Journal of Animal Science and Veterinary Medicine
Volume 9(5), pages 270-278, October 2024
Article Number: D353B3E312
ISSN: 2536-7099
https://doi.org/10.31248/JASVM2024.480
https://integrityresjournals.org/journal/JASVM

Full Length Research

Fermented cassava starch residue and its utilization by broilers

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Received 3rd September 2024; Accepted 26th October 2024

ABSTRACT: Due to an improvement in the nutritional composition of cassava starch residue (CSR) through solid-state fermentation by fungus *Aspergillus niger*. An experiment was, therefore, carried out to assess the effects of varying levels of fermented cassava starch residue (FCSR) in broiler diets. 210-day-old Hybro broiler chicks were fed six isocaloric and isonitrogenous treatments consisting of seven replicates of five birds per replicate each in a Completely Randomized Design (CRD). The experiment lasted 49 days. Maize in control diet (A) was replaced with (FCSR) (diets B, C, D, E and F) at 5, 10, 15, 20, and 25% w/w. Fermentation resulted in an increased protein content of CSR by 72.7% and a decrease in crude fibre composition by 33.9%. The resultant benefit of the fermentation process therefore, ($p>0.05$) better the feed: gain ratio on those birds fed diets B, C and D (1.92) (1.93) (1.94) than their counterparts fed diets E and F (1.99) (2.06) respectively. Apparent nutrient digestibilities were better in FCSR diets B, C, D, E and F compared with control diet A (68.43) (71.03) (53.66) (70.04) and (76.32) for dry matter, crude protein, ether extract and ash, respectively. Similarly, serum biochemical indices of birds fed FCSR were improved ($p<0.05$) significantly. Relative weights of crop and gizzard of birds fed FCSR-based diets were significantly ($p<0.05$) higher compared to those birds fed control diet A (1.20g) and (3.08g), respectively. Birds on 15% inclusion FCSR had significantly ($p<0.05$) highest daily weight gain and better cost/kg weight gain compared to others. This research revealed that solid-state fermentation could be an effective pretreatment method for destructing cellulose in cassava starch residue. Also, replacing maize with up to 15% cassava starch residue fermented with *Aspergillus niger* is not deleterious to growth, organ values, nutrient utilization, serum biochemical indices as well cost/kg weight gain in broilers.

Keywords: Broilers, serum biochemical, solid-state fermentation, weight gain.

INTRODUCTION

The recent developments with the global economic meltdown and global warming, have posed more challenges to the growth and development of poultry industries in Nigeria. For economic growth, therefore, emphasis must be placed on reducing the competition between man and livestock for the same feedstuffs. This suggests an opportunity for exploiting more unconventional feed resources that largely go to waste and pollution hazards if not properly disposed off. Meanwhile, Nigeria is still leading the production of cassava in the world (FAO, 2017). More than 291 million tons of cassava were produced worldwide in 2017, of which Africa accounted for over 60%. In recent times, Nigeria produced 59 million tons making it the world's largest producer (approximately 20% of global production) with a 37% increase in the last decade (FAO STAT, 2017; IITA, 2021). According to Tewe (2004), Olomu (2011); Oluyemi and Roberts (2013), Agbabiaka *et al.* (2013), Etuk *et al.* (2015), Lakurbe *et al.* (2018),Ojewola *et al*. (2016) and Birhanu *et al*. (2023), this knowledge of cheap alternative feed ingredients and levels of inclusion into animal feed without any deleterious effects and or impaired performance will go a long way in solving the problems of high feed cost and also help in increasing the profit margin of poultry farmers. Raw Cassava Starch Residue (RCSR) constitute 10 – 20% of the processed roots. RCSR has been reported by Adedoyin (2014) to have a low nutritive value for monogastric animals and cannot be used as a main energy source; it accounts for low crude protein between 4 – 4.5% and higher crude fibre of about 16.7%. The high fibre content of this by-product has limited its usage by chickens because they do not have the enzyme capable of breaking down this cellulose cell wall (Abouelezz *et al.,* 2018, thus making the nutrient present in this by-product unavailable. One possible way of overcoming this problem is by fermentation (Iyayi and Aderolu, 2004, Bachtar, 2005; Longe, 2006; Mosobalaje *et al.,* 2019). Research efforts in this direction include the works of Onilude (1999), Iyayi and Losel (2001), Aderolu and Oyedokun (2009), and Dairo and Egbeyemi (2012) and Alabi *et al.* (2016). Fermentation procedure has been used to improve the nutritive quality of waste of many farm products by reducing the fibre content while increasing protein contents therefore making raw substances rich in non-digestible carbohydrates a major functional feedstock (Dairo and Egbeyemi, 2012; Adedoyin *et al.,* 2013). However, there is a paucity of information on the nutritional improvement of *Aspergillus niger* fermented cassava starch residue (FCSR) and its utilization on growth, digestibility, serum biochemical and organs weight by broiler.

