The effects of incorporating dried cashew apple in the diet of broiler chickens on growth performance, total tract digestibility, and gut health

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Abstract

A total of two hundred and ten one-day-old Ross 308 broiler chicks were utilized in this study to investigate the effects of incorporating Dried Cashew Apples (DCA) in the diet of broiler chickens on growth performance, total tract digestibility, and gut health. The birds were weighed and randomly allotted to seven treatment groups with three replicates, each having 10 birds. The experimental design was a (2 X 3) + 1 augmented factorial arrangement in a completely randomized design. Diet D1 (control diet) was a maize-soybean meal-based; diets D2, D3, and D4 comprised 10, 20, and 30% DCA without exogenous enzyme supplementation, whereas diets D5, D6, and D7 included 10, 20, and 30% DCA treated with exogenous enzyme. Data were collected on growth performance, total tract digestibility, and gut morphology. Collected data were analyzed using SAS (2002) and separation of means was done using Duncan's Multiple Range Tests of the same statistical software. The difference was set at $p < 0.05$. The study found that birds fed diets containing 10% DCA, with or without enzyme supplementation (D2 and D5), had a significantly higher Average Daily Gain (ADG) compared to those fed the control diet (D1). The ADG of birds fed diets D3 and D6 was similar to that of birds fed the control diet (D1). However, a significant decrease in ADG was observed as the dietary inclusion level of DCA increased to 30%, as seen in birds offered diets D4 and D7. In addition, a significant linear rise ($p < 0.05$) in Average Daily Feed Intake (ADFI) was seen when DCA was included in the diet. In addition, birds that were given diets containing DCA showed significantly higher nutrient digestibility ($p < 0.05$) compared to birds that were given the control diet (D1), except for birds that were given a diet containing 30% DCA without enzyme supplementation (D4), which showed significantly lower nutrient digestibility ($p < 0.05$) compared to birds that were given the control diet (D1). Ultimately, birds that were given meals containing DCA exhibited a significant enhancement in GIT development compared to birds on the control diet. Based on the findings of this study, it can be concluded that including DCA in the diet of broiler chickens at a level of up to 20% does not have any detrimental effects on their performance.

Keywords: broiler, non-conventional feedstuff, dried cashew apples, growth performance, nutrient digestibility.

Os efeitos da incorporação de caju desidratado na dieta de frangos de corte sobre o desempenho do crescimento, a digestibilidade total do trato e a saúde intestinal

Resumo

Um total de duzentos e dez pintos de corte Ross 308 de um dia de idade foram utilizados neste estudo para investigar os efeitos da incorporação de maçãs de caju secas (DCA) na dieta de frangos de corte no desempenho de crescimento, digestibilidade total do trato e saúde intestinal. As aves foram pesadas e distribuídas aleatoriamente em sete grupos de tratamento com três repetições, cada um com 10 aves. O delineamento experimental utilizado foi um arranjo fatorial aumentado (2 X 3) + 1 em delineamento inteiramente casualizado. A dieta D1 (dieta controle) era à base de milho e farelo de soja; as dietas D2, D3 e D4 incluíram 10, 20 e 30% de DCA sem suplementação enzimática exógena, enquanto as dietas D5, D6 e D7 incluíram 10, 20 e 30% de DCA tratada com enzima exógena. Foram coletados dados sobre desempenho de crescimento, digestibilidade total do trato e morfologia intestinal. Os dados coletados foram analisados pelo SAS (2002) e a separação das médias foi feita por meio dos Testes de Faixa Múltipla de Duncan do mesmo software estatístico. A diferença foi fixada em $p < 0,05$. O estudo constatou que as aves alimentadas com dietas contendo 10% de DCA, com ou sem suplementação enzimática (D2 e D5), tiveram um Ganho Médio Diário (GMD) significativamente maior em comparação com aquelas alimentadas com a dieta controle (D1). O GMD das aves alimentadas com as dietas D3 e D6 foi semelhante ao das aves alimentadas com a dieta controle (D1). No entanto, foi observada uma diminuição significativa no GMD à medida que o nível de inclusão dietética de DCA aumentou para 30%, como observado nas aves que receberam as dietas D4 e D7. Além disso, foi observado um aumento linear significativo (p < 0,05) no consumo médio diário de ração (CMDA) quando o DCA foi incluído na dieta. Além disso, as aves que receberam dietas contendo DCA apresentaram digestibilidade de nutrientes significativamente maior ($p <$ 0,05) em comparação com as aves que receberam a dieta controle (D1), exceto as aves que receberam dieta contendo 30% de DCA sem suplementação enzimática (D4).), que apresentaram digestibilidade dos nutrientes significativamente menor ($p < 0,05$) em comparação às aves que receberam a dieta controle (D1). Em última análise, as aves que receberam refeições contendo DCA exibiram uma melhoria significativa no desenvolvimento do TGI em comparação com as aves na dieta controle. Com base nos resultados deste estudo, pode-se concluir que a inclusão de DCA na dieta de frangos de corte em um nível de até 20% não tem quaisquer efeitos prejudiciais sobre o seu desempenho.

Palavras-chave: frango de corte, ração não convencional, caju desidratado, desempenho produtivo, digestibilidade de nutrientes

1. Introduction

The use of non-conventional feedstuffs in poultry diets has become increasingly popular in recent years, as it offers a more sustainable and cost-effective alternative to conventional feed ingredients (Swain et al., 2014). Non-conventional feedstuffs such as crop residue, agro-industrial by-products, and food waste have been found to supply the necessary nutrients for chickens while also decreasing environmental effects. Additionally, introducing non-conventional feedstuffs into chicken diets can help minimize the wastage of potential feed resources, and foster a more circular economy within the agricultural business (Amata, 2014). By employing these alternative feed ingredients, farmers can also minimize their demand on conventional feed supplies such as maize, soybean meal, groundnut cake, etc. making their operations more resilient to fluctuations in feed prices and availability (Dumont et al., 2013). One such feedstuff is dried cashew apples (DCA), a waste product of the cashew production industry.

Cashew apple is a rich source of carbohydrates, fibre, and antioxidants, making it a potential ingredient in poultry diets (Das; Arora, 2017; Reina et al., 2022; Akyereko et al., 2023; Van-Walraven; Stark, 2023). However, like other agro-industrial by-products, cashew apple has several limitations in its usage as a feed component, including its low nutrient density, high fibre content, and presence of anti-nutritional elements (Vergara et al., 2010; Tamiello-Rosa et al., 2019; Dakuyo et al., 2022; Akyereko et al., 2023). These variables may alter chickens' nutritional digestibility, growth performance, and health status (Gilani et al., 2012). Despite these limitations, researchers have been studying strategies to address the challenges associated with utilizing cashew apples in poultry diets. Strategies such as fortification with enzymes to promote nutrient digestibility, and processing techniques to reduce anti-nutritional elements have shown promise in enhancing the utilization of cashew apples in poultry feed (Selvamuthukumaran, 2024).

