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Proximate Composition of *Clarias gariepinus* Fed Graded Levels of *Sesame indicum* (Beni seed) Diets

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Abstract

This present study investigates the effect of replacing fishmeal with varying levels of Beni seed *(Sesamum indicum)* meal on the diet of *Clarias gariepinus*. Three hundred and sixty (360) healthy *C. gariepinus* (African mud catfish) were stocked in eighteen (18) experimental tanks and fed different graded levels of diets that were developed to contain 40% crude protein using graded levels of sesame seed meal (0%, 25%, 50%, 75%, and 100%) as a replacement of fish meal. Proximate compositions of both diets and fish carcasses were analyzed following the AOAC (2019) methods. Significant differences ($p<0.05$) were observed in moisture, ash, crude fibre, carbohydrate, fat, and crude protein contents among the treatments. Fish fed diets with 50% and 75% Beni seed inclusion (DT4 and DT5) demonstrated superior protein deposition compared to the control and other treatments. However, fish fed a 100% Beni seed diet (DT6) showed reduced ash and protein levels, indicating a nutritional limitation at complete substitution. This research concludes that partial replacement of fishmeal with Beni seed meal, particularly between 50% and 75%, is both nutritionally sound for *C. gariepinus* culture. Complete replacement (100%) may not support optimal growth due to reduced protein quality and the potential presence of anti-nutritional factors. Thus, incorporation of Beni seed meal up to 75% in fish feed is recommended. Further research may also be conducted on amino acid supplements, processing methods to minimize anti-nutritional value, and long-term performance to improve the practical use of Beni seed meal in aquaculture.

INTRODUCTION

It is widely acknowledged that feed costs constitute the largest share of production costs in aquaculture grow-out systems. Despite the growth in fish production, culture-based aquaculture is not profitable enough due to the high costs of conventional feeds. Protein supplements, in particular, are both costly and hard to obtain, prompting the search for alternative sources of protein. Fish farming is mainly determined by the application of affordable, nutritious feeds [1]. In *C. gariepinus* farming, a significant portion of production costs is incurred in feed procurement [2, 3]. Commercial feeds are usually costly, and prices are rising due to competition over major feed sources, such as cereals, oils, and protein meals, among other animal feed companies [3,4]. This is one of the reasons small and medium-scale fish farmers are facing challenges; alternative feed resources need to be considered. Fishmeal, which constitutes a major part of fish feed, provides important nutrients but is relatively costly and not available in large quantities. The most common plant-based protein source used in place of fishmeal is Soybean meal, as it provides high protein content and sufficient levels of amino acids [5,6,7,8]. However, several local plants that are free and have high protein content offer alternatives to soybean meal, are less expensive, and can reduce feed cost [5,6].

Sesame indicum (also known as Beni seed) belongs to the Pedaliaceae family [9,10]. It is among the ancient cultivated oil-bearing crops used extensively in Africa and Asia. The varieties of Beni seeds contain abundant amounts of protein, oil, essential amino acids, and bioactive compounds (lignans (sesamin and sesamolin)) that have antioxidant activity [11]. Following oil extraction, the Beni seed meal is a byproduct with a high protein content and can be added to animal feeds. Beni seed is mostly fed on in different forms. This includes fresh, dried, and fried, when blended with sugar. Nutritionally, it is also used as a paste in some local soups. Yakubu et al. [12] found that supplementation of Beni seed (*Sesame indicum*) meal in the diets of *Clarias gariepinus* significantly enhanced growth and feed utilization parameters, such as weight gain, specific growth rate, protein efficiency ratio, feed intake, and survival rate. The rising demand for fish meals, combined with decreasing supply and high costs, presents the main challenge for the aquaculture industry [13,14]. Although Beni seed meal holds some potential as an available alternative to fish meal, its species remain largely unexplored. Thus, this research aims to investigate the proximate composition effects on *Clarias gariepinus* fed graded levels of Sesame indicum (Beni seed) meal.

MATERIALS AND METHODS

Sample collections

Beni seed (white cultivar), fishmeal, groundnut cake, and maize were purchased at Lapai market and used to formulate the diets. Three hundred and sixty (360) healthy *Clarias gariepinus* were procured from White Light Fish Farm and General Enterprise, along Lapai-Agaie, Niger State.

