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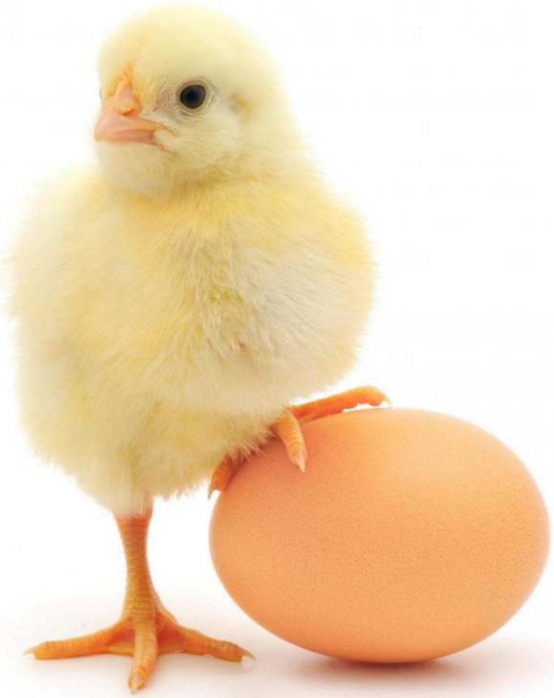

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Research Article
Grasshopper Meal (*Ornithacris cavroisi*) in Broiler Diets in Niger: Bioeconomic Performance

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Abstract

Objective: This study was conducted to evaluate the bioeconomic performance of grasshopper meal (GM) when used to replace fish meal (FM) in broiler diets during a period of 49 days. **Materials and Methods:** A total of 360 one-day-old broiler chicks (Cobb 500) were used in this experiment. The FM was replaced with GM on a kg per kg basis at 0% (control), 25% (25% GM+75% FM), 50% (50% GM+50% FM), 75% (75% GM+25% FM) and 100% (100% GM+0% FM) in broiler diets. Treatments (G0, G25, G50, G75 and G100) were randomly distributed into 20 pens of 18 birds each with 4 replications (4 pens/treatment). Data were analyzed in R 3.2 using ANOVA and regression was executed in Microsoft Excel 2013. **Results:** At the end of the experiment, the daily feed intake, body weight and weight gain linearly and significantly decreased ($p<0.05$) with increasing substitution rates of fish meal with grasshopper meal. Also, the results showed that feed conversion ratios linearly increased and were significantly affected by the treatments ($p<0.05$), with the highest performance observed in broilers fed the control diet. Carcass characteristics also significantly decreased ($p<0.05$) with increasing levels of grasshopper meal in broiler diets. However, the substitution did not significantly affect feed efficacy of broilers during the growing phase ($p>0.05$). In addition, during the 49 days of experimentation, the body weight, feed conversion ratio, economic feed efficiency and carcass yield of broilers fed G0, G25 and G50 were similar ($p>0.05$). **Conclusion:** Therefore, in Niger, fish meal may be substituted with up to 50% grasshopper meal in broiler feed.

Key words: Bioeconomic performance, broiler, fish meal, grasshopper meal, Niger, protein

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Broilers require energy and proteins to support their growth. In Niger, the major source of proteins in broiler diets is based on peanut meal and fish meal. The availability of protein sources, especially fish meal, is most often a constraint in Niger[1]. Indeed, the large-scale trade in industrial fishmeal has caused overfishing in some parts of the world and will not grow in proportion to the needs of intensive livestock production, so this resource will be limited in the future[2]. Insects can be used as an alternative to fish meal in poultry feeds[3]. Insects such as grasshoppers have a high protein and calorie content[4]. Grasshoppers, which are known to have a high capacity for destroying farm crops and causing great financial losses, could be turned into feed ingredients[5], especially in Niger.

The protein content of grasshopper meal ranges from 43.9-77.1%[6]. In addition, field cricket has an advantage in amino acid composition for poultry, especially due to its contents of lysine, methionine and cysteine and might constitute a new source of dietary nitrogen for poultry[7].