Enzyme supplementation has been found to increase the nutritive value of agro-industrial byproducts, including DCA, by breaking down the fibre and other anti-nutritional components, thereby boosting nutrient digestion and absorption (Ugwuanyi, 2016). Several studies have tested the fortification of poultry diets containing fibrous feed ingredients with exogenous microbial enzymes, showing promising results (Alabi et al., 2019). These findings suggest that fortifying DCA-based diets with exogenous microbial enzymes can help improve the overall nutritional content of the diet for effective utilization by chickens (Venkatramana et al., 2019; Ofori et al., 2022).

By breaking down the fibre and anti-nutritional components contained in these agro-industrial wastes, enzymes may promote the digestion and absorption of essential nutrients, eventually leading to enhanced poultry performance (Jha; Mishra, 2021). Further study into appropriate enzyme dose and inclusion methods for cashew apples in poultry feed might lead to even greater improvements in poultry productivity and health. Therefore, this study intends to investigate the effects of DCA-based diets with or without exogenous enzyme supplementation on the growth performance, nutrient digestibility, and gut morphology of broiler chickens

2. Materials and Methods

2.1 Experimental site

The study was conducted at the Poultry unit, Teaching and Research Farm, Ladoke Akintola University of Technology, Ogbomoso, Oyo State, Nigeria. The region is situated at Latitude 8o 10’ 0’’ north Longitude 4o16’ 5’’east (Google map, 2023).

2.2 Test ingredients

Cashew apples were obtained from local farms in Ogbomoso and its environs after the removal of the nuts. This collection process took place during the harvest season of raw cashew nuts, which typically occurs from January to May. The harvested cashew apples were carefully packed in plastic baskets and then rinsed under running water to eliminate any foreign materials. Subsequently, they were bagged and subjected to mechanical pressing to extract the juice. The residue was sun-dried until a constant weight was achieved, the resulting product is called Dried Cashew Apples (DCA). Particle size reduction of the DCA was achieved using a burr mill, ensuring it passed through a 2mm sieve before being incorporated into the experimental diets.

A portion of the DCA was reserved for subsequent analysis, including the determination of dry matter (DM): crude protein (CP): crude fibre (CF): ether extract (EE): and total ash. The analysis was conducted using the methods prescribed by the AOAC (2005). Additionally, a sample of the DCA was analyzed to characterize the crude fibre component using the procedure described by Van Soest et al. (1991). Additionally, a Polyzyme ™ multi-enzyme cocktail was used in this experiment. The enzyme is in powdered form and was added to the diets at the rate of 1 kg per ton of feed. This inclusion level is within the range recommended by the manufacturer (500 g – 2 kg per ton of feed).

2.3 Experimental diets

Materials used in the preparation of the experimental diets used in this experiment were sourced at local feed mills in Ogbomoso, Nigeria. The experimental diets were formulated to meet the nutrient requirement of broiler chickens (NRC, 1994). The gross composition of the finisher's diet is shown in (Table 1). The dietary plan adopted in this study is highlighted below:

(1) Diet 1 (Control diet): Formulated with maize and soya bean meal as primary energy and protein sources, this diet did not contain DCA and was not supplemented with exogenous enzymes.

(2) Diets 2, 3, and 4 contain DCA replacing maize at levels of 10%, 20%, and 30%, respectively, without the addition of exogenous enzymes.

(3) With the addition of exogenous microbial enzyme supplements, diets 5, 6, and 7 replace 10%, 20%, and 30% of maize with DCA, respectively.

Table 1. Gross composition of the finisher experimental diets fed to the chickens.

Ingredients (%)	Control diet (0%) DCA	Diet 2 (10%) DCA	Diet 3 (20%) DCA	Diet 4 (30%) DCA	Diet 5 (10%) DCA + Enzyme	Diet 6 (20%) DCA + Enzyme	Diet 7 (30%) DCA + Enzyme
Maize	56.00	50.40	44.80	39.20	50.40	44.80	39.20
Soybean Meal	25.00	25.00	25.00	25.00	25.00	25.00	25.00
*DCA	0.00	5.60	11.20	16.80	5.60	11.20	16.80
Wheat Offal	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Corn Bran	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Fish Meal (72%)	3.00	3.00	3.00	5.00	3.00	3.00	5.00
Vegetable Oil	1.50	1.50	1.50	1.50	1.50	1.50	1.50
Bone Meal	2.50	2.50	2.50	2.50	2.50	2.50	2.50
Oyster Shell	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Methionine	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Lysine	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Salt	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Vit Premix**	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Polyzyme***	-	-	-	-	+	+	+
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Calculated Composition							
Crude protein (%)	19.66	19.77	19.87	19.97	19.77	19.87	19.97
+ME (kcal/kg)	2997.34	2966.26	2935.19	2904.11	2966.26	2935.19	2904.11
Crude fibre (%)	3.80	4.49	5.19	5.88	4.49	5.19	5.88
Ether extract (%)	3.90	4.18	4.47	4.76	4.18	4.47	4.76
Methionine (%)	0.57	0.56	0.55	0.54	0.56	0.55	0.54
Lysine (%)	1.27	1.25	1.24	1.23	1.25	1.24	1.23
Available Phosphorus (%)	0.73	0.73	0.72	0.72	0.73	0.72	0.72
Calcium (%)	1.49	1.49	1.49	1.49	1.49	1.49	1.49

Note: *DCA: Dried Cashew Apple. **Vitamin premix: Folic acid 750.00 mg; Biotin 60.00 mg; Vitamin A 10,000,000.00 IU; Vitamin B1 1,800.00 mg; Vitamin B2 5,500.00 mg; Niacin 27,500.00 mg; Pantothenic acid 7,500.00 mg; Vitamin B6 3,000.00 mg; Vitamin B12 15.00 mg; Vitamin D3 2,000,000.00 IU; Vitamin E 23,000.00 mg; Vitamin K3 2,000.00 mg; Choline chloride 300,000.00 mg; Cobalt 200.00 mg; Copper 3,000.00 mg; Iodine 1,000.00 mg; Iron 20,000.00 mg; Manganese 40,000.00 mg; Selenium 200.00 mg; Zinc 30,000.00 mg; Antioxidant 1,250.00 mg. ***Polyzyme Composition: Pectinase 200-300 U/g, Alpha-Amylase 700-3400 U/g, Cellulase 525-700 U/g, Beta-glucanase 375-500 U/g, Protease < 1200 HUT/g. +ME: Metabolizable energy. Source: Authors, 2024.