Sample preparation

Sample processing took place at the Laboratory of Biochemistry at Ibrahim Badamasi Babangida University, Lapai, Niger State. Nigeria. The Beni seed (*Sesamum indicum)* used was the white cultivar. To reduce the moisture levels, the feed ingredients were dried in the sun before milling. The ingredients were then ground separately in a RICHI SFSP56×40 feed hammer mill (China) fitted with a 1.0 mm mesh, ensuring all materials were ground to a fine particle size. The ground ingredients were weighed according to the required proportions for each diet. A sensitive weighing balance (TH-2000, Hangzhou Gongheng Weighing Equipment Co., Ltd., China) was used to measure the amount of each ingredient. Once all the ingredients had been mixed, cassava starch was added as a binding agent to help hold the feed together. Hot water was added to make a dough for pelletizing with the pelleting machine (Hobart A-2007, Hobart LTD, London) using a 2 mm mincer. The pellets were sun-dried, packed, and then kept until required.

Stocking and acclimatization of experimental Fish

Three hundred sixty (360) *Clarias gariepinus* (African mud catfish) of the same age, with a size of 5.0±0.20 cm, were selected and purchased from White Light Fish Farm and General Enterprise, located along the Lapai-Agaie road in Niger State. The fish were transported in aerated containers at an early morning (6:00 am-7:00 am) to the Animal House at Ibrahim Badamasi Babangida University, Lapai, Niger State. They were acclimatized for two (2) weeks and fed commercial feed twice daily at 3% of their body weight. Fish were starved for 24 hours before the feeding trial commenced. The initial length and weight of the fish were recorded. water quality parameters, such as pH, temperature, and dissolved oxygen, were monitored, and the water in each tank was changed once a significant accumulation of residual feed and faecal material was noticed. This was performed to maintain fish health. Water temperature (°C) ranged from 25.00 to 34.00°C, pH ranged from 6.00 to 9.2, and dissolved oxygen demand (mg/l) ranged from 4.00 to 6.10.

Feed Formulation and Experimental Design

The Pearson square method was used to achieve 40% crude protein, based on NRC guidelines [15], and modified according to the methods of Ndatsu et al. [16,17].

A total of six experimental diets with varying proportions of Beni seed (*S. indicum*) meal and soy bean meal were prepared and labeled 1, 2, 3, 4, 5, and 6, as shown in the table below. Diet 1 serves as the control diet (commercial diet). Diet 2 has 0% Beni seed meal with 100% soybean meal. Diet 3 consists of 25% Beni seed meal with 75% soybean meal. Diet 4 contains 50% Beni seed meal with 50% soybean meal. Diet 5 is composed of 75% Beni seed meal and 25% soybean meal. Diet 6 includes 100% Beni seed meal with 0% soybean meal.

Table 1. Feeding trial and treatment.

RT	NF	DT (5% Body Weight daily)
1	20	Commercial diet (Control)
2	20	0% Beni seed and 100% fishmeal
3	20	25% Beni seed and 75% fishmeal
4	20	50% Beni seed and 50% fishmeal
5	20	75% Beni seed and 25% fishmeal
6	20	100% Beni seed and 0% fishmeal

RT: Rearing tank, NF: Number of fish, and DT: Diet

The experiment involved 18 transparent plastic tanks (60 x 30 x 30 cm) and six dietary treatments, with three replicates each. Each tank was stocked with 20 fish and was netted to keep predators out. The feeding trials lasted for 12 weeks (90 days), with fish fed at 5% of their body weight daily. [18-20].

Sampling of Fish

Fish sampling was done every week. A weighing balance and a measuring board were used to measure the standard length, the total length, and the weight. Mortality was also monitored and recorded whenever a dead fish was observed, and the fish was then removed from the tank.

Proximate analysis

The proximate analysis of feed and fish flesh (pre- and post-trial) was performed using AOAC [21] standardized procedures. Samples were taken from each of the three replicates to determine the moisture content (measured by oven drying), crude fat (via Soxhlet extraction), protein (micro-Kjeldahl digestion), ash content (muffle furnace combustion), crude fibre (acid/base digestion and incineration), and carbohydrate (calculated by difference) [22,23]. All proximate data were expressed on a dry-matter basis.

