

Research Article

Effects of Diets and Rearing Periods on the Yield and Nutritional Quality of Cockroach Meal as Source of Protein to Broiler Chicken

Elisha Christian Lyawatwa^{1,*} , Martin John Martin² , Germana Henry Laswai¹ 

¹Department of Animal, Aquaculture and Range Sciences, Sokoine University of Agriculture, Morogoro, Tanzania

²Institute of Pest Management, Sokoine University of Agriculture, Morogoro, Tanzania

Abstract

A 3 x 4 factorial experiment was conducted to assess the effects of three diets (D1, D2 and D3) and four rearing periods (T30 (30 days), T60 (60 days), T90 (90 days) and T120 (120 days) on the performance and economics of mass production of American cockroaches as source of animal protein in the diets of broiler chickens. A total of 1380 cockroach nymphs (10th-14th instars) were allotted randomly to the diets and rearing periods and replicated five (5) times in buckets. Data on feed intake, growth performance, survival rates, number of ootheca and cost components were recorded and analysed. Samples of the feed ingredients, diets and cockroach meal were collected and analysed for nutritional values using standard methods. Diet D1 was a well-balanced commercial broiler starter, whereas diets D2 was made from three organic wastes and D3 being made from various organic wastes with fortification of minerals and vitamins. The cumulative feed intake by the cockroaches on diet D2 (45.26 g) was higher ($p < 0.05$) than that of diets D1 (26.8 g) and D3 (37.74 g). Cockroaches fed on diet D2 had higher weight gain (7.4 g) than diets D1 (5.9 g) and D2 (4.1 g). Similarly, cockroaches reared for 90 days had higher weight gain (7.6 g) than those reared for 30 (2.5 g), 60 (5.7 g) and 120 (7.3 g) days. The number of ootheca produced were higher ($P < 0.05$) on diet D2 (35) than on diet D1 (13) and D3 (12). The higher ($P < 0.05$) mean survival rate was observed in cockroaches reared for 30 days (91.3%) and 90 days (81.4%) than those reared for 60 days (67.8%) and 120 days (54.9%) periods. The average crude protein content of the cockroach meal was higher at 90 days (720.4 g/kg) and 60 days (716.8 g/kg) than other periods. In conclusion, rearing cockroach nymphs on diet D2 for 90 days was found to be the most effective way of producing cockroaches with relatively low production costs. Further study is recommended on evaluation of the produced cockroach meal as source of animal protein in the diets of broiler chicken.

Keywords

Cockroaches, Feeding, Growth, Oviposition, Nutritional Quality, Cost Analysis

1. Introduction

The increased demand for protein sources led to escalating competition between human and animals for conventional sources, such as fishmeal and soybean. This situation has driven attention of nutritionists towards searching for

*Corresponding author: elisha.lyawatwa@sua.ac.tz (Elisha Christian Lyawatwa)

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alternative sources of protein from none conventional feed sources. Insect species, such as cockroaches are increasingly becoming an alternative protein source for humans and livestock, a scenario which results into their increased demand. Traditionally, these insects are exploited from their natural habitats, hence unable to yield sufficient amount to meet the current demand [1]. This trend necessitates insect farming in the controlled environment, with quality and cost-effective feeds to meet the demand. Insect farming presents several environmental and economic advantages, since it is resource-efficient, requiring less land, water and feed compared to conventional livestock production. Additionally, insect farming aligns well with tropical climate conditions, where high ambient temperatures can enhance insect productivity [2]. These attributes position insect farming as an ecologically sustainable method of addressing protein shortages.

Cockroaches, in particular, are notable for their efficiency in converting organic waste into high-value protein. Despite growing interest in insect farming, there is limited research on the production of cockroaches as a protein source, using locally available organic wastes, formulated to mimic monogastric animal diets. Studies have shown that German cockroaches can achieve significant weight gain (86mg) when fed on a mixture of organic wastes for 42 days [1]. Given that the anatomical and physiological characteristics of the digestive system of cockroaches and that of monogastric animals are similar [3, 4], there is possibility of compatibility in their nutritional requirements. Previous studies have shown that American cockroaches (*Periplaneta americana*) can thrive more effectively on a composite of locally available organic wastes than on individual waste products. This suggests a synergistic effect of mixed substrates on their growth and development. However, the specific combination of organic wastes that yields the highest performance in terms of biomass production and nutritional quality remains unknown. Limited information is available on the use of simple diets and those supplemented with a number of micronutrients on the promotion of growth and reproductive performance in cockroaches. In addition, there is scarce literature on the optimal harvesting time that would maximize both yield and nutritional value of cockroach meal. Moreover, the reproductive behavior of cockroaches under controlled feeding conditions remains underexplored, which poses challenges to their potential for mass production. The present study aims at evaluating the effects of diets made from different organic wastes and rearing periods on the performance of American cockroaches, with a focus on the reproduction, growth metrics and nutritional value of the cockroach meal as protein source to chickens.

2. Materials and Methods

2.1. Description of the Study Area

The experiment was conducted at Mkundi ward in Morogoro region of Tanzania. The ward is located at 6° 40' S, 37° 39' E, altitude of 475 meters above sea level, approximately 20 km southwest of Morogoro municipal. The area experiences a tropical climate, characterized by distinct seasonal variations in temperature. The minimum temperature ranges from 16 to 18°C, typically observed from June to July, associated with cool dry season, while the hotter months of October to December the maximum temperature is 35°C. The area receives bimodal kind of rainfall, with long rains occur between March and May, and while short rains being between October and December [5].