MATERIALS AND METHODS

Study area

This experiment was carried out at the Teaching and Research Farms, University of Ibadan, Ibadan, Nigeria at the deep litter unit, and it lasted for 49 days. Ibadan is geographically located within 7°23' 47" N and 3° 55' 0" E.

Sources of ingredients

Dried Raw Cassava Starch Residue (RCSR) used was obtained in large quantities from Cassava Processing Factory (Martna, Akure, Ondo State). All other ingredients were purchased from a reputable commercial feed producer in Ibadan, Oyo State, Nigeria.

Culturing of organism and fermentation procedure

Native *Aspergilus niger* utilized in this study was isolated from cassava waste soil. Pure culture was maintained on potato dextrose agar medium (pH 5.5), with slants kept at 30 ± 2°C in the laboratory. The fermentation lasted for 14 days following the specified procedure of Onilude (1999) and Iyayi and Losel (2001).

Large scale fermentation of Raw Cassava Starch Residue (RCSR)

Five samples of 200 g each milled RCSR were placed in each of five, 250 ml conical flash that first plugged with cotton wool and followed by aluminum foil and sterilized at 121°C for 15 minutes in autoclave. Then 50 ml sterile maize pomace liquor was added to scale up and raise the moisture of the substrate to 30% as described by Ofuya and Nwajuibi (1990) and Onilude (1999). 10 mm^2 of inoculum (*Aspergillus niger*) was added under aseptic conditions and then incubated in the oven for 4 days at 30°C. Each of these sub-culture samples in the conical flasks was then poured into 10 kg milled sterilized, moistened RCSR and mixed thoroughly with glove hands. It was then incubated in the black nylon bag in a silo prepared from a used cylindrical steel drum (60 cm diameter, 110 cm height) for 10 days and then turning was done every alternate day. The samples were oven-dried and stored for use as fermented cassava starch residue (FCSR) as shown in Table 2.

Experimental design and diets

The design adopted was Completely Randomized Design (CRD). There were six dietary treatments for isonitrogenous and isocaloric nutrient levels. Diet 1 is the control (basal) diet, while diets 2 – 6 had graded levels of fermented cassava starch residue (FCSR) (5, 10, 15, 20 and 25% inclusion, respectively) as shown in Table 1.

Management of birds and data collection

One hundred and eighty day-old hybro broiler chicks were randomly allocated to the six dietary treatments, with thirty birds/treatment and five birds per replicate. Standard management practices were observed. The birds were reared in a deep litter house; feed and water were provided ad libitum, according to Olomu (2003) and Oluyemi and Roberts (2013). Data on feed intake, feed: gain ratio, weight gain and economy of production were collected.