Determination of Moisture Content:

Five (5.0g) grams of the dried samples were weighed into a pre-weighed crucible and heated for 3 hours at 105˚C to a stable weight (AOAC 925.10). The weight loss of the sample divided by its original weight was taken as the percentage moisture.

$$\%\,Moisture = \frac{W_2 - W_3}{W_2 - W_1} x100$$

Where,

W1 initial mass of empty crucible
W2 mass of crucible with sample pre-drying
W3 final weight of dry crucible and sample

Total ash content determination:

The ash content of a substance is the percentage of inorganic material that remains after the total burning or oxidation of its organic components. Two (2g) grams of the dried sample were measured into an empty pre-weighed crucible. The sample was incinerated in a muffle furnace at 550 °C for 6 hours (AOAC 923.03). The percentage of ash was determined by use of the following formula:

$$\% Ash = \frac{W_2 - W_1}{Weight\ of\ sample} x100$$

Where:
W_1 = initial weight of empty crucible
W_2 = mass of crucible + ash residue

Determination of crude protein:
Five (5g) grams were digested in a micro-Kjeldahl flask, and 20 cm³ of distilled water was added. It was swirled and left to rest for about 6 minutes. One tablet of Selenium catalyst with 20 cm³ of concentrated Sulfuric acid was added to the solution. Digestion was carried out at 100 °C for 4 hours until the digest was clear. Dilution to 50 cm³ was followed by titration of 10 cm3 of aliquots with sodium hydroxide, distillation of 10 cm³ of the product with sodium hydroxide, and titration of the distillate with 0.01 M H_2SO_4. The crude protein value was determined by calculation of the percentage of Nitrogen and multiplying by 6.25 (AOAC 979.09).

$$\% Nitrogen = \frac{Vs - Vb \times Nacid \times 0.01401}{W} x100$$

Where:
Vb = Volume of acid necessary to titrate
Vs =titer value of the sample
N acid = normality of acid
W =Weight of sample in grams

Estimation of crude lipid:
10 g of the powdered sample was weighed on filter paper, then placed in a thimble. A thimble was wicked with cotton wool and inserted into the extraction column, which was attached to a condenser to extract the lipid in the formula. The extract was filtered through filter paper and placed in a Soxhlet extractor using 200 mL of n-Hexane (reagent grade). The solvent of n-Hexane (200 mL) was used to extract lipids (AOAC 920.39). The estimate of the percentage lipid content was made by means of the following formula:

$$\% Fat = \frac{W_2 - W_3}{Weight\ of\ sample} x100$$

Where
W_2 = weight of filter paper and sample prior to extraction.
W_3 =the weight of filter paper and sample after extraction.

Determination of crude fibre:
A sample was ground into a fine powder. 5g of the powder was placed in 200 ml of 1.25% H2SO4, heated for 30 min, filtered, and washed until the solution was neutral. Afterwards, 200 mL of 1.25% NaOH was added to the residue, which was then boiled for 30 minutes, filtered, and washed until it was free of alkalinity. It was subsequently washed once with 10% HCl, twice with ethanol, and then lastly with petroleum ether. The dried residue was heated to 105 °C overnight, cooled, then burnt in a muffle furnace at 550 °C for 90 minutes (AOAC 978.10)—the percentage weight loss after incineration was used to determine the amount of crude fibre.

$$\% Fibre\ content = The\ loss\ in\ weight\ after\ incineration\ x\ 100$$

Determination of carbohydrate
Calculation of carbohydrate content was performed using the 100-moisture-protein-lipid-fiber-ash method.

$$\% Carbohydrate = 100 - (\%Moisture + \%Ash + \%Protein + Fat + \%Fibre$$

Statistical analysis
The collected data were subjected to one-way Analysis of Variance (ANOVA) and expressed as mean ± SD to test for differences in diet at $p<0.05$ (Zar, 2010) [24]. A post hoc test (Tukey's test) was used to rank the differences in means. Statistical Package for Social Sciences (SPSS) version 27 was used as a statistical tool.

RESULTS

Proximate Composition of Experimental Diets
Table 1 shows the proximate composition of the experimental diets. Significant ($p < 0.05$) differences were observed among treatments for most proximate parameters. A higher moisture content and crude fibre values, which are not significantly ($p < 0.05$) different, were observed in DT1 (7.89, 8.03%), DT2 (7.43, 8.63%), DT3 (7.20, 8.21%), and DT6 (7.51, 8.85%), respectively. However, the group of fish served DT4 (6.98, 5.21%) and DT5 (6.24, 5.88%) shows no significant differences in moisture content or fiber compared to the others.