2.2. Experimental Design and Treatments

The experiment followed a 3x4 factorial arrangement, where cockroaches were allocated to three (3) different diets and reared for four (4) different periods. Diet one (D1) was a control treatment, whereas diets two (D2) and three (D3) were the test diets. The periods included 30 (T30), 60 (T60) 90 (T90) and 120 (T120) days of rearing. A total of 1380 nymphs were randomly placed into 60 buckets, each bucket carrying 23 nymphs. The buckets were allotted randomly to the experimental diets and the periods. Each unique combination of diet and rearing period had five buckets as replicates.

2.3. Housing and Experimental Setup

A well-ventilated building, roofed with corrugated iron sheets was constructed for setting up the experiment. The windows were secured with 12 mm iron bars and covered with mosquito nets. In addition, three-quarter ($\frac{3}{4}$) of the windows was covered with black nylon sheet from the bottom to prevent direct wind and sunlight hitting inside the building. The top part of the windows was left uncovered to let ventilation and light penetration. Sixty (60)-twenty (20) litre capacity buckets, measured 27.5 cm diameter and 33.7 cm height were labeled for corresponding treatments and replications and used as experimental units for rearing the cockroaches. In each bucket, there were two plastic bowls, to be used as feeder and drinker, respectively. In addition, each bucket had five (5) pieces of egg paper trays as hibernation cases to provide hiding places for the cockroaches to imitate their natural habitats. A 3 cm-wide ring of an odourless petroleum jelly, a Vaseline ®product manufactured by Unilever company limited, USA, was smeared around the inside wall of the bucket, 6 inches from the top, to stop cockroaches from escaping. In addition, all buckets were covered with pierced bucket lid to prevent cockroaches from escaping, while allowing air circulation inside the bucket.

2.4. Source of Ingredients and Preparation of the Experimental Diets

The experimental diet D1 was a pelleted commercial broiler starter feed produced by Irvine poultry Tanzania. The diet contained crude protein 230 g CP/kg DM and energy 12 MJ ME/kg DM. The feed was purchased from an Agrovvet shop in Morogoro municipal at a price of 2000 Tsh/kg. This diet was considered as a control diet because of its known value of promoting growth performance in chicks. The physical composition of diets 2 and 3 is presented in Table 1. Diet D2 was formulated based on the formula tested in Kenya for raising German cockroaches by [1]. Diet D3 was formulated to meet the nutrient requirements of cockroaches in accordance to [1]. The diet was fortified with minerals and vitamins, which are essential for growth, reproduction and other body functions. All the ingredients used in compounding diets D2 and D3 were procured from the suppliers of animal feeds in Morogoro town. Samples of the ingredients and compounded feeds were collected and stored for subsequent laboratory analyses.

Table 1. Physical composition (g/kg as fed) and prices of the ingredients used in the experiment

Feedstuff	Diet 2	Diet 3
Hominy feed		200
Irish potato peels		300
Wheat bran	400	
Molasses		300
Brewers spent grain	400	
Fish wastes		80
Shrimps	200	
Blood meal		100
Dicalcium phosphate		17.5
¹ Broiler premix		2.5
Total	1000	1000
Price (Tsh/Kg)	960	1436
CALCULATED COMPOSITION		
Crude Protein (%)	23	22.7
Metabolisable energy (MJ/kg)	10.3	11.8

¹Broiler premix composition (g/kg): Calcium-260, Phosphorus-90, Salt-40, Selenium-40. Choline chloride-150,000 IU, Vitamin E-8000 IU, Vitamin D3-30,000,000 IU, Vitamin K-200MG, Vitamin A-8,000,000 IU, Pantothenic acid-5000 mg, Lysine-25 mg, Methionine-25 mg, Threonine-25mg, Tryptophan-25 mg

2.5. Sources and Management of Experimental Cockroaches

One thousand, three hundred and eighty (1380) nymphs, aged 10-14 instars were procured from a local cockroach producer, located nearby the experimental site. The nymphs were split into 60 groups of 23 each, weighed in groups and randomly placed in the buckets. At the onset of the experiment, 50 g of each diet was weighed using an electronic weighing balance, placed on the plastic bowl and inserted in each respective treatment bucket. In addition, a plastic bowl with a piece of sponge for anchorage of nymphs was filled with water and placed in each bucket. The bowls were refilled weekly to allow free access of drinking water to the nymphs. Each bucket was checked weekly to identify and record any change occurring in the bucket, including deaths. At intervals of 30 days, refusals were removed from each bucket, weighed, recorded and stored for subsequent analyses. Thereafter, 50 grams of the respective diet was replenished in each buckets for the proceeding rearing intervals.

2.6. Assessment of the Reproductive Performance

To evaluate the reproductive performance of the cockroaches under different dietary treatments and rearing periods, the oothecae laid in each bucket were collected and counted at each 30th day intervals, for the whole experimental periods. All visible oothecae were carefully collected using forceps and counted manually. Thereafter, the oothecae were returned to their original places immediately after counting, for ensuring development and minimizing disruption of the reproductive environment.

2.7. Assessment of the Yield and Preparation of Cockroach Meal

At the end of each rearing period, that is after 30, 60, 90 and 120 days of setting the experiment, all the adult cockroaches in each bucket were removed and placed into a pre-weighed plastic bottle and weighed, using an electronic weighing balance. Thereafter, they were poured into warm water at 60 °C for 30 seconds, letting them dead. Thereafter, the cockroaches were sieved out and dried under the sun for two days and their weight was taken. The whole dried adult cockroaches were then ground to pass through a 1 mm sieve to obtain cockroach meal which was then stored in a freezer for subsequent analysis.

