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(Research Article)

Total substitution of soybean meal with okara in cockerel diets in Benin: Growth performance, nutrient digestibility and carcass characteristics

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Abstract

The use of soy pulp or okara, in pig feed is widespread. The study aimed to evaluate the effect of dried okara-based diets on zootechnical performance and nutrient digestibility of cockerels. Thus, an eleven-week experiment was carried out on seventy-two eight-week-old Harco cockerels. The cockerels were divided into nine groups of eight based on their live weight and then randomly assigned to one of three experimental diets (F0, F10, and F20), corresponding to feed incorporation levels of 0%, 10%, and 20% dried okara. The bromatological analysis of the okara and of the three experimental diets was performed. The studied parameters were feed intake, weight gain, nutrient digestibility, and carcass characteristics. The results showed that okara had 26% protein and 3109 kcal/kg DM of metabolizable energy. Feed intake increased significantly with the okara incorporation ($p < 0.05$), reaching 85.81 g DM/day for diet F20. The average daily gain (14.26 to 15.06 g) and feed conversion ratio (3.84 to 4.24) were statistically similar ($p > 0.05$) but diet F10 had the best numerical efficiency (FCR = 3.84). The apparent digestibility coefficients of dry matter and organic matter were stable but, a significant decrease in protein digestibility was observed for the okara-based diet (72.34% to 75.20%) compared to the control (81.21%). Furthermore, diet F10 had the highest carcass yield (70.94%) and the highest eviscerated weight (1270 g). These results suggest that dried okara can be used at a rate of 10% in Harco cockerel feed without affecting growth performance while optimizing carcass yield.

Keywords: Soy pulp; Cockerels; Feed intake; Nutrient digestibility; Carcass; Benin

1. Introduction

Poultry production contributes significantly to nutrition and household income in rural areas of developing countries [1]. However, for a good productivity, the potential of livestock cannot be optimized without effective and efficient feeding based on local feed resources. Among these local feed resources is soybean, which is often unavailable because it's mostly diverted to other uses, such as the starch industry and human consumption. The global food problem emergency has challenged nutritionists to explore the possibilities of using potential protein sources other than soybean [2]. One inexpensive protein source available to replace soybean in poultry diets is soy pulp, also called okara, which is a by-product of soy milk and tofu production. It is a white by-product resembling chopped coconut and containing 80%

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moisture [3]. Several studies on the macronutrient composition of okara have revealed its relatively high protein content ranging from 25 to 35% dry matter.

In Benin, soybean processing into food products such as cheese and milk has considerably developed thanks to local initiatives and small production units. This process generates by-products of which the most important and readily available is okara. Although available throughout the country, the use of okara in animal feed is not yet widespread among livestock farmers. After testing okara in the feed of Rhode Island Red (RIR) broiler chickens, [2] recommended its use in Beninese poultry farming. However, few studies have examined the effect of completely substitution of soybean meal by okara, particularly in Harco cockerels, from improved breeds, which show growth comparable to that of local chickens, widely raised in Benin [4]. Therefore, the present study was initiated to determine the impact of a dried okara-based diet on the zootechnical performance of Harco cockerels raised in Benin. The objective was to evaluate the effect of the complete substitution of soybean meal by dried okara on growth and nutrient digestibility in Harco cockerels.

2. Materials and Methods

The experiment was carried out at the Analysis and Research Unit for Animal and Fisheries Health and Nutrition of the National Institute of Agricultural Research of Benin (INRAB), located in the Atlantique department in southwestern Benin. The region has a sub-equatorial climate [5]. The yearly average rainfall is 1.200 mm and the average monthly temperatures vary between 27 and 31 °C with a difference of 3.2°C between the hottest month (March) and the coolest (August). The relative humidity fluctuates between 65%, from January to March and 97%, from June to July. The average annual temperature is 27°C [6].

2.1. Preparation process of dried okara

Fresh okara was collected from a small-scale soybean processing unit in the township of Abomey-Calavi, Atlantique Department. The processing method used in this unit corresponded to that described by [7]. At the research station, the fresh okara was spread in thin layers on clean tarpaulins for solar drying. This drying process, lasting forty-eight (48) to seventy-two (72) hours, was performed in accordance with [8] recommendations concerning the dehydration of agri-food products, with regular turning to ensure uniform drying. Each evening, the device was put into a ventilated room to protect it from nocturnal humidity. The dryness level was visually assessed and by touch. Once completely dry, the okara was packaged in polypropylene bags and stored in a well-ventilated area for later use.