In West Africa, locusts and grasshoppers are used to feed animals and they have great potential as a more affordable source of protein in broiler diets[8]. Adeyemo *et al*.[9] observed that substituting fish meal with up to 50% locust meal (*Schistocerca gregaria*) do not affect broiler weight gain and its utilization did not cause physiological disorders in broilers. Hassan *et al*.[5] found no significant effect on broiler weight gain, feed intake and feed conversion ratio when grasshopper meal replaced fish meal in broiler starter diets. However, the carcass characteristics and economic aspects were not considered for all broiler production phases.

Thus, the aim of this study was to determine the optimal rate of substitution of fish meal with grasshopper meal in broiler diets and to evaluate the feed efficiency of such substitution.

MATERIALS AND METHODS

Procurement and processing of ingredients: Grasshoppers are a commercial product in Niger and the main species used in the experiment is *Ornithacris cavroisi*, which is the main commercial species sold in local markets. Grasshoppers generally cost approximately 600 FCFA (0.92 €) kg^{-1} versus 625 FCFA (0.95 €) kg^{-1} for fish meal during the experimental period. However, grasshoppers may cost approximately 300 FCFA (0.46 €) kg^{-1} during the harvest period (from September to November), while the lowest price of fish meal in the country is approximately 500 FCFA (0.76 €) kg^{-1} throughout the year. All ingredients, including grasshopper meal and fish meal, were purchased from the local markets. Grasshoppers and fish were ground separately to obtain the meal and the whole diets were processed into pellet form.

Experimental diets: Five experimental diets or treatments (one control and four grasshopper meal (GM)-based diets) having 22.13-20.31% crude protein (CP) and 2840-2831 kcal kg^{-1} metabolizable energy (ME) at the starter phase (from 1-21 days old) and 18.67-17.77% CP and 2875-2865 kcal kg^{-1} ME at the grower phase (from 22-49 days old) were used in this study (Table 1). Corn was the major source of energy, while fish meal, grasshopper meal and peanut meal were the major protein sources. Synthetic amino acids such as lysine and methionine were used in the diets. The G0 (0% grasshopper meal) was the control diet, while G25, G50, G75 and G100 were the experimental diets. In G25, G50, G75 and G100, only fish meal (FM) was substituted with the grasshopper meal (GM) in the proportions of 25% (25% GM+75% FM), 50% (50% GM+50% FM), 75% (75% GM+25% FM) and 100% (100% GM+0% FM).

Experimental birds, management and design: A total of 360 unsexed day-old broiler chicks of the Cobb 500 strain were used during the 49 days of experiment at the poultry house of the Faculty of Agronomy in Niamey, Republic of Niger. Birds were randomly distributed in 20 pens of 18 chicks each with 4 replications (4 pens per replication). They were vaccinated against Newcastle and Gumboro diseases and protected against coccidiosis. Anti-stress measures were taken during the vaccination and weighing period.

Chemical analysis: Samples of yellow corn, wheat bran, peanut meal, fish meal and grasshopper meal used in the different experimental feeds were submitted to chemical analyses at the "Laboratoire d'Alimentation et de Nutrition Animale (LANA)" of the Institut National de la Recherche Agronomique du Niger (INRAN) in Niamey, Niger. The analyses included the evaluation of dry matter (DM), crude protein (CP), ether extract (EE), crude fiber (CF) and ash.

Data collection: Feed intake was collected daily, while birds were weighed at 1-21 days old and 49 days old. The cost (in the local markets) of the ingredients used in this study and the price of live chickens were used to determine the economic parameters. The following variables were determined; daily feed intake, daily weight gain, feed

Table 1: Composition of diets fed to broilers in a 49 days experiment at Niamey, Niger