2.4 Experimental animals, design, and management

Two hundred and ten 1-day-old Ross broiler chicks were employed for this study. Upon arrival, the chicks underwent individual weighing and were then randomly assigned to seven treatment groups, each comprising 30 birds. Within these groups, the chicks were subdivided into three replicates, with each replicate having ten birds within an experimental layout structured in a (2 x 3) + 1 augmented factorial arrangement in a completely randomized design. An open-sided, deep-liter poultry pen divided into cells was used to house the birds and keep them separated throughout the study.

Throughout the experimental duration, the birds were offered feed and water ad libitum. To safeguard their health, routine vaccination, medication, and prophylactic anti-coccidia treatment were administered to the birds. These measures were put in place to ensure the welfare and well-being of the experimental birds during the study.

2.5 Data collection

2.5.1 Growth performance

Average Daily Feed Intake (ADFI) and Average Daily Gain (ADG) data were used to assess the growth performance of the experimental birds. Variables from these parameters were then utilized to compute the Feed Conversion Ratio (FCR), following the method outlined by Diarra et al. (2015).

2.5.2 Nutrient digestibility

A total tract digestibility study was conducted on day 35 of the experiment, a metabolic cage was used for this procedure in which forty-two (42) birds i.e., two (2) birds per replicate were randomly selected for this trial. The trial runs for seven days, during which the first 3 days were to acclimatize the birds to the metabolic cage, while the remaining four (4) days were for the collection of fecal samples adopting the procedure described by Aya et al. (2013).

The nutrient digestibility of the experimental diets was estimated using the formula adopted by Dialoke et al. (2020) as shown below:

$$\text{Nutrient Digestibility} = \left\{ \frac{\left(\frac{\text{Nutrient in feed}}{100}\right)(\text{Feed Intake}) - \left(\frac{\text{Nutrient in faeces}}{100}\right)(\text{weight of faeces})}{\left(\frac{\text{Nutrient in feed}}{100}\right)(\text{Feed Intake})} \right\} \text{X } 100$$

2.5.3 Intestinal morphology

On day 35 of the study, a random selection of 21 birds (1 bird per replicate) was made, and these birds were subjected to an 8-hour fasting period to facilitate the emptying of their crop contents. Subsequently, the birds were humanely slaughtered by severing the jugular vein, complete bleeding of the slaughtered birds was ensured by hanging each bird with the leg up until the blood was fully drained. Following the bleeding process, the slaughtered birds were excised, and 2 cm of the intestinal segment (jejunum) was collected for intestinal morphological analysis adopting the methods of Emiola et al. (2007).

2.6 Statistical analysis

Data collected were subjected to One-Way Analysis of Variance using the General Linear Model Procedure of Statistical Analysis Systems (S.A.S, 2002); separation of treatment means was done using Duncan's Multiple Range Tests of the same software. The difference was set at $p < 0.05$.

3. Results

3.1 Growth performance

Table 2 presents the main effects of dietary inclusion of DCA with or without exogenous enzyme supplementation on the growth performance indices of broiler chickens. All growth performance metrics, except for initial weight, exhibited statistically significant differences ($p < 0.05$) across the experimental diets. The dietary interventions had a significant ($p < 0.05$) impact on ADG. The highest ADG values of 40.33 g and 40.26 g per bird per day were recorded in birds offered diets D2 (10% DCA without enzyme) and D5 (10% DCA with enzyme), respectively. Birds fed diets D3 and D6 had ADG values of 38.47 g and 38.56 g, which were statistically similar to the ADG value of 38.61 g recorded for broiler chickens fed the control diet. The lowest ADG values of 35.89 g and 36.09 g were observed in birds fed diets D4 and D7, respectively.

Similarly, ADFI and FCR were substantially ($p < 0.05$) impacted by the experimental diets, with the lowest ADFI and FCR reported in birds given the control diet. There was a substantial ($p < 0.05$) increase in both ADFI and FCR with the dietary addition of DCA in broiler chickens. Broiler chickens fed the Diet D1 (control) had significantly ($p < 0.05$) lower ADFI and FCR values compared to those receiving diets with varying levels of DCA inclusion. Notably, as the DCA inclusion level rose from 10% to 30%, the ADFI values showed an interesting fluctuating trend.

Table 2. Main effects of dietary inclusion of graded levels of DCA with or without exogenous microbial enzyme supplementation on the growth performance of the experimental animals.

	Diets*							SEM
Parameters	D1	D2	D3	D4	D5	D6	D7	
Initial Weight (g/bird)	46.03	45.93	46.23	45.98	45.89	45.97	45.96	0.18
Final Weight (g/bird)	1667.40^{ab}	1739.96^{a}	1661.43^{ab}	1553.76^{b}	1736.85^{a}	1629.12^{ab}	1561.82^{b}	10.89
ADG (g/bird/day)	38.61^{ab}	40.33^{a}	38.47^{ab}	35.89^{b}	40.26^{a}	38.56^{ab}	36.09^{b}	0.31
ADFI (g/bird/day)	71.07^{d}	87.67^{b}	81.98^{c}	99.16^{a}	87.81^{b}	80.43^{c}	94.95^{ab}	0.92
FCR	1.84^{c}	2.17^{b}	2.13^{b}	2.76^{a}	2.18^{b}	2.08^{b}	2.63^{a}	0.03

Note: a b c Means within rows with different superscripts differ ($p < 0.05$). ADFI: Average Daily Feed Intake; ADG: Average Daily Gain; FCR: Feed Conversion Ratio; SEM: Standard Error of Means.

Furthermore, the influence of various dietary inclusion levels of DCA, and exogenous microbial enzyme supplementation on the growth performance of the experimental birds is presented in (Tables 3 and 4), respectively. The results demonstrate a significant ($p < 0.05$) reduction in weight gain among experimental birds as the level of DCA inclusion in the diet increases. A quadratic response is noted in the ADFI of the experimental birds. Additionally, compared to birds given diets containing 10% (2.20) and 20% DCA (2.13), the FCR considerably ($p < 0.05$) rises in birds provided diets containing 30% DCA (2.73). However, supplementation with exogenous microbial enzymes did not have significant ($p > 0.05$) effects on most growth performance indices measured in this study, except for ADFI. Birds given diets fortified with exogenous enzymes had a considerably reduced feed consumption (88.63 g) compared to birds fed DCA-based diets without exogenous enzyme supplementation (90.50 g).