2.8. Parameters Measured and Derived

Parameters measured were the number and weight (IW) of the cockroach nymphs at the onset and weight of cockroaches at the end (FW) of each rearing period. The numbers of ootheca at the end of each rearing period were also taken. Other parameters recorded were the amount of feed supplied and refusals collected at 30th day intervals. The prices, in

Tanzanian shillings (Tsh.) of all the ingredients used to formulate the diets and the commercial diet were also recoded. Feed intake (FI) in each rearing period was obtained by computing the difference between the amounts of feed supplied and refusals collected at the end of each rearing period. Weight gain (WG) was calculated as the difference between the FW and IW of cockroaches in each bucket. Growth rate (GR) was obtained by taking the ratio between WG and the number of days of rearing. Specific growth rate (SGR) was calculated as the percentage of the ratio of the difference between natural logarithm of means FW and IW of the cockroaches to the rearing period [6]. The feed conversion ratio (FCR) was computed by taking the ratio of FI to WG [7]. Survival rates (SR) was calculated as percent of the number of cockroaches in a bucket at the end of rearing period divide by the number at the onset of rearing period [8].

2.9. Experimental Analyses

2.9.1. Economic Analysis

The economic implication of cockroach meal production was assessed by using feed cost component. The cost per gain (C/G) was computed by taking the intake cost (IC) per bucket divide by the WG of cockroaches. The intake cost (IC) was obtained by taking the product of FI per bucket and feed cost (Tsh/g of feed). To determine the cost of producing one kilogram of cockroach biomass, the C/G was multiplied by 1,000g.

2.9.2. Laboratory Analyses

The samples of the feed ingredients, compounded diets, feed refusals and cockroach meal produced at different harvesting periods were analysed for dry matter (DM), ash, crude protein (CP), crude fibre (CF), ether extract (EE) and nitrogen free extracts (NFE) in accordance to the Association of Official Analytical Chemists [9]. Values of metabolisable energy (MJ ME/kg DM) were estimated using the formula demonstrated by [10] for non-ruminant feeds. The amino acid profiles of the collected samples were analysed using High-performance liquid chromatography (HPLC) as described by [11].

2.9.3. Statistical Analysis

The collected data were analysed using R software version

R 4.3.2 by subjecting them to two-way analysis of variance (ANOVA), whereby diets and rearing periods being regarded as treatments and factors, respectively influencing performance and nutritional values of the cockroach meal. To identify the significant differences between group means, a turkey's honestly significant difference was used at ($P < 0.05$).

$$Y_{ijk} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + \epsilon_{ijk}$$

Where:

- 1) Y_{ijk} was the response variable (weight gain, growth rate, feed intake and feed conversion ratio),
- 2) μ was the overall mean,
- 3) α_i was the effect of the i -th level of factor 1 (diet),
- 4) β_j was the effect of the j -th level of factor 2 (periods),
- 5) $(\alpha\beta)_{ij}$ was the interaction effect between the i -th level of factor 1 (diet) and the j -th level of factor 2 (harvesting periods),
- 6) ϵ_{ijk} was the random error term.

3. Results

3.1. Nutritional Values of the Ingredients and Experimental Diets

The chemical composition of the different ingredients used in formulating the experimental diets D2 and D3 are presented in Table 2. Blood meal had higher value of crude protein (CP) content compared to the other feedstuffs. The CP contents of fishmeal and shrimps were more or less similar. Among the energy sources, brewers spent grains contained higher content followed by Irish potato peels, wheat bran, hominy meal and the least in molasses. The crude fibre (CF) content was highest in brewers spent grain followed by wheat bran, and least content in blood meal. The metabolisable energy (ME) content was lowest in wheat bran compared with other ingredients. Table 2 also presents the chemical composition of the three diets used in the experiment. The CP content was highest in diet D1 and lowest in diet D3. The energy content of diet D1 was higher than other diets. Diet D2 had higher values of CF, crude fat (EE) and ash contents and lower value of ME content than the other two diets.

Table 2. Chemical composition (g/kg DM) and energy (ME, MJ/kg DM) contents of the ingredients and experimental diets.

Ingredients ¹	DM	CP	CF	EE	ASH	ME
Fish wastes	905	632	42.4	83	122	12.08
Hominy meal	911	126	6	124	40	15.24
Blood meal	936	919	5	NA	35	11.63
Shrimps	880	656	85	64	77	11.93

Ingredients ¹	DM	CP	CF	EE	ASH	ME
Wheat bran	891	166	114	52	50	9.94
Molasses	901	72	28	NA	NA	13.53
Irish potato peels	867	150	55	31	79	10.58
Brewers spent grain	887	253	143	67	21	13.95
Experimental diets						
Diet 1	902	235	29	30	76	12.16
Diet 2	891	230	94	55	97	8.99
Diet 3	882	198	58	36	72	11.72

¹In this and subsequent tables;

DM = Dry matter, CP = Crude protein, EE = Ether extract, CF = Crude fibre, ME = Metabolisable energy NA = Not analysed

3.2. Effects of Diets and Rearing Periods on the Growth Performance of the Cockroaches

The mean effects of diets and rearing periods on the feed intake and growth performance of the cockroaches are presented in Table 3. Cockroaches fed on diet D2 had higher ($P < 0.05$) cumulative feed intake (CFI) followed by those on diet D3 and least for those on D1. However, the Lsmean of CFI by the cockroaches fed on diet D2 was similar ($P > 0.05$) to those on diet D3, which was not different ($P > 0.05$) from those on diet D1. The Lsmeans on CFI by the cockroaches increased with increasing rearing periods, been lowest ($P < 0.05$) at 30 days (T30) and highest at 120 days (T120) of rearing. The Lsmeans of CFI by cockroaches for 30 days and 60 days (T60) of rearing were similar ($P > 0.05$). Similarly, the mean difference in CFI between 90 days (T90) and 120 days (T120) of rearing was not significant ($P > 0.05$). The mean daily feed intake (DFI) was higher in cockroaches fed on diet D2 followed by those on diet D3 and the least was on diet D1 ($P < 0.05$). There was no significant ($P < 0.05$) difference in DFI between cockroaches under different rearing periods.