Table 1. Proximate composition of graded levels of the dietary treatments.

Diets	Moisture content (%)	Ash content (%)	Crude fiber (%)	Crude protein (%)	Fat content (%)	Carbohydrate (%)
DT1	7.89±0.02^b	5.32±0.02^b	8.03±0.02^b	45.51±0.02^a	12.01±0.02^b	21.24±0.03^c
DT2	7.43±0.04^b	5.84±0.02^b	8.63±0.01^b	45.74±0.03^a	12.74±0.02^b	19.62±0.04^b
DT3	7.20±0.10^b	5.21±0.02^b	8.21±0.02^b	45.82±0.03^a	12.88±0.04^b	20.68±0.02^c
DT4	6.98±0.02^a	6.85±0.02^c	5.21±0.02^a	56.85±0.02^b	9.57±0.02^a	15.54±0.04^a
DT5	6.24±0.02^a	6.48±0.03^c	5.88±0.03^a	55.61±0.01^b	9.81±0.02^a	15.98±0.02^a
DT6	7.51±0.03^b	4.38±0.02^a	8.85±0.03^b	46.27±0.02^a	12.16±0.02^b	20.83±0.01^c

Data are shown as mean ± SD of three replicates. Means with different superscript letters in each column are significantly different ($p<0.05$). DT refers to diets, and DT1 is the commercial diet. DT2 is formulated with 0% Beni seed meal and 100% soybean meal, DT3 is formulated with 25% Beni meal and 75% soybean meal, DT4 contains 50% Beni seed meal, and 50% soybean meal, DT5 is composed of 75% Beni seed meal and 25% soybean meal, DT6 is 100% Beni seed meal and 0% soybean meal.

Table 2. Proximate composition of fish carcass before and after the treatment.

DIETS (%)	Moisture content (%)	Ash content (%)	Crude Protein (%)	Crude fibre (%)	Fat content (%)	Carbohydrate (%)
DT1	6.85±0.01^b	3.20±0.01^b	58.32±0.03^b	4.65± 0.02^a	8.73±0.03^b	18.25±0.03^b
DT2	6.33±0.02^b	3.21±0.02^b	58.22±0.02^b	4.86±0.03^a	8.51±0.02^b	18.87±0.02^b
DT3	6.24±0.04^b	3.05±0.04^b	57.95±0.05^b	4.22±0.02^a	8.14± 0.05^b	20.40±0.04^c
DT4	5.45±0.02^a	4.43±0.02^a	60.64±0.04^c	5.34 ±0.10^b	7.48 ±0.04^a	16.66±0.04^a
DT5	5.33±0.02^a	4.98±0.04^a	61.22±0.30^c	5.02±0.04^b	7.21±0.04^a	16.24±0.02^a
DT6	6.29±0.03^b	3.86±0.03^a	55.83±0.02^a	4.74±0.03^a	8.67±0.02^b	20.61±0.05^c

Data are shown as mean ± SD of three replicates. Means with different superscript letters in each column are significantly different ($p<0.05$). DT refers to diets, and DT1 is the commercial diet. DT2 is formulated with 0% Beni seed meal and 100% soybean meal, DT3 is formulated with 25% Beni meal and 75% soybean meal, DT4 contains 50% Beni seed meal, and 50% soybean meal, DT5 is composed of 75% Beni seed meal and 25% soybean meal, DT6 is 100% Beni seed meal and 0% soybean meal.

Likewise, the levels of Ash and protein contents in the group of fish fed DT4 and DT5 were higher insignificantly so, compared to others. In contrast, higher insignificant differences of fat and carbohydrate were observed in fish fed DT1, DT2, DT3, and DT6 compared to others (**Table 1**). The values were expressed on a dry matter basis.

Proximate analysis of fish carcasses before and after the graded levels of the dietary treatments

Table 2 shows the proximate composition of fish carcasses fed different levels of Beni seed meal. Higher crude protein values were observed in DT4 (60.64%) and DT5 (60.22%), which were significantly ($p < 0.05$) higher than those in other treatments. Moreover, lower moisture, crude fat, and carbohydrate contents, albeit not significantly ($p < 0.05$) different than other groups, were also observed in fish that were fed DT4 and DT5. Compared to other treatments, on the other hand, fat percentages were significantly ($p < 0.05$) higher in DT1, DT2, DT3, and DT6 (**Table 2**). All figures are presented on a dry matter basis.