	Starter diet*					Grower diet*				
Ingredient (%)	G0	G25	G50	G75	G100	G0	G25	G50	G75	G100
Corn	59.95	59.95	59.95	59.95	59.95	65.10	65.10	65.10	65.10	65.10
Wheat bran	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00
Peanut meal	14.00	14.00	14.00	14.00	14.00	11.00	11.00	11.00	11.00	11.00
Fish meal	13.00	9.75	6.50	3.25	0.00	11.00	8.25	5.50	2.75	0.00
Grasshopper meal	0.00	3.25	6.50	9.75	13.00	0.00	2.75	5.50	8.25	11.00
Methionine	0.10	0.10	0.10	0.10	0.10	0.05	0.05	0.05	0.05	0.05
Lysine HCl	0.20	0.20	0.20	0.20	0.20	0.10	0.10	0.10	0.10	0.10
Bone meal	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Salt	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Vit/Min premix[1]	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Calculated nutritional composition										
ME (kcal kg^{-1} DM)[2]	2840.00	2838.00	2835.00	2833.00	2831.00	2875.00	2874.00	2872.00	2870.00	2868.00
Crude fiber (%)	4.21	4.60	4.99	5.38	5.77	4.28	4.61	4.94	5.27	5.60
Crude protein (%)	22.13	21.67	21.22	20.83	20.31	18.67	18.44	18.22	17.99	17.77
Lysine (%)	1.24	1.23	1.22	1.21	1.20	1.02	1.02	1.01	1.00	0.99
Methionine (%)	0.55	0.55	0.54	0.54	0.53	0.46	0.45	0.45	0.45	0.44
Calcium (Ca) (%)	1.48	1.50	1.52	1.53	1.55	1.40	1.42	1.43	1.45	1.46
NPP (%)[3]	0.51	0.51	0.51	0.51	0.51	0.52	0.52	0.52	0.52	0.52
Ca/NPP	2.88	2.92	2.95	2.98	3.02	2.71	2.74	2.77	2.79	2.82

*Diets that substituted FM with GM at 0% (G0), 25% (G25), 50% (G50), 75% (G75) and 100% (G100), [1]Premix content kg^{-1}: 220 mg of Mg, 220 mg of Zn, 110 mg of Fe, 248 mg of Cu, 33 mg of I, 77,105 IU of Vit A, 27,538 IU of Vit D, 165 IU of Vit E, 0,11 mg of Vit. B12, 8 mg of menadion, 66 mg of riboflavin, 11 mg of thiamine, 66 mg of pantothenic acid, 275 mg of niacin, 14 mg of Vit B6, 7 mg of folic acid, 3,855 mg of choline and 0.33 mg of biotin, [2]Metabolizable energy in kcal kg^{-1} of dry matter. [3]Non-pythic phosphorus

conversion ratio, feeding cost and economic feed efficiency. The economic feed efficiency (EFE) was calculated using the following formula described by Houndonougbo *et al.*[10]:

$$EFE = \frac{WG \times WGP}{FI \times FC}$$

Where:

EFE = Economic feed efficiency
WG = Weight gain (kg)
WGP = Revenue from weight gain (FCFA kg^{-1})
FI = Feed intake (kg)
FC = Feed cost (FCFA kg^{-1})

Carcass characteristics were evaluated using 20 broilers per diet. Carcass weight, carcass yield, feather yield, head and leg yield, empty gizzard yield and liver yield were determined.

Statistical analysis: One-way ANOVA were performed in this study using R version 3.4[11] with general linear model (GLM) procedures. The statistical model used was as follows:

$$Y_i = \mu + R_i + \varepsilon_I$$

Where:

Y_i = Dependent variable observed
μ = General mean
R_i = Fixed effect of substitution rate of fish meal with grasshopper meal
ε_i = Residual error

Variable means are presented in tables with standard errors (SE) and probability values (p-value). Significant differences between treatments were assessed by least significance difference. The fish meal substitution with grasshopper meal was determined to be significant if the $p<0.05$. Regression analysis was performed in Microsoft Excel 2013.

RESULTS AND DISCUSSION

Chemical composition: Proximate chemical composition of fish meal (FM) and grasshopper meal (Table 2) revealed that grasshopper meal (GM) contained 1.94% more water and 8.14% less crude protein (CP) than fish meal. Also, grasshopper meal had 1.74% more ether extract (EE), 4.06% more ash and 9.23% more crude fiber (CF) than fish meal.