The initial weight (IW) of the cockroaches was similar ($P > 0.05$) between diets and rearing periods. The Lsmeans of the

final weight (FW) of cockroaches reared on diet D1 and D2 were higher ($P < 0.05$) than those on diet D3. The mean difference in FW between cockroaches on diet D1 and D2 was not significant ($P > 0.05$). The FW at 90 days (T90) was higher ($P < 0.05$) than that of 30 days (T30). The mean differences of the FW between 60, 90 and 120 days were not significant ($P > 0.05$). The mean differences in weight gain (WG), growth rate (GR) and specific growth rates (SGR) between cockroaches fed on diets D1 and D2 were not significant ($P > 0.05$), however they were significantly higher ($P < 0.05$) than those fed on D3. Cockroaches reared at periods 60, 90 and 120 days had similar ($P > 0.05$) mean WG, but higher ($P < 0.05$) than those reared at 30 days. The mean differences in GR and SGR between rearing periods were not significant ($P > 0.05$). Cockroaches fed on diet D1 had similar ($P > 0.05$) mean feed conversion ratio (FCR) to those fed on D2, however the mean value was lower ($P < 0.05$) than for those fed on diet D3. The Lsmeans of FCR by cockroaches fed on diets D2 and D3 were similar ($P > 0.05$) and higher ($P < 0.05$) than those fed on diet D1. The mean differences in FCR by the cockroaches between the rearing periods were not significant ($P > 0.05$). The mean interaction effects between diets and rearing periods for all the parameters assessed on growth performance were not significant ($P > 0.05$).

Table 3. The Ls means \pm SEM of the effects of diets and rearing periods on the feed intake and growth performance of the cockroaches

¹ Parameter (g)	DIET			Rearing Period				SEM		p-value	
	D1	D2	D3	T30	T60	T90	T120	Diet	Period	Diet	Period
n	20	20	20	15	15	15	15				
Cumulative feed Intake	26.8 ^b	45.3 ^a	37.7 ^{ab}	16.8 ^b	30.1 ^b	44.5 ^a	54.3 ^a	4.19	3.38	0.013	0.001
Daily Feed intake (mg/d)	379.3 ^c	636.3 ^a	495.8 ^b	559.5	501.1	494.1	452.4	29.3	44.0	0.001	0.42
Initial weight (g)	21.5	21.2	21.4	22.2	21.3	20.9	21.1	0.32	0.35	0.76	0.07

¹ Parameter (g)	DIET			Rearing Period				SEM		p-value	
	D1	D2	D3	T30	T60	T90	T120	Diet	Period	Diet	Period
Final weight (g)	27.4 ^{ab}	28.4 ^a	25.5 ^b	24.7 ^b	27 ^{ab}	28.6 ^a	28.2 ^a	1.2	1.46	0.047	0.021
Weight gain (g)	5.9 ^{ab}	7.4 ^a	4.1 ^b	2.5 ^b	5.7 ^{ab}	7.6 ^a	7.3 ^a	0.84	0.85	0.031	0.006
GR (mg/d)	85.7 ^{ab}	105.5 ^a	51.7 ^b	82.2	94.8	84.7	61.2	9.35	12.14	0.001	0.306
SGR (%)	0.35 ^a	0.42 ^a	0.22 ^b	0.35	0.39	0.33	0.25	0.04	0.04	0.002	0.189
FCR	4.5 ^b	6.1 ^a	9.2 ^a	6.8	5.2	5.8	7.4	1.1	1.3	0.003	0.588

¹In this and subsequent tables; GR = Growth rate, SGR = Specific growth rate, FCR = Feed conversion ratio, n = number of observations, SEM = Standard error of the mean, ^{a, b, c}, mean values in the same row with different letters differ significantly at (p<0.05)

3.3. Effects of Diets and Rearing Periods on Oviposition and Survival Rates of Cockroaches

Table 4 presents the mean effects of diets and rearing periods on the percent survival rates (SR) and number of ootheca (NO) produced by the cockroaches. The mean difference of the percentage SR of cockroaches between diets was not significant (P>0.05). Initial number of cockroach nymphs (INC) at the onset of experiment was significantly similar (P>0.05) between diets as well as between rearing times. The final numbers of adult cockroaches (FNC) were statistically similar (P>0.05) between diets but FNC between different rearing times were significantly different (P<0.05)

with the higher FNC at 30 days and 90 days while the lowest FNC were at 60 days and 120 days. Cockroaches reared at period 30 days had higher (P<0.05) mean SR than those reared at 60, 90 and 120 days, although the mean difference between periods 30 and 90 was not significant (P>0.05). The Lsmean of the percent SR of the cockroaches reared at T60 was similar (P>0.05) to those reared at T120. The Lsmeans of the number of ootheca (NO) produced by cockroaches fed on diet D2 was higher (P<0.05) than those on diets D1 and D3, which had similar (P>0.05) mean values. The effect of rearing periods on the average NO was not significant (P>0.05). Similarly, the interaction effect of diets and rearing periods on average NO and survivability was not significant.

Table 4. The Lsmeans ± SEM on the effects of diets and rearing periods on the number of ootheca, survival rates and cost of production of cockroaches.