2.2. Experimental diets

Soybean meal, the main conventional protein source in chicken feed, was substituted at 0%, 10%, and 20% with dried okara (DO) to obtain the three (3) experimental diets F0 (control), F10, and F20, respectively. The diets were balanced to meet the energy and protein requirements of growing cockerels, in accordance with nutritional recommendations. Other ingredients used in diets preparation were: maize grain, wheat bran, corn bran, cottonseed meal, oyster shells, salt, and meat concentrate. The percentage composition and calculated nutritional characteristics of the tested diets are shown in Table 1.

Table 1 Percentage composition of experimental diets

Feedstuffs	Diets (% FM)		
	F0	F10	F20
Soy pulp	0	10	20
Maze grain	53.5	51.5	50.5
Corn bran	9	7	3
Wheat bran	11	9	9
Soybean meal	10	0	0
Cottonseed meal	8	14	9
Oyster shells	3	3	3
Meat concentrate	5	5	5

Nacl	0.4	0.4	0.4
Iron sulfate	0.1	0.1	0.1
Total (%)	100.0	100.0	100.0
Metabolizable energy[1] (Kcal/kg DM)	2637.02	2612.36	2632.99
Crude proteins[2] (% DM)	16.8265	16.8345	16.7955

FM = Fresh matter; F0 = Diet containing 0% okara; F10 = Diet containing 10% okara; F20 = Diet containing 20% okara

[1,2] The metabolizable energy and crude protein content of the diets was obtained using feed formulation software from the sum of the metabolizable energy and crude protein content provided by each feedstuff.

2.3. Experimental animals and design

A total of seventy-two (72) Harcot cockerels of eight (8)-week-old and with an average live weight of 831.11 ± 2.57 g, were used. A randomized complete block design with three (3) feeding treatments and three (3) replicates was used. Each replicate was a group of eight (8) cockerels. The three (3) treatments were the three (3) tested diets F0, F10, and F20, representing the three diet incorporation levels (0%, 10%, and 20%) of dried okara. Each group was randomly assigned to an experimental diet. The cockerels' groups were raised on the floor, on wood shavings, in 3 m^2 pens. Before the start of the experiment, all cockerels were vaccinated against Newcastle disease, dewormed, treated for coccidiosis, and given vitamins. In addition, daily monitoring was performed, with care administered as needed.

2.4. Evaluation of growth performance

After a seven (7)-day dietary transition phase, the feeding trial was carried out for eight (8) weeks, or fifty-six (56) days. Each of the nine (9) groups of eight (8) cockerels was randomly assigned to one of the three experimental diets F0, F10, and F20. Each cockerel received between 70 and 120 g (FM for Fresh Matter) of feed daily, from the experiment beginning to the end, with water provided *ad libitum*. For each group, the quantities of served diet and feed leftovers (in g FM) were weekly weighed and recorded. The individual live weights of the cockerels were measured at the experiment beginning and then at fourteen (14) day intervals. These data were used to calculate, by dietary treatment, the Feed Intake (FI, in g DM), the average daily gain (ADG, in g) as well as the feed conversion ratio (FCR).

2.5. Digestibility evaluation of the experimental diets

At the end of the feeding trial, at eleven (11) weeks of age, a seven (7)-day *in vivo* digestibility study was done according to [9] on eighteen (18) cockerels. The experimental design was a complete randomized block with three (3) dietary treatments (F0, F10, and F20) and six (6) replicates. Based on their average live weight (1647.43 ± 15.31 g), the cockerels were divided into three (3) homogeneous groups of six (6) individuals, each randomly assigned to an experimental diet. Each cockerel was housed in a 40 × 35 × 40 cm metal metabolic cage equipped with a waterer, a feeder, and a droppings collection device. The cockerels received each, 120 g FM of feed daily and *ad libitum* water. They were weighed at the beginning and end of the evaluation period. The amounts of served diet and feed leftovers were weighed daily for each bird to determine feed intake (FI). Concurrently, droppings were collected at a fixed time each morning, by cockerel, then grouped by feed treatment before being stored in airtight containers in a refrigerator at +4 °C. At the end of the collection period, the grouped droppings were weighed, thoroughly homogenized, and sampled by feed treatment before being transported to the laboratory. According to the official methods of [10], the dry matter (DM), organic matter (OM), and crude protein (CP) contents were determined. These results were used to calculate the apparent digestibility coefficients (ADC) of DM, OM, and CP of the experimental feeds.