Previous studies have shown that the chemical composition of grasshopper meal is variable: DM ranged from 91%[12] to 96%[13], CP ranged from 22%[14] to 58%[7], EE ranged from 4%[12] to 12%[9], CF ranged from 8%[3] to 15%[13] and ash ranged from 2.9%[7] to 10%[9]. These variations may be due to the differences associated with the grasshopper species used, the sources of procurement, the processing method[3], the sex, the stage of maturity or environmental factors[15].

The GM used in the present study was characterized by a high fiber and ash content and a low CP content compared with FM. These contents affected the feed formulation. Consequently, CF and Ca of the experimental diet increased with increasing GM, while CP decreased with increasing rates of GM in the diet.

Feed intake: A linear negative correlation (R^2 = 0.45) was found between replacement rate of FM with GM in broiler diet and their feed intake (Fig. 1). This decrease had a statistically significant effect on daily feed intake (p<0.05). Birds fed with G0 showed the highest average daily feed intake, while those fed with G75 showed the lowest intake during the starting and growing phases (Table 3). During all experimental phases, birds fed with G0 consumed more feed by approximately 6, 12, 34 and 13% than broilers fed G25, G50, G75 and G100, respectively.

Table 2: Chemical composition of fish meal and grasshopper meal used in broiler diets

Ingredients	DM (%)	CP (%)	EE (%)	CF (%)	Ash (%)
Fish meal	95.02	55.87	10.52	2.66	5.07
Grasshopper meal	93.08	47.73	12.23	11.89	9.13

DM: Dry matter, CP: Crude protein, EE: Ether extracts, CF: Crude fiber

Table 3: Average daily feed intake (g/day) of broilers fed diets containing increasing levels of grasshopper meal (GM)

Phases	G0	G25	G50	G75	G100	SE	p-value
Starter	52^a	50^b	45^d	33^e	48^c	1	0.001
Grower	115^a	106^{ab}	101^b	77^c	96^b	7	0.001
Overall	83^a	78^b	73^c	55^d	72^c	3	0.001

^{a,b,c,d}Means with the same superscripts along the same row are not significantly different (p>0.05). G0, G25, G50, G75 and G100: Diets that substituted FM with GM at 0, 25, 50, 75 and 100%, respectively

The crude fiber rate increased with increasing levels of GM in the diets. Consequently, the level of CF contained in the G75 and G100 feeds exceeded the recommendations of 5% crude fiber in broiler feed[16]. Therefore, broilers fed the control diet ingested more feed than those fed the experimental diets containing grasshopper meal and the daily feed intake decreased with increased levels of GM in diets. Khempaka *et al.*[17] reported a significant decrease in feed intake with increasing levels of shrimp meal in broiler diets. This could be related to the rate of crude fiber, which decreased the palatability of diets[18] compared to grasshopper meal. However, replacing fish meal with silkworm pupae[19] and groundnut cake with maggot meal[20] in broiler diets did not significantly affect their feed intake. This may be due to the low CF content of silkworm pupae and maggot meal compared to grasshopper and shrimp. The daily feed intakes observed in this experiment were similar to results reported by Adeyemo *et al.*[9], who used locust meal in broiler diets but were higher than those reported by Okah and Onwujiariri[21], who used maggot meal in finisher broiler diets and were lower than those reported by Rosenfeld *et al.*[22], who used different levels of shrimp meal to replace soybean meal in broiler diets.

Growth performance: Figure 2 reveals that the live body weight of broilers was negatively correlated (R^2 = 0.54) with the gradual replacement of fish meal with grasshopper meal in their diet. Moreover, the increase in grasshopper meal in broiler diets decreased body weight. The initial weight of birds was similar (p = 0.774) in all of the treatments (Table 4). However, at the end of starter phase, live weight was significantly lower in the GM treatments (p = 0.001).