¹ Parameters	DIETS			Rearing periods				SEM		P-Value	
	D1	D2	D3	T30	T60	T90	T120	DIE T	Period	DIETS	Periods
n	20	20	20	15	15	15	15				
IN	23	23	23	23	23	23	23	0	0	0.39	0.38
FN	16	17	17	21 ^a	15 ^{bc}	18 ^{ab}	12 ^c	1.2	1.12	0.61	0.001
SR	69.78	76.66	75.52	91.3 ^a	67.8 ^{bc}	81.4 ^{ab}	54.97 ^c	5.23	4.89	0.61	0.001
NO	13.15 ^b	35.2 ^a	12.84 ^b	12	19.6	23.3	26	2.6	3.73	0.001	0.087
IC	53.6	43.4	54.2	23.4 ^c	41.6 ^b	60.9 ^a	75.9 ^a	5.7	3.6	0.334	0.001
C/G	6.2 ^a	3.6 ^b	7.4 ^a	5.3	4.8	5.2	5.9	0.69	0.89	0.001	0.15
CP1	6156 ^a	3554 ^b	7394 ^a	5342	4829	5225	5895	692	889	0.001	0.15

¹In this and subsequent tables; IN = Initial number of cockroach nymphs, FN = Final number of adult cockroaches, SR = Survival rate (%), NO = Number of ootheca, IC = Intake cost (Tsh/g feed), C/G = Cost per gain (Tsh/g gain), CP1 = Cost of producing one kilogram of cockroaches (Tsh/kg)

3.4. Effects of Diets and Rearing Periods on the Cost of Production of the Cockroaches

The mean effects of the costs of producing cockroach meal as influenced by diets and rearing periods are also presented in Table 4. The mean difference in intake cost per gram (IC) was higher on diet D3 followed by D1 and least in diet D2, however the differences between diets were not significant ($P>0.05$). The IC increased linearly with increasing rearing periods, been highest ($P<0.05$) and lowest for cockroaches harvested at 120 and 30 days, respectively. However, the mean difference in IC by cockroaches harvested between 90 and 120 days was not significant. The Lsmeans of the cost per gain (C/G) and the cost of producing one kilogram of cockroaches (CP1) by the cockroaches fed on diets D3 and D1 were similar ($P>0.05$) and higher ($P<0.05$) than those fed on diet D2. The mean differences in the C/G and the CP1 by the

cockroaches between the rearing periods were not significant ($P>0.05$). The interaction of diets and rearing periods had no significant effect on all cost parameters.

3.5. Effects of Diets and Rearing Periods on the Nutritive Value of the Cockroach Meal

The Lsmeans of the nutritional values of the cockroach meal as affected by diets and rearing periods are presented in Table 5. The mean difference in CP content of the cockroach meal obtained from cockroaches fed on the different diets was not significant ($P>0.05$). The cockroach meal obtained from cockroaches harvested at 90 days contained higher ($P<0.05$) mean CP content followed by those at 60 days and least mean value in those at 120 days. However, the mean difference in CP content between the meal obtained at 30 and 120 days was not significant ($P>0.05$).

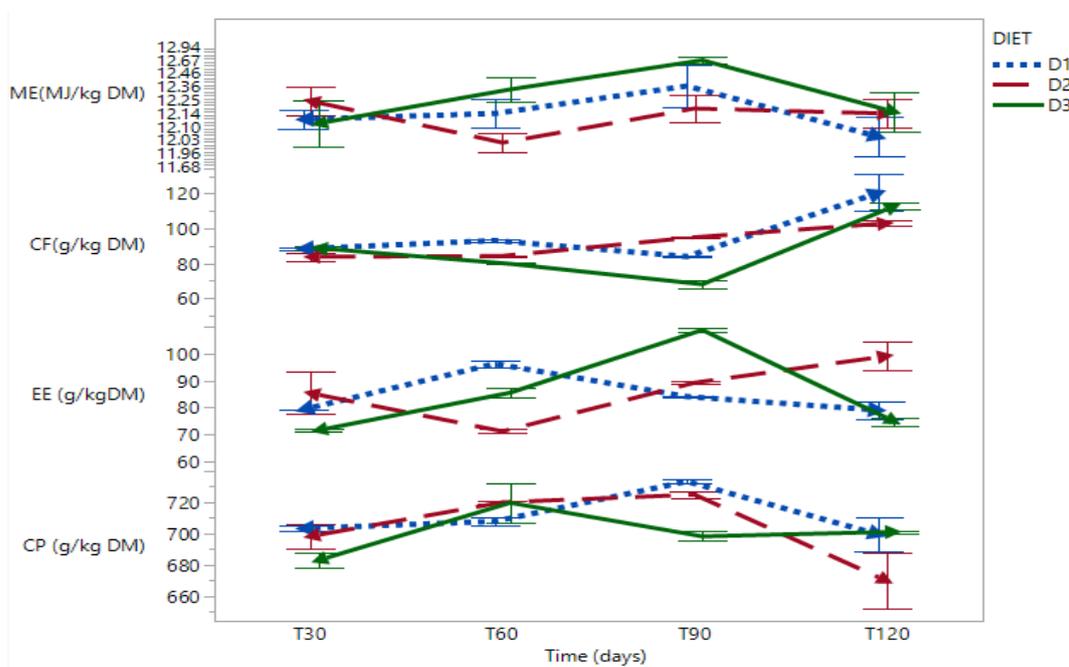


Figure 1. The trends of the mean CP, CF, EE and ME contents of the cockroach meal as influenced by the different diets and rearing periods.

Table 5. Ls means \pm SEM of the effects of diets and rearing periods on the chemical composition (g/kg DM) and energy (ME, MJ/kg DM) values of the cockroach meal.