2.6. Carcass characteristics evaluation

At twelve (12) weeks of age, or seventy feeding days, 25% of the cockerels from each type of diet, were used for meat characteristics evaluation. A total of eighteen (18) cockerels, namely six (6) per treatment group, were slaughtered using a traditional method after a twelve (12)-hour of feed withdrawal. The live weight (in g) was measured before slaughter and after plucking and evisceration, the weights of the whole carcass, eviscerated chicken, gizzard, liver, and heart were recorded. Finally, the carcass yield was calculated for each type of diet.

2.7. Nutritional evaluation of dried okara and experimental diets

The okara and experimental diets were analyzed in the laboratory according to analytical methods approved by [10] to determine their respective contents of dry matter (DM), organic matter (OM), crude protein (CP), ether extracts (EE), crude fiber (CF), and total ash (TA).

2.8. Statistical analysis

Data were processed in Excel and analyzed using Statistix 10.0.0.9 software. A one-way analysis of variance (ANOVA) was used to examine the effects of the level of dried okara incorporation (n = 3: 0, 10, 20%) on feed intake, average daily gain, feed conversion ratio, and carcass characteristics of experimental cockerels. Similarly, Apparent Digestibility Coefficients (DM, OM, and CP) were subjected to a one-way ANOVA with the same factor. Tukey's HSD all-pairwise comparisons test was used to separate homogeneous groups at a significance level of 5% when the difference was statistically significant.

3. Results

3.1. Nutritional value of dried okara and experimental diets

The various nutrients contents in dried okara (DO) and experimental diets are presented in Table 2. Dry matter content was approximately 87% and remained comparable across the three diets. DO had a high organic matter content (95.21% DM). The diets containing the dried okara also had a higher organic matter content, reaching 93% DM, approximately 3% higher than the control diet. In terms of protein, the dried okara had a relatively high content of around 26% DM, allowing F10 and F20 diets to maintain contents above 16% DM, with a maximum of 17.67% DM for F20 diet. Paradoxically, although the DO contained a significant amount of crude fiber (11.5%), diets incorporating this by-product had lower fiber contents (approximately 4.9% DM) than the control diet (6.29% DM).

Furthermore, the metabolizable energy (ME) of the dried okara, estimated at 3109 kcal/kg DM, was lower than those of the experimental diets. The ME content, initially 3328 kcal/kg DM for the control diet (F0), increased significantly with the incorporation of okara, reaching 3525 kcal/kg DM (F10) and 3639 kcal/kg DM (F20).

Table 2 Nutritional value of dried okara and experimental diets

Composition	Dried okara	F0	F10	F20
Dry matter (%)	88.83	87.43	87.50	87.33
Organic matter (% DM)	95.21	90.31	92.47	93.85
Crude proteins (% DM)	26.37	16.45	16.52	17.67
Ether extracts (% DM)	6.87	6.08	5.69	6.89
Crude fiber (% DM)	11.50	6.29	4.83	4.91
Total ash (% DM)	4.79	9.69	7.53	6.15
Metabolizable energy* (Kcal/Kg DM)	3109	3328	3525	3639

F0 = Diet containing 0% okara; F10 = Diet containing 10% okara; F20 = Diet containing 20% okara; *Metabolizable energy (ME) = 3951 + (54.4 x ether extracts) – (40.8 x total ash) – (88.7 x crude fiber) [11].

3.2. Growth performance of cockerels fed with dried okara-based diets

The results of feed intake, growth, and feed efficiency are presented in Table 3. The initial weights of the cockerels were similar for the three treatments (F0, F10, and F20). Similarly, their final weights did not significantly vary according to the diets ($p > 0.05$) and averaged 1647 g. Consistent with this weight stability, Average Daily Gain (ADG) was not significantly influenced by the inclusion level of dried okara ($P=0.6196$), although cockerels in group F10 had the fastest growth trend with 15.06 g. In contrast, feed intake was significantly influenced ($P < 0.05$) by the okara inclusion level in the diets. Birds in groups F10 (85.26 g DM/day) and F20 (85.81 g DM/day) consumed more feed than those in the control group (83.08 g DM/day). Finally, regarding the Feed Conversion Ratio (FCR), although the difference between treatments was not statistically significant ($P=0.0512$), a lower trend was observed for F10 (3.84) compared to F20 (4.18) and F0 (4.24).