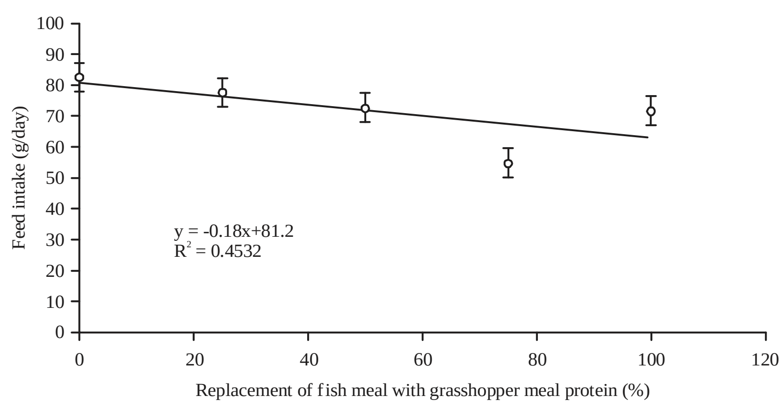

Fig. 1: Relationship between the substitution rate of fish meal with grasshopper meal and the feed intake of broilers

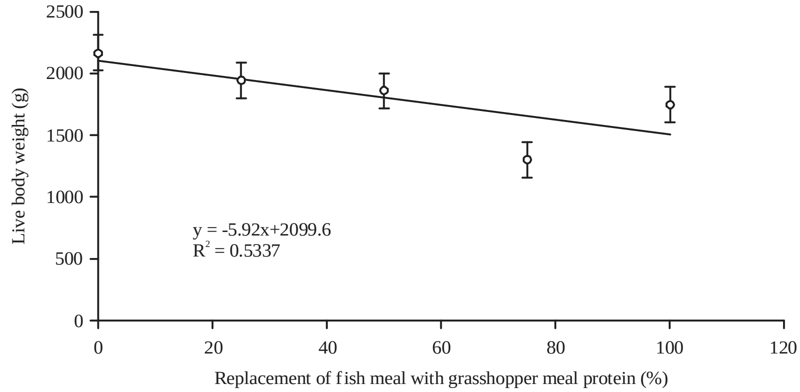

Fig. 2: Relationship between the substitution rate of fish meal with grasshopper meal and live body weight of broilers

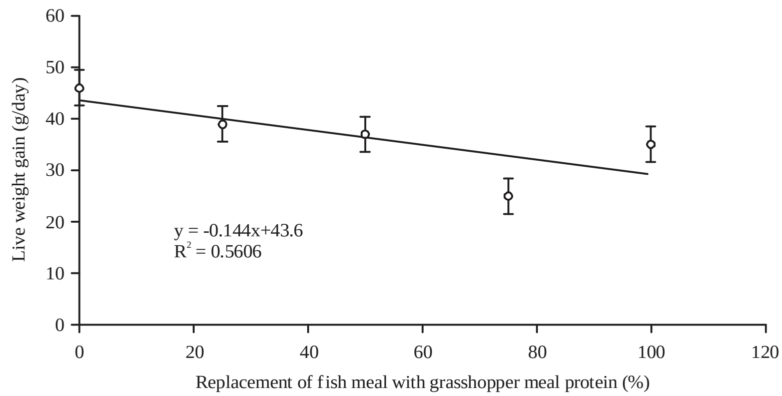

Fig. 3: Relationship between the substitution rate of fish meal with grasshopper meal and live weight gain of broilers

Table 4: Effect of fish meal (FM) gradual substitution with grasshopper meal (GM) on broiler final live body weight (g)

Phases	G0	G25	G50	G75	G100	SE	p-value
Initial weight	44^a	43^a	44^a	43^a	43^a	2	0.774
Starter	744^a	590^b	548^b	418^c	554^b	52	0.001
Grower	2166^a	1944^{ab}	1859^{ab}	1302^c	1747^b	168	0.001

a,b,cMeans with the same superscripts along the same row are not significantly different (p>0.05). G0, G25, G50, G75 and G100: Diets that substituted FM with GM at 0, 25, 50, 75 and 100%, respectively

Table 5: Average daily weight gain (ADWG) (g/day) of broilers when fish meal (FM) was gradually substituted with grasshopper meal (GM) in their diets