The weight gain was obtained by subtracting the initial weight from the final weight of the broiler chickens at the end of the experiment. The feed: gain ratio (FGR) was calculated as follows:

$$FGR = \frac{Feed\ intake}{Body\ weight\ gain}$$

In the seventh week of the experiment, a digestibility trial was carried out. Two birds from each replicate whose weights were similar to the mean were selected for metabolic trial with facilities for feeding, water supply and collection of droppings. Birds were fed daily with the same quantity of feed. To estimate the total amount of specific nutrients absorbed from the gastrointestinal tract, a three-day acclimatization period was observed before a three-day collection period. Faecal voided by each bird was collected daily at 09:00 hours. Care was taken to avoid contamination with feathers, scales, debris and feeds. Total faeces voided from the birds in each replicate were collected using a collection tray. The faeces were weighed (wet basis) and oven-dried at 45°C (for 48 hours) until a constant weight was obtained. After which the total dry faeces for each replicate was bulked, and thoroughly mixed and 30% of it was weighed and milled to a size that could pass through a 2 mm sieve for proximate analysis as outlined by Pond *et al.* (1998). The difference between the nutrient in the feed consumed and the faeces or nutrients in the faeces voided multiplied by 100 gives the apparent digestibility coefficient of the feed.

Dry matter digestibility

After oven drying, the dry matter contents of the samples were determined as a percentage of the initial weight.

$$\%\ \mathrm{D.M.} = \frac{Weight\ after\ oven\ drying\ gm}{Weight\ before\ oven\ drying\ gm} \times \frac{100}{1}$$

$$\mathrm{D.M.\ digestibility} = \frac{F_0 - A_0\ X\ 100}{F_0}$$

Where: F_0 = DM Intake = % DM of Feed x Total amount of feed intake; A_0 = DM Output = % DM of faeces x Total amount of faeces voided.

Nutrient digestibility

The digestibility of nutrients was calculated using the following formula.

$$\mathrm{Digestibility} = \frac{(F_0\ X\ F_i) - (A_0\ X\ i)}{F_0\ X\ F_i}$$

Where: F_i = % Nutrient (ash, NFE, CF, EE and E^0) in the feed; F_0 = Dry matter weight of feed consumed (Dry matter intake); A_i = % Nutrient (ash, CF, EE, - NFE, E^0) in the faeces; A_0 = Dry matter weight of faeces voided (Dry matter output).

Metabolisable Energy (ME) determination of cassava starch residue

It was calculated using Pauzenga formular (1985) as:

ME = 37 x %CP + 81 X%EE + 35.5 X % NFE.

Serum collection and determination

Blood was samples from four birds per treatment at the seventh week of the experiment and collected into sterile sample tubes without anticoagulant. The tubes were kept in a slanted wooden rack at 36°C and the blood was allowed to clot. The clotted blood was centrifuged and spun for 15 minutes at 3,500 revolutions per minute. A clear fluid which is the serum was pipetted out into a clean and sterilized bottle and then deep frozen.

The serum protein and albumin were analysed using sigma assay kits, and glucose and cholesterol with Randox kits. The biuret method was utilized in the determination of the total protein fraction while the serum was subjected to the direct colourimetric method for albumin with Bromocresol green (BCG) as the dye as described by Kaneko (1989). The globulin concentration was obtained by subtracting albumin from the total protein.

The albumin/globulin ratio was obtained by dividing the albumin value by the calculated globulin value as described by Kaneko (1989).

Organs assessment

At the end of the seventh week, two birds per replicate were slaughtered after they were starved overnight. The Liver weight and dressed weight were taken. The abdominal fat was also weighed and recorded. The weights of the organs (liver, heart, gizzard, kidney, and spleen) were also taken.

Cost of production

Feed cost per kg live weight gain was calculated by multiplying the cost of each kg of diet by the feed-to-gain ratio (FCR). The existing market price of each feedstuff at the time of the feeding trial was used to calculate the cost per kg of each diet.

$$\text{Relative cost benefit (\%)} = \frac{Cost\ differential}{Cost/kg\ weight\ gain\ of\ control\ diet}\ X\ 100$$

Table 1. Composition of broiler diets containing different levels of *Aspergillus niger* fermented cassava starch residue (FCSR).