Table 3. The effects of varying inclusion levels of DCA on the growth performance of the experimental birds.

	Inclusion levels			
Parameters	10% DCA	20% DCA	30% DCA	SEM
Initial weight (g)	45.98	45.98	46.12	0.34
Final weight (g)	1738.4^{a}	1630.64^{b}	1557.79^{c}	20.25
Weight gain (g)	1692.42^{a}	1584.66^{b}	1511.67^{c}	20.16
Average daily gain (g/b/d)	40.30^{a}	38.52^{b}	35.99^{c}	0.47
ADFI (g/b/d)	88.64^{b}	82.11^{c}	97.95^{a}	1.84
FCR	2.20^{a}	2.13^{a}	2.73^{b}	0.06

Note: $^{a\ b\ c}$ Means within rows with different superscripts differ ($p < 0.05$). ADFI: Average Daily Feed Intake; FCR: Feed Conversion Ratio; SEM: Standard Error of Means.

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Table 4. Effect of exogenous enzyme supplementation of dried cashew apple-based diet on the growth performance of the experimental birds.

Parameters	Enzyme supplementation		SEM
	No enzyme	With enzyme	
Initial weight (g)	46.02	46.03	0.28
Final weight (g)	1651.72	1632.85	16.53
Weight gain (g)	1606.69	1586.81	16.46
Average Daily Gain (g/b/d)	38.23	38.30	0.38
ADFI (g/b/d)	90.50^{a}	88.63^{b}	1.50
FCR	2.38	2.33	0.05

Note: $^{a\,b\,c}$ Means within rows with different superscripts differ ($p < 0.05$). ADFI: Average Daily Feed Intake; FCR: Feed Conversion Ratio; SEM: Standard Error of Means. Source: Authos, 2024.

The interaction effect of exogenous microbial enzyme supplementation, and dietary inclusion levels of DCA on the growth performance of the experimental birds is presented in (Table 5). While exogenous enzyme supplementation did not demonstrate a significant effect ($p > 0.05$) on most of the growth performance metrics, a notable exception was observed in the ADFI of birds-fed diets with 30% DCA. Specifically, birds consuming the diet with 30% DCA, along with exogenous enzyme supplementation (D7), exhibited a significant reduction in ADFI compared to their counterparts fed the unsupplemented diet (D4) ($p < 0.05$).

Table 5. The interaction effects of exogenous enzyme supplementation and dietary inclusion levels of DCA on the growth performance of the experimental birds.

Parameters	Enzyme	Inclusion Levels			SEM
		10%	20%	30%	
Final Weight (g/bird)	No Enzyme	1739.96^{a}	1661.43^{b}	1553.76^{c}	20.25
	With Enzyme	1736.85^{a}	1629.12^{b}	1561.82^{c}	20.25
	SEM	16.53	16.53	16.53	-
ADG (g/bird/day)	No Enzyme	40.33^{a}	38.56^{b}	35.89^{c}	0.47
	With Enzyme	40.26^{a}	38.47^{b}	36.09^{c}	0.47
	SEM	0.38	0.38	0.38	-
ADFI (g/bird/day)	No Enzyme	87.67^{b}	81.98^{c}	99.16^{Ax}	1.84
	With Enzyme	87.81^{b}	80.43^{c}	94.95^{Ay}	1.84
	SEM	1.50	1.50	1.50	-
FCR	No Enzyme	2.17^{b}	2.13^{b}	2.76^{a}	0.06
	With Enzyme	2.18^{b}	2.08^{b}	2.63^{a}	0.06
	SEM	0.05	0.05	0.05	-

Note: $^{a\,b\,c}$ Means within rows for different groups with different superscripts differ ($p < 0.05$). $^{X\,Y\,Z}$ Means within the column for each parameter with different superscripts differ ($p < 0.05$). ADFI: Average Daily Feed Intake; ADG: Average Daily Gain; FCR: Feed Conversion Ratio; SEM: Standard Error of Means. Source: Authors, 2024.

3.2 Total tract digestibility

The results presented in Table 6 highlight the impact of dietary treatments on total tract digestibility in the experimental birds. Notably, all measured parameters were significantly affected ($p < 0.05$) by the treatment diets. Observing the responses across the treatment groups, birds offered diet D5 (10% DCA with enzyme) demonstrated the most efficient nutrient utilization across all measured parameters. Subsequently, birds on diet D2 (10% without enzyme) displayed notable nutrient utilization.

In contrast, birds on diet D4 (30% without enzyme) exhibited the least efficient nutrient utilization for all measured parameters. Moreover, birds on the control diet (0% DCA without enzyme) displayed relatively better nutrient utilization than those consuming diet D4 (30% without enzyme). These outcomes underscore the considerable impact of dietary variations, particularly in DCA levels and enzyme supplementation, on nutrient utilization among broiler chickens.

Table 6. Total tract digestibility of broiler chickens fed the experimental diets.

PARAMETERS (%)	DIETS							SEM
	D1	D2	D3	D4	D5	D6	D7	
Dry Matter	66.83^{d}	75.17^{a}	72.36^{b}	61.70^{e}	76.80^{a}	69.48^{c}	70.29^{bc}	0.75
Crude Protein	67.50^{c}	77.74^{a}	73.45^{b}	63.28^{d}	77.08^{a}	68.69^{c}	70.42^{c}	0.97
Crude Fibre	37.07^{d}	52.23^{b}	45.73^{c}	32.09^{e}	58.45^{a}	37.39^{d}	36.04^{d}	1.86
Ether Extract	90.65^{d}	95.74^{a}	94.28^{bc}	93.39^{c}	95.95^{a}	93.41^{c}	95.13^{ab}	0.36
Nitrogen Free Extract	74.31^{c}	77.55^{b}	76.40^{bc}	66.64^{d}	79.64^{a}	75.04^{c}	74.90^{c}	0.72
Metabolizable Energy	75.24^{d}	81.79^{a}	79.78^{b}	72.14^{e}	82.73^{a}	77.67^{c}	78.57^{bc}	0.56
Neutral Detergent Fibre	74.72^{e}	81.17^{b}	79.28^{c}	71.26^{f}	83.05^{a}	77.36^{d}	78.20^{cd}	0.50
Acid Detergent Fibre	77.48^{e}	83.15^{b}	81.46^{c}	73.88^{f}	85.17^{a}	80.10^{d}	80.29^{cd}	0.42
Acid Detergent Lignin	74.05^{c}	81.09^{b}	80.43^{b}	71.65^{d}	84.67^{a}	79.44^{b}	80.10^{b}	0.57
Hemicellulose	70.88^{d}	78.40^{a}	76.23^{b}	67.68^{e}	80.07^{a}	73.52^{c}	75.33^{bc}	0.64
Cellulose	78.23^{e}	83.62^{b}	81.70^{c}	74.44^{f}	85.29^{a}	80.26^{d}	80.34^{d}	0.45

Note: $^{a\ b\ c}$ Means within rows with different superscripts differ (p < 0.05). SEM: Standard Error of Means. Source: Authors, 2024.