Phases	G0	G25	G50	G75	G100	SE	p-value
Starter	42^a	29^b	27^b	18^c	27^b	4	0.001
Grower	51^a	48^a	47^a	32^b	43^a	7	0.010
Overall	46^a	39^b	37^b	25^c	35^b	3	0.001

a,b,cMeans with the same superscripts along the same row are not significantly different (p>0.05). G0, G25, G50, G75 and G100: Diets that substituted FM with GM at 0, 25, 50, 75 and 100%, respectively

In addition, the gradual replacement of fish meal with grasshopper meal significantly decreased the final live weight at the end of the growing phase (p<0.05). Broilers fed with G75 had the lowest final body weight compared to birds fed with G0, G25, G50 and G100 by approximately 40, 33, 30 and 26%, respectively. However, the final live weights for broilers fed with G0, G25 and G50 were not significantly different.

A negative correlation was observed between grasshopper meal and average daily weight gain (ADWG) during the 49 days of experimentation (Fig. 3). Increases in grasshopper meal levels in broiler diets significantly decreased broiler ADWG at the starter phase (p<0.05). At the growing phase, the ADWG values were not significantly different (p>0.05) for broilers fed G0, G25, G50 and G100 (Table 5).

During the 49 days of experimentation, the ADWG of broilers was 36 g/day. There was a significant difference between treatments (p<0.05). Broilers fed G0 had the best growth rate (46 g/day). Their ADWG was higher than those of broilers fed G25, G50, G75 and G100 by approximately 15, 19, 46 and 24%, respectively. However, there was no significant difference among the ADWG values of broilers fed G25, G50 and G100.

Broiler growth performance decreased at 75% grasshopper meal substitution in the diet. This observation is in agreement with results reported by Adeyemo *et al.*[9], who

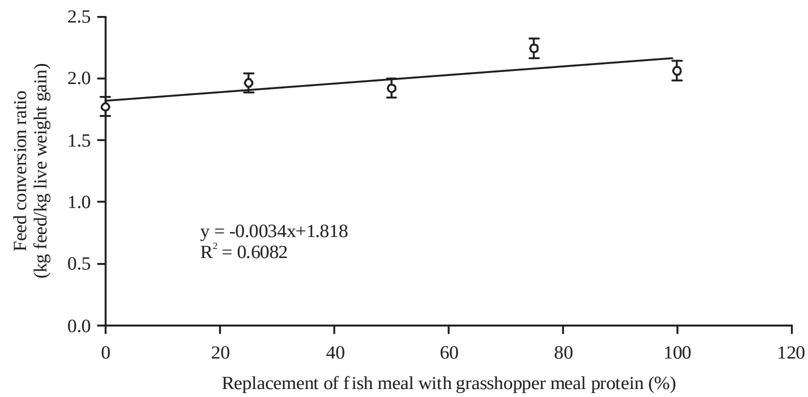

Fig. 4: Relationship between the substitution rate of fish meal with grasshopper meal and the feed conversion ratio

Table 6: Effect of the gradual substitution of fish meal (FM) with grasshopper meal (GM) in broiler diets on their FCR (kg feed/kg live weight gain)

Phases	G0	G25	G50	G75	G100	SE	p-value
Starter	1.26[b]	1.74[ab]	1.68[ab]	1.99[a]	1.78[ab]	0.27	0.010
Grower	2.27	2.18	2.18	2.49	2.34	0.34	0.649
Overall	1.77[b]	1.96[ab]	1.92[b]	2.24[a]	2.06[ab]	0.16	0.001

[a,b]Means with the same superscripts along the same row are not significantly different (p>0.05), G0, G25, G50, G75 and G100: Diets that substituted FM with GM at 0, 25, 50, 75 and 100%, respectively

Table 7: Feeding cost (FCFA[1] feed/kg live weight gain) in broiler production when fish meal (FM) was gradually substituted with grasshopper meal (GM)

Phases	G0	G25	G50	G75	G100*	SE	p-value
Starter	420	567	534	617	538	84	0.053
Grower	679	639	617	699	642	96	0.752
Overall	549[b]	603[ab]	575[ab]	658[a]	590[ab]	45	0.042