PARAMETERS	DIETS			Period				SEM	P-Value			
	D1	D2	D3	T30	T60	T90	T120		DIET	Period	DIET* Period	
n	20	20	20	15	15	15	15					
DM	875.0 ^b	917.9 ^a	901.0 ^{ab}	898.3	896.7	894.5	902.3	0.73	0.94	0.002	0.97	0.001
CP	706.4	688.8	699.8	691.3 ^{ab}	716.8 ^a	720.4 ^a	664.8 ^b	9.64	6.82	0.53	0.001	0.001
EE	86.48	91.45	84.2	80.57	84.6	93.73	90.6	4.59	5.08	0.55	0.33	0.001

PARAMETERS	DIETS			Period				SEM	P-Value			
	D1	D2	D3	T30	T60	T90	T120	DIET	Period	DIET	Period	DIET* Period
CF	51.3	89.78	87.63	85.67 ^b	85.83 ^b	80.60 ^b	119.5 ^a	6.52	4.6	0.34	0.001	0.001
ASH	64.45	66.23	61.25	65.27	58.6	67.67	64.37	2.92	2.69	0.52	0.33	0.001
NFE	41.43 ^b	63.70 ^a _b	67.15 ^a	77.23 ^a	54.10 ^{ab}	37.63 ^b	60.73 ^{ab}	6.63	6.53	0.03	0.01	0.001
ME	12.08	12.19	12.12	11.99	12.2	12.33	11.99	0.1	0.1	0.74	0.09	0.001

DM = Dry matter, CP = Crude protein, EE = Ether extract, CF = Crude fibre, NFE = Nitrogen free extracts, ME = Metabolisable energy

The interaction effects between diets and rearing periods on CP content of the cockroach meal was significant ($P < 0.05$). The CP content of the cockroach meal produced on diet D1 and D2 kept on increasing from 30 to 90 days and reached its maximum level at 90 days (Figure 1). Thereafter the values decreased gradually, whereby at 120 days they attained values similar or less than that from D3. On the other hand, the mean value of CP content of the cockroach meal produced on diet D3 was lowest at 30 days, increased thereafter to maximum at 60 days and then declined abruptly at 90 days, where it maintained at 120 days.

The mean differences of the contents of the EE of the cockroach meal were neither influenced ($P > 0.05$) by the diets nor rearing periods. Interestingly, the mean interaction effect between diets and rearing periods on the content of the EE of the cockroach meal was significant ($P < 0.05$). While the EE content of the cockroach meal produced by diet D3 increased to maximum level at 90 days and decreased to a minimum value at 120 days, that from D2 decreased to minimum at 60 days and then increased to a maximum amount at 120 days (Figure 1). The Lsmeans of the CF content of cockroach meal from cockroaches fed on the different diets and rearing periods were similar ($P > 0.05$), except that higher ($P < 0.05$) value of CF content was observed at 120 days compared with other rearing periods. The interaction effect between diets and rearing periods on the CF was significant ($P < 0.05$) and the trends are also graphically demonstrated in Figure 1.

The Lsmeans of the ash contents of the cockroach meal produced by the different diets and rearing periods were similar ($P > 0.05$). The mean ash content of the cockroach meal was significantly ($P < 0.05$) affected by the interaction between diets and rearing periods, with the minimum ash content from all the three diets observed at 60 days. The maximum Lsmeans of ash contents of cockroach meals from diets D1 and D2 were observed at 120 days, while that of diet D3 expressed at 30 and 90 days. The Lsmeans of ME content of the cockroach meal produced from the cockroaches fed on the different diets and rearing periods were similar ($P > 0.05$), however the interaction effect between diets and rearing periods was significant ($P < 0.05$). The maximum contents of ME of the cockroach meal produced from all the diets were

observed at 90 days (Figure 1).

3.6. Amino Acid Profiles of Fish Meal and Cockroach Meal

Amino acid content of fish meal and cockroach meal are presented in Table 6. The higher proportion of lysine was in cockroach meal from adult cockroaches followed by fish meal and the least was in cockroach meal from cockroach nymphs aged 10 - 14 instars. The higher methionine/cysteine content was also observed in cockroach meal from adult cockroaches followed by nymph and the least was in fish meal. The higher tryptophan content was observed in cockroach meal from sub adult cockroaches followed by adult cockroaches and the least was in fish meal.

Table 6. Amino acid composition of Fishmeal and cockroach meal.

% Amino acid	Fish meal	Cockroach meal	
		Nymph	Adult
Lysine	4.33	2.86	4.6
Methionine/Cystine	2.07	2.12	2.19
Tryptophan	0.48	0.59	0.51

4. Discussion

The general objective of the study was to investigate on the possibility of mass production of American cockroaches for the purpose of preparing meal to be used as a source of animal protein in broiler diets. Specifically, the experiment aimed at assessing the effectiveness of three different diets in supporting the growth and reproductive performance of the cockroaches at various rearing periods.

The observed higher crude fibre (CF) content in diet D2 compared to the other diets could be attributed to the

increased inclusion of fibre-rich ingredients, such as wheat bran and brewers' spent grain (BSG). Despite the observed higher fibre content of this diet, a peculiar ability of cockroaches to digest fibrous feeds made the cockroaches in the present study to utilize this diet efficiently. A similar observation was made by [1], who formulated a composite diet for cockroaches with high levels of BSG and wheat bran, resulting to a diet with a higher CF content of approximately 34%. Moreover, the BSG used in Ngaira's study had considerably higher CF concentration (46.5%) than the BSG used in the present study, which further support the fact that high inclusion of fibre rich ingredients might be the reason for the high fibre content in D2. The observed lower metabolisable energy of diet D2 compared to the experimental diets D1 and D3 could be attributed to the higher inclusion level of wheat bran, which is known for its lower energy density relative to other energy sources. Similarly, [1] noted that diets with high inclusion levels of wheat bran had reduced metabolisable energy, with mean value of 9.7 MJ ME/kg. The observed higher energy density of diet D3 than other diets could be attributed to the higher inclusion of molasses in the diet, which had relatively high energy density.