Furthermore, the interaction effects of dietary inclusion of graded levels of DCA and exogenous enzyme supplementation on total tract digestibility of the experimental birds are presented in (Table 7). Dietary inclusion of exogenous enzymes significantly improved (p < 0.05) nutrient digestibility in birds consuming diets with 10% and 30% DCA. However, there was a decrease in nutrient digestibility among birds fed with a diet that contained 20% DCA fortified with exogenous enzymes compared to those on the unsupplemented diet with the same DCA inclusion. This consistent trend was evident across all nutrient digestibility parameters analyzed in this study.

Table 7. Interaction effects of dietary inclusion of DCA and exogenous enzyme supplementation on the total tract digestibility of the experimental birds.

Parameters	Enzyme	Inclusion Levels			SEM*1
		10%	20%	30%	
Dry Matter (%)	No Enzyme	75.17aY	72.36bX	61.70cY	0.53
	With Enzyme	76.80aX	69.48By	70.39bX	0.53
	SEM*2	0.44	0.44	0.44	-
Crude Protein (%)	No Enzyme	77.74aX	73.45bX	63.28cY	0.74
	With Enzyme	77.08aX	68.69cY	70.42bX	0.74
	SEM*2	0.60	0.60	0.60	-
Crude Fibre (%)	No Enzyme	52.33aY	45.83bX	32.09cY	1.41
	With Enzyme	58.55aX	37.49bY	36.04bX	1.41
	SEM*2	1.15	1.15	1.15	-
Ether Extract (%)	No Enzyme	95.74aX	94.28bX	93.39cY	0.24
	With Enzyme	95.95aX	93.41cY	95.13bX	0.24
	SEM*2	0.20	0.20	0.20	-
Nitrogen Free Extract (%)	No Enzyme	77.55aY	76.40bX	66.64cY	0.47
	With Enzyme	79.64aX	75.04bY	74.90bX	0.47
	SEM*2	0. 38	0.38	0.38	-
Metabolizable Energy (%)	No Enzyme	81.79aY	79.77bX	72.14cY	0.40
	With Enzyme	82.73aX	77.67bY	78.57bX	0.40
	SEM*2	0.33	0.33	0.33	-
Neutral Detergent Fibre (%)	No Enzyme	81.17aY	79.28bX	71.26cY	0.37
	With Enzyme	83.05aX	77.36bY	78.20bX	0.37
	SEM*2	0.30	0.30	0.30	-
Acid Detergent Fibre (%)	No Enzyme	83.15aY	81.46bX	73.88cY	0.31
	With Enzyme	85.17aX	80.10bY	80.29Bx	0.31
	SEM*2	0.26	0.26	0.26	-
Acid Detergent Lignin (%)	No Enzyme	81.09aY	80.43aX	71.65bY	0.40
	With Enzyme	84.67aX	79.44By	80.10bX	0.40
	SEM*2	0.33	0.33	0.33	-
Hemicellulose (%)	No Enzyme	78.40aY	76.23Bx	67.68cY	0.46
	With Enzyme	80.07aX	73.52Cy	75.33bX	0.46
	SEM*2	0.38	0.38	0.38	-
Cellulose (%)	No Enzyme	83.62aY	81.70Bx	74.44cY	0.33
	With Enzyme	85.29aX	80.26By	80.34bX	0.33
	SEM*2	0.27	0.27	0.27	-

Note: $^{a\,b\,c}$ Means within rows with different superscripts differ ($p < 0.05$). ^{XYZ} Means within the column for each parameter with different superscripts differ ($p < 0.05$). SEM*1: Standard Error of Means (Inclusion levels). SEM*2: Standard Error of Means (Enzyme supplementation). Source: Authors, 2024.

3.3 Intestinal Morphology

The intestinal morphometry results for the experimental birds are reported in (Table 8). Parameters assessed include villi height, villi width, cryptal depth, cryptal width, muscle thickness, and the villi height to cryptal depth ratio, all of which were substantially ($p < 0.05$) altered by the dietary treatments, except for cryptal depth. Villi height differed significantly ($p < 0.05$) across the treatment groups, with birds on diet D2 (10% DCA without enzyme) (Figure 1, D2 C and C) showing the highest value of 1378.84 µm, and birds on diet D6 (20% DCA with enzyme) showing the lowest value of 900.46 µm, which differ significantly from the value recorded in birds given the control diet D1 (0% DCA without enzyme) (Figure 1, D1 A and B).

The highest value of 251.61 µm for villi width was recorded in birds on diet D2 (10% DCA without enzyme), while the lowest values of 164.25 µm and 170.43 µm were obtained in birds on diets D5 (10% DCA with enzyme) and D6 (20% DCA with enzyme), respectively. Cryptal width also differs significantly ($p < 0.05$) as a result of the treatment diets.

Birds fed diets D2 (10% DCA without enzyme), D3 (20% DCA without enzyme) (Figure 1, D3 E and F), D4 (30% DCA without enzyme) (Figure 1, D4 G and H), and D7 (30% DCA with enzyme) (Figure 1, D7 M and N) showing significantly ($p < 0.05$) higher cryptal width values compared to birds fed the control diet D1 (0% DCA without enzyme), diets D5 (10% DCA with enzyme) (Figure 1, D5 I and J), and D6 (20% DCA with enzyme) (Figure 1, D6 K and L).

Among these, birds on diet D3 (20% DCA without enzyme) (Figure 3) exhibited the highest muscle thickness value of 233.60 µm, while birds fed diet D6 (20% DCA with enzyme) had the lowest value of 176.41 µm, and birds on the control diet D1 (0% DCA without enzyme) recorded a significantly different value of 188.04 µm. Moreover, birds fed diets D2 (10% DCA without enzyme) and D3 (20% DCA without enzyme) exhibited a considerably greater villi height to cryptal depth ratio, whereas the lowest values for this parameter were observed in birds fed the control diet (D1) and diet D6 (20% DCA with enzyme).