[a,b]Means with the same superscripts along the same row are not significantly different (p>0.05). [1]FCFA: Republic of Niger currency: 1€ = 655.96 FCFA on 2016-10-22. G0, G25, G50, G75 and G100: Diets that substituted FM with GM at 0, 25, 50, 75 and 100%, respectively

substituted fish meal with locust meal in broiler diets and Khempaka *et al.*[17], who substituted soybean meal with shrimp meal. Decreased growth performance may result from the chitin content of grasshoppers. Chitin may decrease the digestibility because of a non-digestible amino polysaccharide[17]. Broilers fed G75 showed lower growth performance than birds fed G100. This trend was observed by Adeyemo *et al.*[9] in gradual substitution of fish meal with locust meal in broiler diet. Khempaka *et al.*[17] also reported that substituting 16% of soybean with shrimp meal in broiler diets permitted more growth performance than a 12% substitution. Rosenfeld *et al.*[22] found that at 42 days, body weight was statistically higher for broilers fed a 100% replacement of soybean meal with shrimp meal than those fed with an 80% substitution. This could be due to chitinase activity. Indeed, Khempaka *et al.*[23] observed more chitinase and lactobacillus activity when 20% of soybeans were replaced with shrimp meal in broiler diets than when it was replaced with 15%. Chitin utilization in poultry was not fully understood. The final body weight observed in this study was similar to the results presented by Adeyemo *et al.*[9], who substituted fish meal with locust meal. The results of the present study were higher than the result obtained by Khempaka *et al.*[17], who replaced soybean meal with shrimp meal in broiler diets, Khatun *et al.*[19], who replaced fish meal with silkworm pupae in broiler diets and Adeniji[20], who replaced groundnut cake with maggot meal in broiler diets. Grasshoppers may be more effective than shrimp, silkworm and maggot meals in broiler diets.

Feed efficacy and efficiency: Increases in grasshopper meal in broiler diets increased the feed conversion ratio (FCR) with a linear correlation (Fig. 4). The FCR significantly increased during all experimental phases with increasing GM in broiler diets (Table 6, p<0.01). Broilers fed G0 had a lower FCR by approximately 11, 8, 27 and 16% compared to those fed G25, G50, G75 and G100, respectively. However, during the growing period, FCR was statistically indistinguishable in all treatments (p = 0.649). The efficacy of the grasshopper-based diets is, therefore, better at the growing phase than at the starting phase.

Feed cost (FC) was not significantly affected by the substitution of fish meal with grasshopper meal during the growing phase (p = 0.649), but it was affected at the starter phase and across all phases (Table 7). The average cost of feed for producing 1 kg of live weight was 595 FCFA. In the starting and growing phases, the FC was 535 and 655 FCFA kg^{-1}, respectively.

Economic feed efficiency (EFE) was significantly affected by the treatments during the starting phase and throughout the 49 days of experimentation (Table 8, p<0.05). In general, EFE decreased from G0 to G75. However, during the growing period, EFE was not significantly affected by the dietary treatment (p = 0.806). Broilers in the G75 treatment had the lowest EFE (Table 8).

Table 8: Economic feed efficiency (FCFA live weight gain/FCFA feed) of broilers when fish meal (FM) was gradually substituted with grasshopper meal (GM)

Phases	G0	G25	G50	G75	G100	SE	p-value
Starter	2.39[a]	1.80[ab]	1.89[ab]	1.71[b]	1.87[ab]	0.27	0.024
Grower	1.48	1.58	1.63	1.47	1.62	0.24	0.806
Overall	1.93[a]	1.69[ab]	1.76[ab]	1.59[b]	1.74[ab]	0.14	0.048

[a,b]Means with the same superscripts along the same row are not significantly different (p>0.05). G0, G25, G50, G75 and G100: Diets that substituted FM with GM at 0, 25, 50, 75 and 100%, respectively

Table 9: Effect of replaced fish meal (FM) with grasshopper meal (GM) in the diet on the carcass characteristics of broiler chickens