Table 3 Growth performance of Harco cockerels

Parameter	Diets			**p Value**
	F0	F10	F20	
Initial weight (g)	833.75	821.67	837.92	0.7281
Final weight (g)	1640.20	1665.20	1636.87	0.9186
Feed Intake (g DM)	83.08 ± 3.07b	85.26 ± 3.88a	85.81 ± 3.9a	0.0209
ADG (g)	14.40 ± 0.89	15.06 ± 0.78	14.26 ± 0.69	0.6196
FCR	4.24 ± 0.73	3.84 ± 0.41	4.18 ± 0.44	0.0512

F0 = Diet containing 0% okara; F10 = Diet containing 10% okara; F20 = Diet containing 20% okara; ADG = Average Daily Gain; FCR = Feed Conversion Ratio.; (a,b) means of the same row followed by different letters are significantly different at the 5% level. P value = Probability of significance

3.3. Apparent Digestibility Coefficients of dried okara-based diets in cockerels

The Apparent Digestibility Coefficients (ADC) of nutrients from the different experimental diets are presented in Table 4.

Table 4 Apparent Digestibility Coefficients (ADC) of nutrients in dried okara-based diets for cockerels

ADC (%)	**Diets (Mean ± Standard Error)**			**p Value**
	F0	F10	F20	
DM	53,50 ± 3,17	53,42 ± 3,24	52,50 ± 3,69	0,9734
OM	58,95 ± 2,90	58,10 ± 2,90	57,95 ± 3,30	0,9696
CP	81,21 ± 1,70a	75,20 ± 1,71b	72,34 ± 2,18b	0,0137

F0 = Diet containing 0% okara; F10 = Diet containing 10% okara; F20 = Diet containing 20% okara. ADC = Apparent Digestibility Coefficient; DM = Dry Matter; OM = Organic Matter; CP = Crude Protein; (a,b) means of the same row followed by different letters are significantly different at the 5% level. p value = Probability of significance.

No significant difference ($p > 0.05$) was found between treatments for the apparent digestibility coefficients (ADC) of dry matter (DM) and organic matter (OM). Mean values ranged from 52.50% to 53.50% for DM and from 57.95% to 58.95% for OM However, a significant difference ($p < 0.05$) was observed in crude protein digestibility between the three diets in cockerels. The control diet (F0) had the highest ADC value (81.21%) for crude protein, while the diets containing dried okara showed similarly lower values (75.20% for F10 and 72.34% for F20).

3.4. Carcass characteristics of cockerel fed with dried okara-based diets

Table 5 Carcass characteristics of cockerels (Mean ± Standard Error)

Parameters	**F0**	**F10**	**F20**	**p Value**
Live Weight (g)	1725.0±9.30	1790.0±6.95	1710.0±8.24	0.8779
Whole Carcass Weight (g)	1422.5±7.83	1490.8±8.00	1285.7±6.28	0.1739
Eviscerated Weight (g)	1152.5±15.74b	1270±12.13a	1095.2±3.51c	0.0000
Carcass Yield (%)	66.81±0.73b	70.94±0.43a	64.04±0.16b	0.0006
Gizzard Weight (g)	44.667±1.14a	39.667±0.71b	47.167±1.49a	0.0012
Heart Weight (g)	9.0000±0.44	9.6667±0.21	9.6667±0.33	0.3147
Liver Weight (g)	28.333±0.21b	29.833±0.74ab	31.667±0.91a	0.0139

F0 = Diet containing 0% okara; F10 = Diet containing 10% okara; F20 = Diet containing 20% okara.; (a,b) means of the same row followed by different letters are significantly different at the 5% level. p value = Probability of significance.