DISCUSSION

The nutritional composition of the diets, as determined by proximate analysis, revealed various constituents and their corresponding proportions. This type of composition defines the quality of the feeds used in fish farming. Significant differences ($p < 0.05$) in the composition of the proximate food treatments indicated differences in diet costs. Lower moisture content, and therefore significantly different ($p<0.05$) in diets DT1, DT2, DT3, and DT6 as compared to those of DT4 and DT5, which are lower than the recommended range (0-13%), could be due to the proportion and interaction of the blend as demonstrated by James [25]. This can also reveal that the sample is hygroscopic, indicating a longer shelf life. Moisture content and water activity of food products are significant factors in determining product quality [26, 6]. The observation agrees with other works sampled by [6], which state that samples with a high hygroscopic character absorb more water than their less hygroscopic counterparts.

Recent studies were also able to find similar results on moisture and feed quality in *C. gariepinus* diets were [27] found that moisture control is essential when it comes to stability and storage of feeds in sesame-based diets. The very important ash content values of dietary diets (DT4 and DT5) relative to others might then likely reflect the possible rise in essential minerals. The fact that total inorganic matter and crude fibre are higher in all the treatment diets than in the control indicates that the diets are supplemented with minerals and are thus probably beneficial. This mineral composition is essential for the nourishment of gastrointestinal and metabolic functions in animals [28,29]. This implies that the mineral composition of Beni seed meal is lower than that of soybean meal, as was the case in earlier research that found soybean meal to have a higher ash content [30].

Saidu et al. [31] also found that inclusion of sesame meal produced lower mineral residue as compared to soybean meal, inclusion of this meal, however, enhanced feed texture and palatability. The total ash and fiber content of the results in this experiment was slightly higher than that indicated by [28]. A possible solution is that beni seed meal can be less indigestible fiber compared to soybean meal and, hence, serve as the alternative to the latter with lower anti-nutritional impact [28]. Crude protein is reported to be the most versatile part of food in the life of fish and other living things. Excessive levels of crude protein in diets DT4 and DT5 may show that the inclusion level range of 50-75 percent of the Beni seed best distributes amino acids. Nevertheless, DT6 (46.27%) barely decreased, indicating that a complete replacement of soybean with Beni seed may not fully meet protein needs. This observation is consistent with that of [32], who found that alternative sources of proteins can indeed promote growth when properly prepared. In addition, the increased protein content of diet DT4 indicates that Beni seed meal supports protein production but may be deficient in specific amino acids that facilitate optimal fish development [26]. The findings are consistent with [34], who have documented that Beni seed meal has the effect of increasing the protein content, although it has to be supplemented with amino acids.

Increase in protein values is considerable in all the dietary treatment groups. This may be because of the percentage concentration of *S. indicum* seed incorporated. Beni seed has an adequate percentage of amino acids [26]. As detailed in [26], the chemical scores and net protein utilization rates of these amino acids are at 62% and 54%, respectively, which means that these amino acids are important in determining the quality traits of fish meal protein. Thus, every experimental diet should serve as a good quality protein source to the fish. Moreover, total fats were also considerably greater in each of the dietary treatments, which means that the values were growing with the addition of Beni seed meal. It indicates the Beni seed-based meals have a high content of oil that increases the level of fat in diets with a greater substitution.

Fat may cause rancidity and short feed shelf life, which are issues during fish formulation [34]. Because of the high levels of lipids in Beni seed, it might increase the energy conversion, as reported by [35] on diets composed of maggot meal. As well, Peters et al. [26] and Saidu et al. [31] reported, the high concentration of lipids in fish diets increases the use of energy, but it should not be excessive to avoid the process of lipid oxidation. Similarly, the rising carbohydrate content in the diets that have higher inclusion of Beni seed meal suggests that Beni seed meal might have higher carbohydrates compared to soybean meal. These results imply that carbohydrate is increase by Beni seed meal, which may be alternatively used as a source of carbs in fish [32].