Ingredient	Diet A Control	Diet B 5% FCSR	Diet C 10% FCSR	Diet D 15% FCSR	Diet E 20% FCSR	Diet F 25% FCSR
Maize	50	45	40	35	30	25
FCSR	-	5	10	15	20	25
GNCM	13	14	14.5	15	15.5	16
Wheat offal	4	2.5	2.0	1.00	0.75	0.25
Palm kernel oil	-	0.75	0.75	1.25	1.00	1.00
Full fat soya	26	26	26	26	26	26
Fish meal	2.0	2.0	2.0	2.0	2.0	2.0
Bone meal	2.5	2.5	2.5	2.5	2.5	2.5
Oyster shell	1.25	1.25	1.25	1.25	1.25	1.25
Broiler premix	0.25	0.25	0.25	0.25	0.25	0.25
Methionine	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
Salt	0.25	0.25	0.25	0.25	0.25	0.25
Total	100	100	100	100	100	100
Calculated Nutrients						
Crude protein	23.23	23.36	23.58	23.61	23.09	22.9
Crude fibre	3.23	3.44	3.61	4.01	4.33	5.16
M.E. Kcal/kg	3003	3079.9	3082.4	3097.8	3001.1	2898.1
Analyzed values						
Dry matter	87.76	87.91	87.63	87.34	87.44	86.33
Crude protein	22.61	22.51	22.43	22.48	22.04	21.81
Crude fibre	3.11	3.42	3.56	3.69	4.01	5.01
ME Kcal/kg	3041	3034	3021	3010	3000.9	2899.1

FCSR = Fermented Cassava Starch Residue, GNC = Groundnut Cake Meal.

Table 2. Nutrient composition of raw and fermented cassava starch residue (% DM).

Nutrient	Raw CSR (%)	Fermented CSR (%)
Crude protein	4.5	6.99
Crude fibre	16.70	11.07
Ether extract	2.85	1.45
Ash	2.90	2.01
Nitrogen free extract	62.45	71.22
Cellulose	17.07	8.01
Hemicelluloses	36.03	33.08

Chemical and statistical analysis

Samples of diet and droppings were used for proximate analysis according to the procedure of the Association Officials of Analytical Chemists (AOAC, 2005). Data collected were subjected to analysis of variance of completely randomized design using the SAS (1999) package and the means were separated using Duncan's (1955) multiple range test of the same software.

RESULTS

Performance characteristics of broiler chicken-fed diets containing different levels of *A. niger* fermented cassava starch residue (FCSR) are shown in Table 3. Birds on diet D (15% inclusion) had the highest weight gain (46.38g/bird/day), followed by birds fed diet C (45.36±0.4/bird/day) while those fed diet A (control diet) gave the least (39.96 g/bird/day). The feed consumption

Table 3. Performance of broiler chicken fed supplemented diets containing different levels of *A. niger* fermented cassava starch residue.

Parameters	Diets						±SEM
	A (0%) (control)	B (5%)	C (10%)	D (15%)	E (20%)	F (25%)	
Feed intake g/bird/day	76.6^{f}	84.07^{e}	86.86^{c}	89.46^{ab}	86.6^{ab}	89.74^{a}	14.25
Weight gain g/bird/day	39.96^{d}	43.70^{c}	45.36^{ab}	46.38^{a}	45.01^{a}	44.88^{b}	6.24
Feed: gain	1.92^{c}	1.92^{c}	1.93^{c}	1.94^{c}	1.99^{bc}	2.06^{a}	0.11
Cost/kg feed (₦)	57.11	56.88	56.82	56.55	56.30	56.18	
Cost/feed consumed	244.9	267.78	276.4	283.3	282.4	282.3	
Cost/kg weight gain (₦)	613.0	612.78	609.3	610.82	627.4	628.9	

^{a,b,c} : Means in the same row with different superscripts are significantly different (P<0.05); ±SEM: Standard error of the means.

Table 4. Apparent nutrients digestibility of broilers fed supplemented diets containing different levels of *A. niger* fermented cassava starch residue.