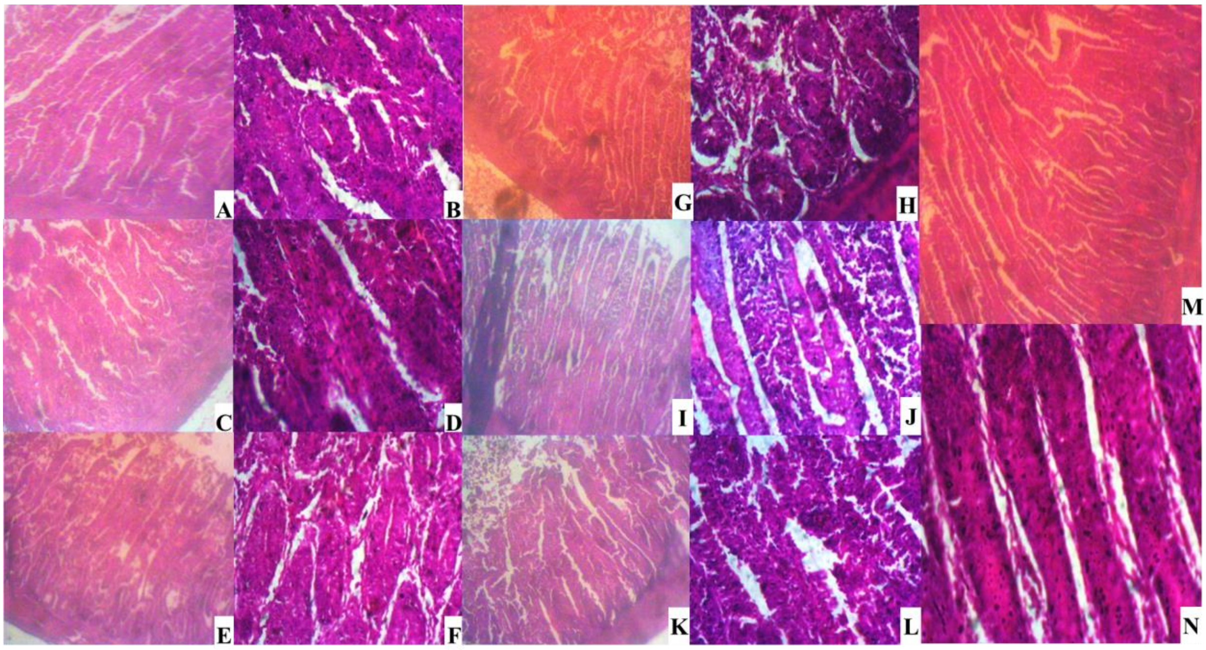

Figure 1. Photomicrographs of the jejunum of broiler chickens fed the control diet (D1 Containing 0% DCA without enzyme supplementation). In (**A**) Intestine - There is no observable lesion, HE 100x, and (**B**) Intestine - There is no observable lesion. HE 400x. Photomicrographs of the jejunum of broiler chickens fed diet D2 containing 10% DCA without enzyme supplementation. In (**C**) Intestine- There is no observable lesion. HE 100x, and (**D**) Intestine - There is no observable lesion, HE 400x. Photomicrographs of the jejunum of broiler chickens fed diet D3 containing 20% DCA without enzyme supplementation. In (**E**) Intestine - There is no observable lesion. HE 100x, and (**F**) Intestine - There is no observable lesion. HE 400x. Photomicrographs of the jejunum of broiler chickens fed diet D4 containing 30% DCA without enzyme supplementation. In (**G**) Intestine- There is no observable lesion. HE 100x, and (**H**) Intestine - There is no observable lesion, HE 400x. Photomicrographs of the jejunum of broiler chickens fed diet D5 containing 10% DCA with enzyme supplementation. In (**I**) Intestine - There is a loss of enterocytes and inflammation (arrow), HE 100x, and (**J**)

Intestine - There is a loss of surface enterocytes (arrow), HE 400x. Photomicrographs of the jejunum of broiler chickens fed diet D6 containing 20% DCA with enzyme supplementation. In (**K**) Intestine - There is a loss of surface enterocytes (arrow) HE 100x, and (**L**) Intestine - There is a loss of surface enterocytes (arrow), HE 400x. Photomicrographs of the jejunum of broiler chickens fed diet D7 containing 30% DCA with enzyme supplementation. In (**M**) Intestine - There is no observable lesion. HE 100x, and (**N**) Intestine - There is no observable lesion, HE 400x. Source: Authors, 2024.

Table 8. Intestinal morphometry of broiler chickens fed the experimental diets.

	Diets*							
Parameters (μm)	D1	D2	D3	D4	D5	D6	D7	SEM
Villi Height	959.47^{bc}	1378.84^{a}	1125.17^{b}	1156.60^{b}	1036.45^{bc}	900.46^{c}	1156.29^{b}	29.55
Villi Width	190.07^{cd}	251.61^{a}	216.24^{bc}	215.19^{bc}	164.25^{d}	170.43^{d}	223.31^{b}	5.02
Cryptal Depth	321.27	357.98	307.97	361.81	324.7	300.41	360.00	8.79
Cryptal Width	184.10^{b}	246.17^{a}	223.98^{a}	220.76^{a}	174.92^{b}	160.28^{b}	225.92^{a}	5.28
Muscle Thickness	188.04^{bc}	218.41^{ab}	233.60^{a}	225.89^{a}	184.34^{bc}	176.41^{c}	188.45^{bc}	4.84
VH: CD Ratio	3.06^{c}	3.83^{a}	3.70^{ab}	3.27^{bc}	3.26^{bc}	2.98^{c}	3.33^{abc}	0.07

Note: $^{a\,b\,c}$ Means within rows with different superscripts differ ($p < 0.05$). VH: CD Ratio: Villi Height-Cryptal Depth Ratio. SEM: Standard Error of Means. Source: Authors, 2024.

The combined effects of incorporating graded levels of DCA into the diet and supplementing with exogenous enzymes on the intestinal morphometry of the experimental birds are given in (Table 9). The data suggest that all parameters measured were significantly influenced ($p < 0.05$) by the dietary interventions, except for cryptal width, which did not exhibit a significant difference ($p > 0.05$). Enzyme supplementation had a significant ($p < 0.05$) impact on villi height, with birds fed diets containing 10% and 20% DCA without enzyme supplementation showing significantly greater villi height compared to those that received diets with enzyme supplementation.