The carbohydrate content growth with increment in Beni seed meal implies that Beni seed meal has got a high level of carbohydrate as compared to soybean meal, which is corroborated by other research on seed-based protein substitute [36]. All the proximate composition of the entire carcass of the fish involved in the experimental dietary groups was significant (less than the p-value $p<0.05$). The reduction of moisture value with the increase in the content of Beni seed meal indicates a higher percentage of oil in Beni seed meal that can lessen the retention of water in fish body. This is in association with the results of [23], and Hamisu [27], who noted that the increase in the dietary lipid level led to decreased moisture levels in fish carrases. Reduced moisture level is useful in extending the shelf life of fish and minimizing spoilage [23,31].

The ash content that is a manifestation of the mineral content of the fish carcass was also very high with fish fed on DT4 and DT5. The intense rise at the levels of increased Beni seed meal of fish carcasses is an indication that Beni seed meal is more abundant in minerals. Similar trends were reported by Beshaw et al. [37] and Olude & Ogunbiyi [38], where the authors showed that a plant-based diet formulation can be used to augment mineral retention and bone mineralization through calcium and phosphorus fortification. It is known that crude protein is the most essential food content ingredient in fish and other living organisms. This increase in crude protein values which were very different and reported in all experimented fish carcasses at various levels of inclusion may be attributed to the increase in protein values in Beniseed meal.

The reduction in values of the protein in fish carcasses that were fed diet DT6 may indicate that the total substitution of fish meal with Beni seed meal does not reduce the protein deposition. Similar results were indicated in [23] who also reported that moderate supplementation of plant proteins increases protein deposition. But when in excess, they lower protein digestivity because they contain anti-nutritional properties like phytates and tannins. The gradual rising compound of crude fiber with an increment in the proportion of Beniseed meal inclusion in all fish carcasses indicates a higher level of fiber content in Beniseed meal. High fiber content probably enhances gut motility but might impair nutrient digestibility when unnaturally high, which might be the cause of lower protein content in DT6 [39].

The fat quantity increases with an insignificance in the entire carcasses of the fish fed on experimental diet treatments, and this might be because of different proportions of Beniseed meal in the rations. The first increment with moderate incorporation of Beni seed meal can be attributed to its high lipid content. Nevertheless, the reduction at 100% substitution might indicate the impairment of lipid metabolism, which could be driven by anti-nutritional factors. Past research has shown similar results, with high-fiber diets decreasing fat retention in *Clarias gariepinus* [32,40]. The increasing carbohydrate concentrations with increasing inclusion of Beni seed meal indicate that the experimental fish may be relying on carbohydrates as an alternative energy source due to the low availability of proteins and lipids. Enyidi et al. [41] found that carbohydrate intake in plant-based diets increased as fish altered their metabolism to reduce protein content, a finding also reported by [31].

CONCLUSION

This experiment has shown the nutritional levels and the potential for partially replacing soybean meal with Beni seed (*Sesamum indicum*) meal in the diets of *Clarias gariepinus* (African mud catfish). The final composition of the two experimental diets and the fish carcasses showed substantial variation across dietary treatments. The findings also showed that a range of 50 to 75 percent Beni seed meal (DT4 and DT5) had the best growth performance, with an optimal crude protein level and a good balance between carbohydrates and fat. Nevertheless, at 100% substitution (DT6), the protein and fat deposition of the fish reduced, which meant that the overall substitution of soybean or fishmeal with Beni seed meal might not be nutritionally sufficient because there might be shortages in essential amino acid contents, and since anti-nutritional factors might be present. The research also established that Beni seed meal is high in fat and carbohydrates and has a reasonable level of crude protein, meeting the dietary requirements of catfish at a specific inclusion level. However, excessive substitution may alter ash and moisture content, affecting digestibility, nutrient retention, and the overall health of the fish. Thus, it seems that a moderate (50-75 percent) level of inclusion can be the optimal balance of economic sustainability and nutritional adequacy. The recommendations made included the following; (i) it is suggested that the inclusion level of Beni seed meal in the diet of *Clarias gariepinus* be within 50 to 75 percent, as this provides the best balance of protein, growth performance, and cost-effectiveness, (ii) when diets contain more Beni seed meal as a component, it is recommended to supplement with limiting amino acids (e.g., lysine, methionine) to improve protein quality and address deficiencies, and (iii) future research ought to emphasize food processing (e.g., fermentation, toasting, or enzymatic treatment) to minimize anti-nutritional compounds in Beni seed, and hence enhance the digestibility and absorption of nutrients.

CONFLICT OF INTEREST

The authors do not identify any conflict of interest in regard to this article.

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