Parameters	Diets						±SEM
	A (0%) (control)	B (5%)	C (10%)	D (15%)	E (20%)	F (25%)	
Dry matter	68.43	69.76	68.07	67.89	68.02	69.18	1.03
Crude protein	71.03^{d}	78.14^{a}	77.68^{ab}	77.85^{ab}	75.01^{c}	69.88^{d}	1.11
Crude fibre	53.66^{c}	62.01^{a}	64.03^{a}	63.33^{a}	60.01^{b}	59.03^{b}	0.28
Ether extract	70.04^{c}	74.66^{ab}	76.84^{ab}	78.31^{a}	69.78^{d}	71.11^{c}	1.14
Ash	76.32^{c}	81.41^{a}	82.09^{a}	80.94^{ab}	79.89^{c}	80.01^{ab}	1.10

abcd: Means on the same row with different superscripts are significantly different (p<0.05); ±SEM: Standard error of the means.

pattern significantly (P<0.05) increased as levels of *A. niger* fermented CSR increased in the diets. The highest feed intake was observed with birds fed diet F (89.74±0.10/bird/day), while the least feed intake was recorded for birds fed diet A (76.60g/bird/day) control. The gain ratio, however, was similar across the dietary treatments. Broiler chicken fed diet C (10% inclusion FCSR) had the least cost/kg weight gain (₦609.30k), followed by (15% inclusion FCSR) that recorded (₦610.82k).

Nutrient digestibility

The nutrient digestibility of broiler chicken fed FCSR supplementation in the diets is presented in Table 4. Crude protein was significantly (p<0.05) highest in birds fed diets B (78.14%) and D (77.85%), while birds on diet A (control) gave the least crude protein (71.03%) value. Birds on diets A and F however, showed no significant differences in their crude protein digestibility. Crude fibre digestibility improved with birds on diets B (62.01%), C (64.03%), D (63.33%), and E (60.07%) compared to birds on diet A control (53.66%). Ether extract digestibility ranged from 69.78 to 78.31%. There were significant (p<0.05) differences in the ash digestibility of birds fed with different levels of the FCSR in the diets.

Serum metabolites

Serum metabolites of broiler chicken-fed diets containing different levels of *A. niger* FCSR are shown in Table 5. An improvement in the total protein of broiler chicken was observed in the entire treatment. No significant (p<0.05) difference was observed in the total protein content and values obtained ranged between 3.98 and 5.04 mg/100ml. The values obtained for the albumin: globulin ratio were similar across the dietary treatments. The highest cholesterol value was observed in birds fed diet A control (146.91 mg/100ml) while the least was observed with birds fed diet F (110.98 mg/100ml). Serum glucose level was significantly increased (p<0.05) in diet A (142.4 mg/100ml) to diet D (145.0 mg/100m), the level for birds on diets (E (130 mg/100ml) and F (128.9 mg/100ml) being significantly (p>0.05) lower compared to other diets. Similarly, cholesterol decreased significantly (p<0.05) as the inclusion of FCSR increased with birds on diet F having the lower concentration of 110.98 mg/100ml and birds on treatment A (control) having the highest concentration of 148.91 mg/100ml.

Organs characteristics

Relative weights of organs of broiler chicken fed diets

Table 5. Some serum biochemical indices of broiler chicken fed supplemented diets containing different levels of *A. niger* fermented cassava starch residue.

Parameters	Diets						±SEM
	A (0%) (control)	B (5%)	C (10%)	D (15%)	E (20%)	F (25%)	
Total protein	4.43	4.61	5.04	4.99	4.12	3.98	0.21
Albumin	2.39^{a}	2.27^{b}	2.65^{a}	2.41^{b}	2.01^{c}	1.99^{c}	0.14
Globulin	2.74	2.34	2.19	2.58	2.11	2.37	0.22
Albumin globulin	0.62	0.97	0.76	0.93	0.59	0.67	0.17
Glucose	142.4^{a}	141.1^{a}	143.7^{a}	145·0^{a}	130.0^{b}	128.9^{c}	12.66
Cholesterol	146.9^{a}	132.3^{b}	132.77^{b}	114.3^{c}	117.4^{c}	110.98^{d}	11.74

^{abcd}: Means on the same row with different superscript are significantly different (p<0.05); ±SEM: Standard error of the means.

Table 6. Organ weights of broiler chickens fed diets containing different levels of *A. niger* fermented cassava starch residue.