The carcass characteristics of the cockerels are presented in Table 5. The eviscerated chicken weight (ECW) showed highly significant variations (P=0.0000). In fact, cockerels in group F10 had the highest weight (1270 g) compared to those fed diets F0 (1152.5 g) and F20 (1095.2 g). The carcass yield ($p < 0.05$) for F10 diet (70.94%) was also significantly higher than those of F0 (66.81%) and F20 (64.04%) diets.

Regarding organs, the incorporation level of okara in diet significantly affected ($p < 0.05$) the weights of the gizzard and liver. Gizzard weights were higher for F20 (47.17 g) and F0 (44.67 g) diets compared to F10 (39.67 g). Regarding liver weight, an increase was observed with the incorporation of okara, rising from 28.33 g for the control diet (F0) to 31.67 g for F20. Finally, heart weight showed no statistically significant difference (P = 0.3147) between the tested diets, with an average of approximately 9 g.

4. Discussion

4.1. Nutritional value of dried okara and experimental diets

The dried okara used in this study has a dry matter content of 92.3%, making it comparable to other plant by-products used in animal feed. Its organic matter content is 95.2% DM, confirming a high proportion of organic constituents (proteins, lipids, carbohydrates, fiber) and a relatively low mineral content. As for the three experimental diets, the dry matter content is approximately 87% and remains similar to that found by [12] (86.8%) after using okara in broiler chicken diet. In terms of protein, dried okara contains 26% DM, a value lower than that reported by [13] (36.8% DM) and [14] (35.6% DM). Diets F10 (16.5% DM) and F20 (17.7% DM) have protein levels close to those of the control F0 (16.5% DM) and are conform to recommendations for growing Harco cockerels (16-18% DM) [15]. The energy density of dried okara (3109 kcal/kg DM) is higher than that reported by [13] (2150 kcal/kg DM) and close to that of [14] (2972 kcal/kg DM). Furthermore, its incorporation into the diet at levels of 10% and 20% significantly has increased the diet's energy density (3525 and 3639 kcal/kg DM, respectively), considerably exceeding that of the control (3328 kcal/kg DM) and the recommendations for Harco cockerels (3000–3200 kcal/kg DM) [15].

Although dried okara is inherently richer in crude fiber (11.5% DM) than soybean meal (approximately 6–7% DM), F10 and F20 diets have lower contents (approximately 4.9% DM) than the control one (6.29% DM). This decrease can be explained by a formulation effect: the removal of soybean meal and the reduction of corn and wheat bran, which are the main fiber sources of the control diet (F0), may justify this decrease in the fiber content in F10 and F20. Indeed, okara provided fiber, but its inclusion occurred in a context where other fiber sources were decreasing and where low-fiber ingredients such as maize grain remained predominant. Thus, the observed decrease likely reflects the overall balance of the diets' components and not a contradiction with the intrinsic composition of okara, as also demonstrated by [13].

The ether extracts content of the dried okara in our study (6.9% DM) remains lower than those reported by [12] (14.9% DM) and [14] (21.5% DM), reflecting a variability related to processing methods. In the diets, the lipid contents remain consistent with the recommendations for Harco cockerels (5-7% DM) [15].

Finally, the total ash content of dried okara (4.8% DM) is slightly lower than those found by [14, 13, 16], who reported values between 5 and 6% DM. The F10 and F20 diets, based on okara, have lower total ash contents (6.15% and 7.53% DM, respectively) compared to the control (9.7% DM). This decrease must be linked to the removal of soybean meal, which is rich in minerals, and the reduction of corn and wheat bran, which are also significant sources of ash. Thus, the observed decrease likely stems from an overall formulation effect, where the redistribution of ingredients reduced the total mineral load, rather than a contradiction with the intrinsic composition of the ingredient.

To sum up, our results confirm that dried okara is a valuable co-product due to its high energy content and sufficient protein content to support the growing of Harco cockerels.