Parameters	G0	G25	G50	G75	G100	SE	p-value
Carcass weight (g)	1746.00[a]	1677.00[a]	1482.00[a]	1100.00[b]	1578.00[a]	135.00	0.001
Carcass yield (%)	76.27[a]	74.78[a]	73.49[a]	69.87[b]	73.09[a]	1.66	0.001
Feather yield (%)	3.18	4.36	3.88	5.13	4.83	1.27	0.256
Head and leg yield (%)	6.90[b]	6.56[b]	7.09[b]	8.04[a]	7.00[b]	0.28	0.001
Empty gizzard yield (%)	1.46	1.97	2.07	2.27	2.08	0.36	0.060
Liver yield (%)	1.51	1.84	1.72	2.18	2.03	0.35	0.107

[a,b]Means with the same superscripts along the same row are not significantly different (p>0.05). G0, G25, G50, G75 and G100: Diets that substituted FM with GM at 0, 25, 50, 75 and 100%, respectively

The feed conversion ratio (FCR), feeding cost (FC) and economic feed efficiency (EFE) of broilers in growing phase were not significantly affected by the substitution of fish meal with grasshopper meal. During that phase, grasshopper meal can economically and fully substitute for fish meal in broiler diets. FCR, FC and EFE were not significantly affected at up to 50% substitution. For both phases, grasshopper meal can substitute fish meal at up to 50% in broiler diets with no negative financial impacts. Previous studies revealed that shrimp meal negatively affected FCR when used up to 60%[22] and locust meal up to 75%[9]. However, maggot meal did not affect FCR[20] and silkworm pupae improved it[19].

Carcass characteristics: The weight of the carcass, head and leg yield and carcass yield were affected by the dietary treatment (p<0.05) (Table 9). Birds fed G0 had a higher carcass weight and carcass yield, while broilers fed G75 presented the lowest performance for these parameters. The feather yield, empty gizzard yield and liver yield were not affected (p>0.05) when grasshopper meal replaced fish meal in broiler diets (Table 9).

Carcass yield in this study was higher than the results reported by Okah and Onwujiariri[21], who used maggot meal to replace fish meal, Khatun *et al.*[19], who replaced fish meal with silkworm pupae and Rosenfeld *et al.*[22], who replaced soybean meal with shrimp meal in broiler diets. Feather, empty gizzard and liver yields were not significantly affected by the gradual substitution of fish meal with grasshopper meal in broiler diets. This result agrees with Khatun *et al.*[19] but contradicts the results of Okah and Onwujiariri[21], who reported that substitution of fish meal with maggot meal significantly influenced feather, empty gizzard and liver yields.

CONCLUSION

The substitution of fish meal with grasshopper meal at rates of 0, 25, 50, 75 and 100% in broiler diets during starting and growing phases showed the following:

- Replacing fish meal with grasshopper meal significantly decreased feed intake, growth performance and carcass yield.
- There was no significant effect on feed efficacy and efficiency during the growing phase of broilers.
- Feeds containing 25% (G25) and 50% (G50) of grasshopper meal were similar to the control diet (G0) in term of growth performance, feed efficiency and carcass yield.
- Grasshopper meal can, therefore, replace fishmeal in broiler diets at 50%, especially in the growing phase. For better use of grasshopper meal in broiler diets, it is necessary to determine the role and mechanism of grasshopper chitin in the digestibility of feed by broilers and to evaluate the effect of grasshopper species on the bio-economic performance of broilers.

SIGNIFICANCE STATEMENT

This study reveals the potential of a new animal protein feed resource that can be beneficial in poultry diets in tropical regions, particularly in Niger. Grasshopper meal, therefore, constitutes an alternative to fish meal in broiler diets. Poultry farmers can use grasshopper meal in broiler diets at the growing phase to reduce fish meal use and feed cost. This study will help researchers to explore the role and mechanism of grasshopper chitin in broiler feed digestibility, determine methods to reduce the negative effects of chitin on broiler performance and experiment with possible grasshopper species that contains less chitin.

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