Parameters (g)	Diets						±SEM
	A (0%) (control)	B (5%)	C (10%)	D (15%)	E (20%)	F (25%)	
Crop	1.20^{d}	1.30^{c}	1.39^{ab}	1.41^{a}	1.38^{ab}	1.44^{a}	0.00
Gizzard	3.08^{e}	3.41^{d}	3.58^{bc}	3.69^{bc}	3.88^{b}	4.01^{a}	0.18
Kidney	0.66	0.64	0.61	0.68	0.64	0.66	0.03
Liver	2.24	2.18	2.25	2.31	2.28	2.32	0.04
Heart	0.33	0.36	0.32	0.33	0.34	0.41	0.03
Spleen	0.13	0.10	0.13	0.11	0.09	0.12	0.01
Lung	0.78^{a}	0.66^{a}	0.59^{b}	0.58^{b}	0.60^{b}	0.60^{b}	0.03
Bile	0.13^{b}	0.12^{b}	0.14^{b}	0.18^{a}	0.12^{b}	0.11^{c}	0.03
Abdominal fat	1.69	1.58	1.64	1.55	1.41	1.32	0.10

^{abc}: Means on the same row with different superscripts are significantly different (p<0.05); ±SEM: Standard error of the means.

containing different levels of supplementation of *A. niger* FCSR are shown in Table 6. From the result, the crop and gizzard of birds on FCSR diets were significantly (p<0.05) different from those on the control diet A (1.20 g) and (3.08 g), respectively. Although no significant differences were observed in the weights of kidney, liver, heart, spleen, and abdominal fat of birds in all the dietary treatments including the control, the weight of the lungs of birds on the control diet A (0.79%) was however, higher than the birds fed supplemented diets.

DISCUSSION

Cassava starch residue is the fibrous constituent of the sclerenchyma and xylem parts of the root tuber. For monogastric like broilers, the insoluble non-starch polysaccharides (NSPs) fraction (lignocellulose) a physic-chemical binder, is virtually undigested in the alimentary canal of birds. To effect a breakdown in the structure of the residue, they were milled and fermented with *A. niger* for 14 days before their inclusion in experimental diets. This approach is supported by Iyayi and Aderolu (2004), Adedoyin *et al.* (2013), and Mosobalaje *et al.* (2019), that biodegradation of agro-industrial by-products will enhance their nutritional status and inclusion in poultry diets.

The increase in daily weight gain (diet B: 43:70 g, C: 45.36 g, D: 46.38 g as well as better feed to gain ratio 1.92, 1.93, and 1.94, respectively) of FCSR up to 15% inclusion in diets attested to the effect of enzymes being produced during fermentation that produced appreciable amounts of reducing sugars from raw CSR which eventually improve the body mass of the broilers fed those diets, while decrease in the daily weight gain (g/bird) observed in diets E and F as compared to the other diets could be as a result of the increase in the crude fibre content of the feed (4.33) and (5.16%), respectively which were slightly above the Olomu (2003) recommended value of 2-4% for broilers. Alabi and Ayoola (2010) and Ani *et al.* (2012) reported that the inclusion level of agro-industrial by-products in animal diet is restricted by factors such as the quality and digestibility of the materials, the species concerned and the age of the animals. Soluble NSPs, according to Choct and Annison (1992) are associated with the viscous nature of the polysaccharides, their physiological and morphological effects on the digestive tract, and their interaction with the micro-flora of the gut. The mechanism includes altered intestinal transit time, modification of the intestinal mucosa, and changes in hormonal regulation due to varied rates of nutrient absorption which could probably cause the poor feed conversion efficiency observed in birds fed diets E and F. The β–glucan, xylans, and amylopectin have been reported to be present in the cassava root (Idodo-Umeh, 2011; Roberts *et al.,* 2013) which brings about very low viscous condition in the small intestine thereby leading to interference with nutrient absorption (Onilude 1999; Zhu *et al.,* 2023). Although, feed to feed-to-gain ratio was observed to be better at the finisher stage compared to the starter (early) phase of the birds. This could be due to better utilization of fibre with the increase in the age of the birds as reported by Olomu (2011) and Oluyemi and Roberts (2013), Ogbuewu and Mbajiorgu (2022), and Ogbuewu and Mbajiorgu (2023). The difference between the daily weight gain of birds on the different supplemented diets and control (diet A) could be attributed to the fact that the lignocelluloses contents of the diets were heterogeneous and dissimilar in compositional percentages and forms leading to the varying rate of degradation (Animashahun *et al.,* 2022). Nutrient digestibilities were better in most of the diets supplemented with fermented CSR compared to the control. This was because during *A. niger* fermentation, enzymes were produced which gave a synergistic effect leading to better utilization of nutrients (Olomu, 2011; Verma, 2014; Adedoyin *et al*., 2016). Acromovic (2001) and De Vries and Visser (2001) identified four classes of enzymes involved in the complete hydrolysis of cellulose. These are endoglucanase, cellobiohydrolase, β-glucosidase, and exoglucanase, and all four classes have been identified in *Aspergillus* species. Biodegradation according to Onilude (1999) brings about improvement in carcass parameters as observed in this study. An increase in the inclusion levels of fermented CSR caused an increase in the fibre level of the diets which resulted in the reduction of abdominal fat from 1.69 to 1.32%. This decrease might have been due to the reduction in the rate of absorption of dietary fat through the binding of the fibre to bile acid in the small intestine, leading to a mop-up of bile in the enterohepatic system (Kaneko, 1989; Onilude 1999; Roberts *et al.,* 2003; DSM, 2013). The increased musculature of gizzards of broilers of supplemented diets showed that the organ exerted itself greatly in grinding the diets as compared to the birds on control (diet A), thereby reducing pressure on the gizzard. As much as live weight was influenced by dietary nutrients, the effect of supplementation of FCSR in broiler diets (up to 15%) on carcass yield was positive.