The higher average feed intake observed in cockroaches reared on diet D2 than in other diets could be attributed to its greater proportion of energy-rich ingredients, which are generally more preferred by cockroaches than protein-rich components. This observation aligns with findings by [12], who reported that cockroaches prefer energy-dense ingredients with strong odors over protein-based ones. Additionally, the inclusion of shrimp in diet D2 could have enhanced its aroma and further stimulated feed intake, since aromatic signals are known to influence insect dietary preferences [13]. The higher intake of diets D2 and D3 compared with diet D1, which had a larger particle size, could also be explained by their finer particle sizes, which enhanced feed accessibility and palatability to cockroaches. This is in agreement with the results of [1], who observed that cockroaches consumed more finely ground diets compared to those with larger particles. Notably, the higher average feed intake by cockroaches on diet D2 than their counterparts occurred despite its elevated crude fibre (CF) content, suggesting an innate capacity of cockroaches to digest fibrous material. This ability is likely due to their production of cellulase enzymes in the salivary glands and the presence of cellulose-degrading microorganisms in their gut microbiota [14, 15].

The observed lower mean feed intake by cockroaches fed on diet D3 relative to those on other diets could be attributed to its lower CP content, as the amount of protein consumed by cockroaches often regulates their overall feed intake. Similar findings were reported by [14], who observed that under low-protein diets, cockroaches reduced their total carbohydrate intake in order to increase protein consumption and meet their nutritional requirements. This nutrient-driven feeding behavior has also been observed in other insect

species, such as locust (*Schistocerca gregaria*), where protein intake plays a central role in determining overall diet selection [16].

The observed increased cumulative feed intake (CFI) by cockroaches over time period was expected due to the length of the rearing period. Furthermore, the observed statistical similarity in daily feed intake between rearing periods supports the fact that the increased CFI was attributed to the length of rearing period and not by physiological changes as noted by [17], who argued that feed intake in female cockroaches was intense during ootheca formation and after oviposition, when the female prepares for the next reproductive cycle.

The higher average weight gain (WG) observed in cockroaches reared on diet D2 than their counterparts could be attributed to the observed relatively higher feed intake of this diet. A similar trend was reported by [18], who found a positive correlation between feed intake and WG in cockroaches. Interestingly, cockroaches reared on diet D1 exhibited mean value of WG comparable to those on diet D2, despite its relatively lower average feed intake. This could be explained by the higher CP content (230 g CP/kg DM) of diet D1, which was similar to that of diet D2, a level of CP considered optimal for the growth and maintenance of *Periplaneta americana*. This observation is consistent with the findings by [19], who reported higher WG by crickets when given diets containing 220 g CP/kg DM. In contrast, the lower WG observed in cockroaches reared on diet D3 could be attributed to its sub-optimal protein content (198 g CP/kg DM), which fell below the dietary requirements for optimal growth of cockroaches. This finding is in agreement to that reported by [19], who noted reduced WG in crickets fed diets with 180 g CP/kg DM compared to those receiving diets with CP ranging 200 - 220 g/kg DM.

The observed sharp increase in WG of cockroaches at T90 could be attributed to the improved adaptation of insects, specifically in their gut microbiota population, which are responsible for the enhancement of nutrient utilization which in turn led to the enhanced weight gain. This could also be manifested by the increased survivability of cockroaches at T90, which implies the increased level of their adaptation towards the captive environment and to the experimental diets. Similarly, [20] noted that cockroaches have an ability to maximize their growth even under nutritionally unbalanced diets. This observation aligns with the study conducted by [18], which reported that cockroaches are adapted to environments with feeds that are extremely unfavorable for growth and development. The observed lower feed conversion ratio (FCR) by the cockroaches raised on diets D1 and D2 compared to D3 could be attributed to the higher CP contents in the diets, which enhanced efficient WG relative to diet D3. This implies that, less amount of feed was utilized efficiently to promote weight gain. The higher growth rate (GR) and specific growth rate (SGR) observed in cockroaches fed on diet D2 than those on diet D3 could be attributed to

their greater WG, likely driven by increased feed intake and efficiency of nutrient utilization from the diet. This implies that diet D2 could be the best option for producing cockroaches in large quantities in a shorter time period than other diets.

The observed notably higher number of ootheca produced by cockroaches fed on diet D2 than their counterparts could be due to the relatively higher CP content in this diet than other diets, which plays a central role in supporting oogenesis and overall reproductive capacity in insects. This observation is in agreement with the suggestion by [21] that female insects should consume diets with high protein content for maximizing their reproductive capacity. Furthermore, the findings of [22, 23] noted enhanced egg production in *Gryllus bimaculatus* and *Acheta domesticus*, respectively, when insects were provided with high-protein diets. Although diet D1 contained similar protein content to that of diet D2, the observed lower reproductive performance in cockroaches given the former diet could be due to its larger particle size relative to the later diet, which could have resulted into lower feed intake and consequently limited nutrient uptake and utilization for egg production. On the other hand, the lower CP content in diet D3 was associated with significantly reduced ootheca production, emphasizing the importance of both protein quantity and bioavailability in optimizing reproductive performance. It is important to note that in addition to CP levels, the texture and palatability of the diets play important role in determining reproductive performance of cockroaches.