Conversely, there was no significant difference in villi height among birds fed diets with 30% DCA, regardless of enzyme supplementation. Additionally, a considerable reduction in villi width and cryptal width was observed in birds-fed diets with 10% and 20% DCA fortified with enzymes compared to those on diets without enzyme supplementation. Moreover, the inclusion of exogenous enzymes led to a significant reduction in muscle thickness across different DCA inclusion levels. Furthermore, the villi height to cryptal depth ratio was higher in birds on diets containing 10% and 20% DCA without enzyme supplementation compared to those supplemented with enzymes.

Table 9. Interaction effects of DCA and exogenous enzyme supplementation on the intestinal morphometry of the experimental birds.

Parameters	Enzyme	Inclusion Levels			SEM
		10.00	20.00	30.00	
Villi Height (µm)	No Enzyme	1378.84^{Ax}	1125.17^{bX}	1045.49^{b}	47.92
	With Enzyme	1036.45^{Y}	900.63^{Y}	1155.29	47.92
	SEM	58.69	58.69	58.69	-
Villi Width (µm)	No Enzyme	251.61^{aX}	216.24^{bX}	215.19^{b}	5.66
	With Enzyme	164.25^{bY}	170.43^{bY}	223.31^{a}	5.66
	SEM	6.93	6.93	6.93	-
Cryptal Depth (µm)	No Enzyme	357.98^{a}	307.97^{b}	361.82^{a}	13.56
	With Enzyme	324.70	300.41	360.00	13.56
	SEM	16.61	16.61	16.61	-
Cryptal Width (µm)	No Enzyme	246.17^{aX}	223.99^{bX}	220.76^{b}	6.19
	With Enzyme	174.92^{bY}	160.28^{byY}	225.92^{a}	6.19
	SEM	7.59	7.59	7.59	-
Muscle Thickness (µm)	No Enzyme	218.41^{X}	233.60^{X}	225.89^{X}	6.75
	With Enzyme	184.34^{Y}	176.41^{Y}	188.45^{Y}	6.75
	SEM	8.27	8.27	8.27	-
VH: CD Ratio	No Enzyme	3.83^{aX}	3.70^{aX}	2.87^{bY}	0.12
	With Enzyme	3.26^{abY}	2.98^{bY}	3.33^{aX}	0.12
	SEM	0.15	0.15	0.15	-

Note: $^{a\,b\,c}$ Means within rows for different groups with different superscripts differ ($p < 0.05$). ^{XYZ} Means within the column for each parameter with different superscripts differ ($p < 0.05$). VH: CD Ratio: Villi Height-Cryptal Depth Ratio. SEM*[1]: Standard error of Means (Inclusion levels). SEM*[2]: Standard error of Means (Enzyme supplementation). Source: Authors, 2024.

4. Discussion

The utilization of unconventional feed resources holds significant promise in addressing the ever-growing demand for sustainable and cost-effective livestock production systems, particularly in regions like Nigeria, where challenges related to feed availability and affordability persist. In this regard, the cashew apple (*Anacardium occidentale*), often considered a waste product and underutilized, emerges as a compelling option for augmenting broiler chicken production. Through a thorough analysis of growth performance, nutrient digestibility, and intestinal morphological evaluations, this study explores the multifaceted impacts of cashew apple inclusion in broiler diets to provide valuable insights into the sustainable intensification of broiler chicken production in Nigeria and beyond.

The dietary inclusion of DCA at 10% in broiler chicken diets, supplemented with or without exogenous enzymes, has exhibited a noticeable enhancement in growth performance. This assertion is substantiated by the significant improvement in the Average Daily Gain (ADG) recorded in birds-fed diets with 10% DCA with or without enzyme supplementation in this study. This conclusion accords coherently with the results of Yisa et al. (2017), who also demonstrated that integrating DCA up to 10% in broiler chicken diets resulted in enhanced growth performance, as measured through growth metrics. However, it is pertinent to note that this observation diverges from the findings of Swain et al. (2007), whose investigation indicated that substituting cashew apple waste for maize in broiler chicken's diet at levels ranging from 5% to 20% led to a significant reduction in growth performance, specifically in terms of body weight gain.

It is crucial to underline that the performance displayed by broiler chickens fed with diets containing 20% inclusion of DCA with or without exogenous enzyme supplementation is equivalent to the performance recorded in birds given the control diet (D1). The notable similarity in performance might be attributed to the inherent nutritional composition of DCA, as elucidated through the proximate analysis undertaken in this study. Furthermore, this study strongly corroborates the conclusion of Senthil et al. (2015) who claim DCA to be a potential source of valuable feed resources for non-ruminant animals.

The observed decline in growth performance, specifically weight gain, among birds fed diets containing a 30% inclusion of DCA with or without exogenous enzyme supplementation (diets D4 and D7), correlates well with the conclusions drawn by Swain et al. (2007). This earlier experiment also noticed an enormous reduction in the weight gain of broiler chickens when the dietary inclusion of DCA increased. This finding also coincides with the statements put out by Faria et al. (2008). The second research underlined that diets that are rich in dietary fibre, as represented by DCA, might trigger reduced performance results in non-ruminant animals. This is attributed to the intricate mechanism wherein increased dietary fibre content hinders optimal enzymatic activity within the small intestine, consequently impeding the efficient digestion, absorption, and utilization of nutrients. Further substantiating this trajectory of diminished performance, is the elevated level of fibre present in DCA, this association is consistent with the observations posited by Lumpkins et al. (2004), who reported that a high level of fibre in feed ingredients lowers the energy density in the resultant feed thereby, resulting in depression in weight gain.

Furthermore, Rochell (2012) delineates a significant association between increasing dietary fibre levels, and the concomitant acceleration in the rate of feed transit, decrease in meal retention time, and reduced nutrient digestion and absorption in broiler chickens. This delicate interaction between fibre content and broiler chicken's physiological responses eventually results in a detrimental influence on overall performance metrics. Nonetheless, the intervention of enzyme supplementation appears as a conspicuous mitigating factor, permitting broiler chickens' improved tolerance to dietary inclusion of DCA up to 20%. This ameliorative impact is highlighted by the identical performance in terms of weight increase displayed by birds given diet D6 and their counterparts fed the benchmark control diet, designated as D1. This might be a consequence of enhanced nutritional availability and digestibility linked to fortifying poultry feed with exogenous microbial enzymes as articulated by Khattak et al. (2006).