4.2. Feeding behavior and growth performance of Harco cockerels fed with dried okara-based diets

The originality of this study lies in the use of growing Harco cockerels, a poultry model that is significantly less documented than broiler chickens. As [15] point out, cockerels exhibit slower growth and specific nutritional needs, which are often overlooked in research. This specific characteristic makes our results particularly interesting, as they allow us not only to compare the performance of cockerels with established growth recommendations, but also to compare it with available data for broiler chickens. Our results show that dried okara incorporation in the diet lead to a significant increase in the feed intake for F10 (85.26 g DM) and F20 (85.81 g DM), respectively, compared to the control diet (83.08 g DM). This upward trend corroborates the observations of [12], who, testing an increasing okara incorporation (0 to 50%) in the diet in Marshall broiler chickens, reported an increase in daily feed intake from 122.59

g DM (control) to 125.05 g DM for the group of 50% content. The results of these two studies demonstrate that this by-product does not reduce appetite at this physiological stage. Conversely, [13], studying the partial replacement of soybean meal with okara (25% to 75%) in Ross chickens during the finishing phase, observed a decrease in feed intake from 2580 g for the control group to 2500 g and 2480 g for the groups with 25% and 50% okara incorporation, respectively. This divergence suggests that the reduced crude fiber content in our diets (4.9% versus 6.3%) with the older, more robust Harco cockerel, removes the consumption barrier related to fibrous bulk and favors the diet's metabolizable energy using more effectively than in industrial broiler chickens.

The growth analysis shows continuous and positive development in all groups of birds throughout the experiment. The incorporation of dried okara enabled cockerels to steadily gain weight, increasing from an average initial weight of 831.11 g to an average final weight of 1647.42 g after 56 days. Although the final weight and Average Daily Gain are statistically similar ($P > 0.05$), a numerical superiority was observed for F10 (15.06 g) compared to the control diet (14.40 g). This performance is very close to the 15.4 g reported by [15] for finishing cockerels. This continuous growth trend is consistent with the findings of [14] who demonstrated that in growing broiler chickens, weight gain remains stable and increasing (2660.23 g for the control versus 2639.17 g at 10% okara). Similarly, [12] observed an optimal weight gain of 42.73 g with the incorporation of 40% okara, confirming that this by-product effectively supports growth in chickens depending on the incorporation level. However, [13] observed a marked decline in weight performance as soon as the okara content exceeded 75%, with weight gain dropping by 14.5% (from 1275 g to 1090 g). This contrast suggests that the moderate incorporation in our study supports protein accretion without inducing the metabolic imbalance observed with massive doses.

Finally, the feed conversion ratio, bordering on statistical significance ($P = 0.0512$), shows that F10 diet (3.84) tends to be more efficient than the control diet F0 (4.24) and F20 (4.18). This eventual superior efficiency of F10 can be attributed to an improved digestive performance: the reduction in its crude fiber content (4.83% DM) has optimized the overall digestibility, allowing the cockerel to extract more nutrients per ingested gram. Indeed, as [17] point out, adjusting fiber levels in chickens is crucial for regulating intestinal transit and maximizing absorption. This 10% incorporation level of dried okara has certainly established a nutritional balance where metabolizable energy (3525 kcal/kg) is optimally converted into growth. Conversely, the increase trend in the index observed with diet F20, despite maximum feed intake (85.81 g/day), indicates a metabolic saturation threshold. In fact, the high energy density (3639 kcal/kg) of this diet exceeds the retention capacity of the Harco strain. This caloric surplus, no longer supporting growth, instead led to energy loss (heat or fat deposition), as noted by [18], making then the 10% rate optimal. The average feed conversion ratio (FCR) obtained in this study (4.09) is significantly better than those reported by [15] for growing cockerels (6.00 to 6.66). This superior efficiency, particularly pronounced with diet F10 (3.84), is close to the efficiency observed by [12]. They reported an FCR of 3.45 for a 40% inclusion level, although this result was obtained with commercial broiler chickens, a breed with higher growth potential than the Harco cockerel. Thus, our results validate the nutritional value of okara for optimizing feed utilization, as long as the energy balance remains controlled.

