Gyrllus bimaculatus*) has also been reported when reared on low quality bio-waste products (Dobermann et al. 2019). In this study, the observed low survivorship rate can be attributed to the use of pinhead nymph of 14 days old, could be that they were not well adopted to environment and experimental diet. This is contrary to the study by Megido et al. (2016) where older nymphs (above 14 days) were successfully used indicating that they might have acclimatized enough at the start of the experiments. Nevertheless, this species (*Gyrllus bimaculatus*) has been rarely studied in captives therefore, knowledge on their specific requirements is limited and a comparatively high mortality could be expected when wild species adapt to rearing circumstances.

The time taken to attain sexual maturity was between 10 to 14 weeks, and oviposition took place between the 12th to 15th weeks. Crickets that were fed on experimental food type 4 reported early sexual maturity and early onset of oviposition at the 10th and 12th week respectively. With regard to total egg production, crickets that were fed on protein rich diet-control food type 1 had remarkably high egg production but crickets that were fed on the combined diet (food type 4) produced few eggs. This is consistent with results previously reported in Gutiérrez et al. (2020) for the house cricket *Acheta domesticus*, this study observed that female crickets that were fed on the balanced diet produced few eggs compared to the ones that were fed on protein-rich diet. The influence of protein rich diet on fecundity has also been documented in other species of insects (Lee et al. 2008, Roeder and Behmer 2014). However, other factors such temperature, humidity, insect metabolism and genetics have also been reported to influence egg production among crickets (Megido et al. 2016, Morales-Ramos et al. 2020, Odhiambo et al. 2022). The hatchability rate was highest (81%) for crickets that were fed on a relatively low protein diet compared to the protein rich diets (food types 1 and 4), suggesting that factors other than diet influence the hatchability rate among crickets studied (Ssepuuya et al. 2021). Nothwistanding that, literature on the influence of diet on the egg production, development and hatchability among crickets is scanty thus, studies are wanting.

Investigating the nutritional profile of crickets fed on different diet in comparison to a standard commercial growers mash resulted in no significant differences for the crickets that were fed on combination of food waste type 4. The analysis of protein, ash, and fiber content in the crickets revealed that protein was the most abundant nutrient in all crickets that were fed on all the four food types, with food type 1 (control) and food type 4 (mixed food types) having the highest protein percentages. The variation in protein percentage among the different food types can be attributed to differences in dietary composition. Food type 1 (control) and food type 4 (mixed food) likely had higher protein sources such as meat, seafood, fish, and beans, which could have led to higher protein percentages in the crickets that were fed on these diets. Similarly, Bbosa et al. (2019) observed that a balanced, high-quality diet was a key factor in supporting robust growth and efficient nutrient utilization in cricket production systems. Crickets fed on high protein diets (experimental food type 4 and the control food type 1) had high protein thus justifying the results of a previous studies (Oonincx et al. 2015, Ngonga et al. 2020) that high protein content of diet resulted in high protein content in crickets.

This study has demonstrated that a combination of different food leftovers are suitable for rearing African field crickets (*Gyrllus bimaculatus*). For effective growth and development of crickets, proportional of combined nutrients from food remains may be used as an alternative to an expensive commercial poultry feed (grower’s mash). The findings further show that crickets have the ability to convert food leftovers into body mass and useful nutrients for feed production. However, the nutrient content of the feed remains was determined at a one-time basis and we present it as a limitation of the study because the composition of feed remains might change on a regular basis. Notwithstanding this, since the crickets were fed on locally available food remains, and the performance was similar to the ones that were fed on the standard commercial diet, it is clear that the high protein content can be achieved by local farmers who would like to adopt the simple diet like the use of food leftovers which is easy and cost-effective. Domestic wastes are a major concern in many developing countries, these results therefore, serve as a tool to potentially aid in upcycling of the waste by insects thus progressing towards a circular economy. The use of food remains in rearing insects for feed production is an interesting phenomenon because it also promotes environmental cleanness by recycling, reusing and reducing wastes, therefore it should be encouraged. Further studies should focus on optimizing rearing conditions for various species of crickets that are freely available in the wild in order to efficiently produce insects that meet the quantity and nutritional requirements for aquaculture and poultry production.

Acknowledgments

Authors are grateful to the management of the Kihansi Spray Toad captive facility for providing equipment and space in which rearing of crickets was conducted. The assistance given by Mr. Sylvester Nzumbi during the laboratory experiments is also appreciated. We also thank the technical staff of the College of Agriculture and Food Technology (CoAF) for the assistance during the proximate analysis of the experimental food as well as the harvested crickets.

Declaration of interest

Authors declare no potential conflict of interest.

References

Abbasi, T. & Abbasi, S. A. 2016. Reducing the global environmental impact of livestock production: The minilivestock option. *J. Clean. Prod.* 112: 1754-1766.

Aoac 2016. Official method of analysis. 19 ed. Washington, DC: Association of Official Analytical Chemists.

Ayieko, M. A., Ogola, H. J. & Ayieko, A. I. 2016 Introducing rearing crickets (gryllids) at household levels: adoption, processing and nutritional values. *J. Insects Food Feed* 2(3): 203-211.

Bawa, M., Songsermpong, S., Kaewtapee, C. & Chanput, W. 2020. Effect of Diet on the Growth Performance, Feed Conversion, and Nutrient Content of the House Cricket. *J. Insect Sci.* 20(2): 1–10.

Bbosa, T., Ndagire, C. T., Mukisa, I. M., Fiaboe, K. K. M. & Nakimbugwe, D. 2019. Nutritional Characteristics of Selected Insects in Uganda for Use as Alternative Protein Sources in Food and Feed. *J. Insect Sci.* 16(6): 1–8.