There was a need to determine serum parameters because it is used in assessing the nutritional status of birds (Kaneko, 1989), the total serum protein functions as a defence mechanism and maintenance of osmotic pressure. Although no significant difference was observed in the total protein of the broilers fed diets supplemented with FCSR and the control diet at the early age, however, there was a progressive increase in the total protein of the birds on the different diets as the age advanced. This corroborates the work reported by Choct and Annison (1992) and Adedoyin (2014) who also observed an increase in total protein as the bird aged. The increase in glucose with the increase in FCSR supplementation could be due to an increase in fibre intake which in turn caused an increase in glucose metabolism and insulin response. As the inclusion levels of FCSR increased, more of the soluble polysaccharides which are potential energy sources were available in the birds thus increasing glucose concentration in the serum. The significant decrease of blood glucose with increasing FCSR above 15% inclusion level in diets having more cellulose contents, substantiated the findings of Gu *et al.* (2013) that there was a strong relationship between dietary cellulose and glycaemic index. The implications of lower levels of glucose in the blood of birds fed FCSR on 20 and 25% inclusion levels indicate that less energy was available to those birds (Enig, 2000; Mmereole, 2004; Elagib and Ahmed, 2012). The significant differences ($p<0.05$) observed in serum biochemical parameters with the supplementation of different levels of *A. niger* fermented CSR, however, fell within the normal recommended values for broilers as reported by Mitruska and Rawnsley (1977). The kidneys and livers of the birds fed the control and test diets showed no hyperthrophy lesions in the selected organs. This is an indication that *A. niger* did not produce sufficient toxin that could impair selected organs which made it safe for fermentation of crop residue to be used as a feedstock.

Conclusively, this research revealed that solid-state fermentation could be an effective pretreatment method for destructing cellulose in cassava starch residue. Also, replacing maize with up to 15% cassava starch residue fermented with *Aspergillus niger* is not deleterious to the growth and nutrient utilization of broilers. Serum biochemical indices were improved across the fermented cassava starch residue-based diets compared to the control. This suggests that fermentation might have thus reduced the cellulose as well as hemicellulose considerably and increased the nutrient value of cassava starch residue, or else known as Agro-Industrial By-products (AIBs), making it suitable as feedstock.

FUNDING

The authors thank the University of Ibadan, Ibadan for financing this study via Senate Research Grant SRG/FAF/2006/3[B].

CONFLICTS OF INTEREST

The authors declare that they have no conflict of interest.

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