4.3. Apparent digestibility of nutrients in dried okara-based diets for cockerel

The Apparent Digestibility Coefficients (ADC) reveal a stability for dry matter and organic matter (53.14% and 58.33%, respectively), meaning that the incorporation of dried okara does not alter the overall ability of the Harco strain to use the diet's constituents. Furthermore, this ingredient incorporation results in a significant decrease in crude protein digestibility, from 81.21% for the control diet (F0) to only 72.34% for F20, a reduction of 10.92%. This result contrasts with the observations of [13] and [12], where the protein digestibility of the tested diets in growing broiler chickens remained high and stable (between 80 and 90%). This variability can be explained by the incompatibility between the high fiber content of okara-based diets and the Harco strain's physiology. Indeed, providing insoluble fiber, mechanically stimulates peristalsis, which accelerates intestinal transit [17]. However, in a hardy breed like Harco, intestinal maturation and the secretion of digestive enzymes are naturally slower than in industrial broiler breeds [19]. The decrease in digestibility observed in our study undoubtedly stems from this discrepancy: the feed bolus passes through the intestine too quickly so that, the enzymes in the Harco chickens fully break down the proteins. Furthermore, at a 20% incorporation rate of dried okara in diet (F20), this transit would have been too rapid, preventing nutrient retention. In contrast, diet F10 has overcome its lower protein efficiency thanks to its high energy concentration (3525 kcal/kg). This energy surplus has supported maintenance and growth requirements, explaining the chickens' superior performance.

4.4. Carcass characteristics of cockerels according to the diet

The absence of a significant difference in the live weight at slaughter between the three feeding treatments means that the dried okara incorporation does not alter the overall weight gain of Harco strain cockerels. However, carcass components reveal higher values with chickens fed diet F10. These cockerels have an eviscerated weight of 1270 g, higher than the 1152.5 g of the control diet (F0) and the 1095.2 g of F20. Thus, carcass yield peaks at 70.94% for diet F10, exceeding the 66.81% of the control and the 64.04% of F20, respectively. This optimal performance at 10% incorporation of dried okara corroborates the results of [14], who obtained stable and optimal carcass yields (around 70-71%) in broiler chickens at incorporation rates ranging from 25% to 100%. However, unlike [13], who only observed a decrease in carcass yield at extreme incorporation rates of 75% and above in broiler chickens, our study on the cockerels Harco strain shows a degradation of meat characteristics at 20% incorporation. This discrepancy could be linked to the Harco strain, whose metabolic fiber utilization capacities differ from those of heavy industrial strains, resulting in a physiological priority given to the development of maintenance organs instead of muscle deposition in cockerels fed with the F20 diet. Indeed, at this level, the excess of insoluble fiber has imposed intense mechanical constraint on the digestive tract, as highlighted [20], who demonstrated that the ingestion of structural fibers stimulates gizzard muscle development. Thus, this fiber overload has induced an adaptive hypertrophy of the gizzards (47.17 g) and has increased the hepatic metabolism (31.67 g) in the F20 diet's cockerels, to ensure grinding and digestion. This results in an energy diversion towards vital functions, mechanically reducing the proportion of nutrients available for meat production and explaining the drop in carcass yield observed in these cockerels. The gizzard weight increasing of the cockerels fed diet F20 (47.17 g) is consistent with the trend reported by [20]. These authors showed that incorporating oat hulls, which are insoluble fibers, significantly increases the relative weight of the gizzard compared to a control diet, due to the mechanical stimulus. Our values are higher than those of [14], who reported gizzard weights ranging from 25 to 30 g for okara incorporation rates up to 100% in broiler chickens. Similarly, the liver weight (31.67 g) of F20 cockerels is higher than the 24.5 g reported by [13] for a 25% okara inclusion rate in broiler chickens. This important difference highlights that in the Harco strain, the metabolic and mechanical effort imposed by the 20% okara inclusion rate is significantly higher than in the industrial strains cited in the literature.

5. Conclusion

This study validates the dried okara as a local, sustainable, and efficient protein alternative to soybean meal for the production of Harco cockerels in Benin. Our work demonstrates that a 10% substitution level is the optimal threshold, allowing improvement not only in terms of carcass yield and eviscerated weight, but also in terms of feed intake and trend of feed conversion ratio. This overall improvement proves that the high energy density of okara favorably compensates for the decrease in protein digestibility induced by this by-product, guaranteeing stable weight growth and superior meat quality compared to the conventional diet. By transforming an agro-industrial residue into a true productivity engine for the Harco strain, this study sets a precise recommendation for poultry farmers, offering a probable solution to reduce feed costs while guaranteeing maximum meat productivity.

Compliance with ethical standards

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Disclosure of conflict of interest

The authors declare no conflicts of interest regarding the publication of this paper.

Author's contribution

The first author collected, processed and drafted this article. The other authors read and corrected the manuscript. All the authors read and approved the final manuscript.

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