The addition of DCA into the diet of broiler chickens has a considerable influence on important growth performance indicators such as Average Daily Feed Intake (ADFI) and Feed Conversion Ratio (FCR). Birds given the reference control diet indicated as D1, demonstrated the most beneficial results, with considerably lower values found for both ADFI (70.07 g) and FCR (1.84). These lowered levels imply effective nutrition use under this dietary regimen. Conversely, when the inclusion levels of DCA within the diet rose, noticeable alterations in ADFI and FCR were visible. This is shown by the escalating values reported in birds fed with diets D4 (ADFI: 99.16 g; FCR: 2.76) and D7 (ADFI: 94.95g; FCR: 2.63).

The observed rise in FCR particularly indicates the suboptimal utilization of nutrients within the dietary context, aligning with the well-established role of FCR as a robust tool for assessing the efficacy of nutrient utilization in poultry systems, as emphasized by Pradeep (2020) and Wen et al. (2018). This study reinforces the results of Yisa et al. (2017), whose work revealed a visible increase in feed intake and FCR due to incorporating DCA into the broiler chicken diet as a maize alternative. However, it's crucial to remark that the findings from this research contrast with the conclusions made by Swain et al. (2007) who observed no significant variations in FCR of broiler chickens fed with cashew apples-based diet.

The variance in FCR between the treatment groups for the current investigation might be related to DCA's composition, distinguished by its remarkable amount of dietary fibre. Such fibre-rich elements tend to alter the energy density of the experimental diet. Poultry birds, driven by their energy requirements, often react by consuming additional feed to meet their requirements for energy. This consumption pattern coincides with past studies, as shown by the results of Classen (2017) and Hossain et al. (2012), whereby it is proven that chickens prefer to increase their feed intake to fulfill energy needs. In the present study, as the inclusion level of DCA increases to 30%, a similar elevation in feed consumption is likely attributable to the fibre-rich character of DCA and its influence on energy density.

The incorporation of DCA into the broiler chicken diet distinctly influenced total tract digestibility, a pivotal aspect in assessing nutrient utilization. The introduction of DCA positively impacted nutrient digestibility across all the treatment groups for all assessed digestibility parameters, with a notable exception for birds fed with a diet containing 30% DCA without exogenous enzyme supplementation (D4), which is characterized by the lowest recorded digestibility coefficient. This outcome resonates with prior research, which posits that the moderate inclusion of dietary fibre within poultry diets yields advantageous outcomes such as improving gastrointestinal development and promoting nutrient utilization, as highlighted by Mateos et al. (2012).

Nonetheless, the reduced nutrient digestibility observed in birds fed with a diet containing 30% DCA without fortification with exogenous microbial enzymes (D4) may be attributed to the elevated fibre level and low energy density in the feed. This was however effectively ameliorated through the strategic implementation of exogenous enzyme supplementation, as discerned in the birds receiving diet D7 (30% DCA with enzyme supplementation) which has improved nutrient digestibility coefficient. This observation is notably in consonance with the earlier findings documented in the literature, wherein the supplementation of broiler chicken feed with exogenous enzymes is documented to yield improvements in nutrient digestibility and assimilation in poultry birds, as corroborated by Khattak et al. (2006).

Moreover, another possible explanation of this response could be due to the type of fibre fraction present in DCA as it contains an appreciable amount of insoluble fibre (cellulose 25.34%, hemicellulose 11.70%) of which its moderate inclusion in poultry chicken's diet improves gut development and nutrient utilization contrary to its soluble (β-glucans, pectin, and arabinoxylans) counterpart that increase intestinal viscosity and reduce nutrient utilization in poultry birds (Jha and Mishra, 2021). Consequently, the increased apparent nutrient digestibility coefficient obtained in this study is an indication that broiler chickens take advantage of DCA with good efficiency. Moreover, DCA did not contain any secondary metabolite beyond the tolerable threshold level for broiler chickens as its dietary inclusion did not result in a decrease in the activity of the digestive enzyme or trigger a toxic response from the experimental birds.

The morphometric analysis of the gut (Jejunum) in this study unveiled a distinctive quadratic response pattern among the experimental birds. This intriguing observation suggests that the significant differences observed in gut morphometry cannot be ascribed solely to the dietary inclusion of DCA. It is imperative to emphasize that the structural characteristics of the villi and crypt in the intestinal tract hold profound implications for gut function and, by extension, growth in broiler chickens, as elucidated by the study conducted by Dialoke et al. (2020). These findings underline the intricate interplay between dietary components and gut morphology, shedding light on the potential mechanisms underlying the observed variations in gut morphology.

Moreover, higher intestinal villi are intrinsically linked to an increased absorptive surface area within the intestine, consequently augmenting the absorptive capacity of nutrients and ultimately contributing to enhanced body weight gain, as elucidated by Kai (2021). Within the purview of this study, it is noteworthy that the dietary inclusion of DCA in the broiler chicken diet did not disrupt gut development. On the contrary, an improved gut structure was observed in birds fed diets containing DCA, aligning harmoniously with the research findings reported by Venkatramana et al. (2019). These collective insights underline the harmonious coexistence of DCA with gut development, thereby enhancing our understanding of the potential benefits of DCA as a dietary component within poultry nutrition.

5. Conclusions

Based on the findings of this study, it is therefore concluded that substituting maize with DCA in broiler chicken's diet up to 20% does not adversely impact weight gain and average daily gain. However, it is crucial to note that an increase in feed intake and feed conversion ratio was observed with higher levels of DCA. Additionally, nutrient utilization of birds-fed diets containing up to 20% DCA was better than that of birds on the control diet D1. While dietary inclusion of DCA up to 30% depressed nutrient utilization in broiler chickens however this adverse effect was counteracted by supplementing the diet with enzyme. Hence, it is recommended that dietary inclusion of DCA up to 20%, with or without exogenous enzyme supplementation, can be considered a viable and sustainable alternative to maize in broiler chicken diets.

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7. Authors' Contributions

Oluwatosin Solomon Oyekola: Conceptualized and designed the study, performed the primary data collection and analysis, and drafted the initial manuscript. *Christianah Olagoke*: Assisted in the study design and contributed significantly to data analysis and interpretation. *Taiwo Kayode Ojediran*: Contributed to the literature review and provided critical revisions to the manuscript. *Isiaka Adewale Emiola*: Provided expertise in experimental methods, supervised the project, and reviewed the manuscript for important intellectual content.

7. Conflicts of Interest

The authors confirm that there are no conflicts of interest.

8. Ethics Approval

Yes, applicable. The study was approved by LAUTECH Animal Care and Use Committee (LAUACUC), this is the reference number for the ethical approval LAU/ANB/P/2000403.

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