Clifford, C. W. & Woodring, J. P. 1990. Methods of rearing the house cricket, Acheta domesticus (L) along with base-line values for feeding rates, growth- rates, development times, and blood composition. *J. Appl. Entomol.* 109: 1-14.

Collavo, A., Glew, R. H., Huang, Y. S., Chuang, L. T., Bosse, R. & Paoletti, M. G. 2005. House cricket small-scale farming. *Ecological implications of minilivestock: potential of insects, rodents, frogs and snails.* 27*:* 515-540

Dobermann, D., Michaelson, L. & Field, L. M. 2019. The effect of an initial high-quality feeding regime on the survival of Gryllus bimaculatus (black cricket) on bio-waste. *J. Insects Food Feed,* 5(2): 117-123.

Durst, P. B. & Hanboonsong, Y. 2015. Small-scale production of edible insects for enhanced food security and rural livelihoods: experience from Thailand and Lao People's Democratic Republic. *J. Insects Food Feed* 1 (1): 25 - 31.

Finley, J. W. 2020. Evolution and Future Needs of Food Chemistry in a Changing World. *J. of Agr. and Food Chem.* 68(46), 12956-12971.

Fuah, A. M., Siregar, H. C. H. & Endrawati, Y. C. 2015. Cricket Farming for Animal Protein as Profitable Business for Small Farmers in Indonesia. *J Agr Sci Tech,* A 5, 296-304.

Gutiérrez, Y., Fresch, M., Ott, D., Brockmeyer, J. & Scherber, C. 2020. Diet composition and social environment determine food consumption, phenotype and fecundity in an omnivorous insect. *R. Soc. Open Sci*, 7(200100): 1-14.

Hanboonsong, A. & Durst, P. 2020. Guidance on Sustainable Cricket Farming—a Practical Manual. Bangkok, Thailand: FAO.

Hanboonsong, Y., Jamjanya, T. & Durst, P. 2013. Six-legged livestock edible insect farming, collection and marketing in Thailand. Food and Agriculture Organization of the United Nations, RAP publication. Bangkok, Thailand: FAO.

Lee, K. P., Simpson, S. J., Clissold, F. J., Brooks, R., Ballard, J. W. O., Taylor, P. W., Soran, N. & Raubenheimer, D. 2008. Lifespan and reproduction in Drosophila: new insights from nutritional geometry. *Proc. Natl Acad. Sci,* 105, 2498–2503.

Megido, R. C., Alabi, T., Nieus, C., Blecker, C., Danthine, S., Bogaert, J., Haubruge, E. & Francis, F. 2016. Optimization of a cheap and residential small-scale production of edible crickets with local by-products as an alternative protein-rich human food source in Ratanakiri Province, Cambodia. *J. Sci. Food Agric.* 96: 627-632.

Morales-Ramos, J. A., Rojas, M. G., Dossey, A. T. & Berhow, M. 2020. Self-selection of food ingredients and agricultural by-products by the house cricket, Acheta domesticus (Orthoptera: Gryllidae): A holistic approach to develop optimized diets. *PLoS One*, 15(1), 1-30.

Ngonga, C. A., Gor, C. O., Okuto, E. A. & Ayieko, M. A. 2020. Growth performance of Acheta domesticus and Gryllus bimaculatus production reared under improvised cage system for increased returns and food security. *J. Insects Food Feed* 7 (3): 301 - 310.

Odhiambo, M. A., Ochia, C. O. & Okuto, E. O. 2022. Effects of Temperature on the Development and Survival of Cricket Species; Acheta domesticus and Gryllus bimaculatus (Orthoptera: Gryllidae). *EAJAB* 5(1): 176-189.

Oonincx, D. G. & De Boer, A. B. 2012. Environmental Impact of the Production of Mealworms as a Protein Source for Humans-A Life Cycle Assessment. *PLoS ONE* (7): 45-54.

Oonincx, D. G., Van Broekhoven, S., Van Huis, A. & J.J, V. L. 2015. Feed conversion, survival and development, and composition of four insect species on diets composed of food by-products. *PLoS One* 10(12): 1-20.

Orinda, M. A., Mosi, R. O., Ayieko, M. A. & Amimo, F. 2017. Growth performance of common house cricket (Acheta domesticus) and field cricket (Gryllus bimaculatus) crickets fed on agro-byproducts. *J. Entomol. Zool.* 5: 1664–1668.

Potapov, A. M., Beaulieu, F., Birkhofer, K., Bluhm, S. L., Degtyarev, M. I., Devetter, M. & Scheu, S. 2022. Feeding habits and multifunctional classification of soil-associated consumers from protists to vertebrates. *BIOL REV*, 97(3): 1057-1117.

Roeder, K. A. & Behmer, S. T. 2014. Lifetime consequences of food protein-carbohydrate content for an insect herbivore. *Funct. Ecol.* 28: 1135–1143.

Shah, A. A. & Wanapat, M. 2021. Gryllus testaceus walker (crickets) farming management, chemical composition, nutritive profile, and their effect on animal digestibility. *Entomol. Res,* 51(12): 639-649.

Ssepuuya, G., Sengendo, F., Ndagire, C., Karungi, J., Fiaboe, K. K. M., Efitre, J. & Nakimbugwe, D. 2021. Effect of alternative rearing substrates and temperature on growth and development of the cricket Modicogryllus conspersus (Schaum). *J. Insects Food Feed.* 7, 163-172.

Van Huis, A., Van Itterbeek, J., Klunder, H., Mertens, E., Halloran, A., Muir, G. & Vantomme, P. 2013. Edible Insects - Future Prospects for Food and Feed Security. *FAO Forestry Paper 171.* Roma: Food and Agriculture Organization of the United Nations.