The observed consistent mean values of survival rate (SR) of cockroaches across the experimental diets, averaging 70% implies that feed composition have less effect on the overall survivability of cockroaches. This observation is in contrast to what was reported by [22] that diet had a significant effect on the survival of crickets, with average rates falling below 70%. This disagreement could reflect species-specific differences in dietary tolerance or adaptability, with *Periplaneta americana* possibly being more resilient. On the other hand, the length of rearing period was observed to have a clear effect on the survival rates, with the highest rate recorded at 30 days (T30). This could be due to the fact that the population of cockroaches at this early stage was still small; hence the competition for food and space was minimal. As the cockroaches grew and their numbers increased, survival rates gradually declined, which could be attributed to the growing pressure on limited resources. Interestingly, at day 90 (T90), survival rates seemed to stabilize and were comparable to those at T30. This trend may suggest that the cockroaches had adapted to the conditions of their environment, including the available feed. However, survival rates dropped significantly at day 120 (T120), likely due to overcrowding and intensified competition as space and food became increasingly limited [24]. This observation highlights the importance of managing both diet and rearing conditions to maintain healthy populations of cockroaches over time.

The observed increasing trend on mean intake cost (IC) from T30 to T120 suggests that the longer cockroaches are reared, the higher the cumulative feed costs. The observed trend over time could be attributed by the extended feed requirement over time as a result of an increased insect population. Similar observation was made by [25] who reported that increase in insects population notably through large scale insect production is associated with increased feed requirements. The observed lowest mean cost per gain (C/G) in diet D2 could be attributed to the lower price of this diet, due to fewer and cheaper ingredients used to make it compared to other diets. Consequently, cockroaches raised on diet D2 showed the lowest average cost of producing one kilogram of cockroaches (CP1) than their counterparts. This implies that diet D2 was the most cost-efficient diet in promoting weight gain in cockroaches. Thus, the importance of using locally available organic wastes in diet formulation to minimize the costs of producing cockroaches as protein source to chickens is overemphasized by the present study.

The observed overall mean value of crude protein (CP) content of cockroach meal was higher than that reported by [26]. The observed difference could be attributed by factors like the age at harvest of cockroaches as well as the type of diet provided to the cockroaches. However, the mean value of CP aligns with the findings of [27] which reported CP values of 717.8 g/kg. The observed mean value of CP content of cockroach meal obtained from cockroaches reared on diet D1 been slightly higher ($P>0.05$) than those from D2 and D3 could be attributed by the higher CP content of diet D1 relative to the other diets, which directly influenced the CP content of the cockroach meal. This observation is in line with that of [28] who reported a higher CP content in cockroaches reared on diets with high CP content. The observed higher CP content of cockroach meal produced at T90 compared to that of T30 could be attributed by the age differences of cockroaches. [29] found that adult cockroaches had higher protein content than nymphs. On the other hand, the decline in CP content observed at T120 could be linked to the increased levels of crude fibre (CF) content in the meal at this stage. The elevated CF levels are likely related to increased chitin accumulation in the exoskeleton with age, hence dilutes the protein content. The observed higher EE content of cockroach meal at T90 in cockroaches reared on diet D3 could be attributed to the higher inclusion level of molasses, an ingredient with relatively high energy content, which is normally converted into fats when given in excess to animals. This might have happened as a result of an up-regulation of expression of lipogenic genes in cockroaches in response to increased dietary sugar content [30]. Similarly [31] reported that, fat deposition in cockroaches increased with an increase in carbohydrate intake

Interestingly, the observed CP content of cockroach meal in this study was higher than the CP content of fishmeal, which is commonly used as a conventional protein source in broiler chickens as reported by [32, 33]. Furthermore, the observed

higher proportions of essential amino acids especially lysine, methionine and tryptophan in cockroach meal harvested from adult cockroaches than in fishmeal suggests the potential of using the cockroach meal as an alternative protein source to fishmeal in broiler diets.

5. Conclusions and Recommendations

It is concluded that cockroaches reared for 90 days (T90) using diet D2 produced a cost-effective cockroach performance, in terms of weight gain, growth rate and specific growth rate with lowest cost per gain. In addition, the observed higher crude protein and essential amino acid contents in cockroach meal relative to fishmeal qualifies it to be a good source of animal protein for the growth and development of broiler chickens. Further study is recommended to assess the effect of replacing conventional animal protein sources with the cockroach meal in broiler diets.

Abbreviations

ANOVA	Analysis of Variance
C/G	Cost Per Gain
CF	Crude Fibre
CP	Crude Protein
CP1	Cost of Producing a Kilogram of Cockroaches
D1	Experimental Diet One
D2	Experimental Diet Two
D3	Experimental Diet Three
DAARS	Department of Animal, Aquaculture and Range Sciences
DM	Dry Matter
EE	Ether Extract
FCR	Feed Conversion Ratio
FI	Feed Intake
FN	Final Number of Cockroaches
FW	Final Weight of Cockroach Group
GR	Growth Rate
HPLC	High Performance Liquid Chromatography
IC	Intake Cost
IN	Initial Number of Cockroaches
IPM	Institute of Pest Management
IU	International Unit
IW	Initial Weight of Cockroach Group
ME	Metabolizable Energy
NFE	Nitrogen Free Extract
NO	Number of Ootheca Produced
SGR	Specific Growth Rate
SR	Survival Rate
SUA	Sokoine University of Agriculture
T120	One Hundred and Twenty Days of Cockroach Rearing

T30	Thirty Days of Cockroach Rearing
T60	Sixty Days of Cockroach Rearing
T90	Ninety Days of Cockroach Rearing
Tsh	Tanzanian Shillings
WG	Weight Gain

Author Contributions

Elisha Lyawatwa: Conceptualization, Formal Analysis, Writing - original draft

Martin Martin: Conceptualization, Supervision, Writing - review & editing

Germana Laswai: Conceptualization, Supervision, Writing - review & editing

Conflicts of Interest

The authors declare no conflicts of interest.

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