NATIONAL AGRICULTURAL
AND FOOD CENTRE
RESEARCH INSTITUTE FOR ANIMAL
PRODUCTION NITRA

Slovak J. Anim. Sci., 56, 2023 (1): 3–16
ISSN 1337-9984, E-ISSN 1338-0095
SciCell

IMPACT OF *ZYMOMONAS MOBILIS* TREATED CORN COBS ON GROWTH PERFORMANCE, APPARENT NUTRIENT DIGESTIBILITY, ILEAL DIGESTA VISCOSITY AND COST BENEFITS OF BROILER CHICKENS

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ABSTRACT

The fibrous nature of ground corn cobs limited their utilization in poultry production. *Zymomonas mobilis* derivable from fresh palm sap is proposed to ferment corn cobs to improve their nutritive values. An experiment was carried out to evaluate the effect of ground corn cobs inoculated with *Zymomonas mobilis* (CCZ) on growth response, apparent nutrient digestibility, ileal digesta viscosity and cost benefits of broiler chickens. Five diets containing treated and untreated corn cobs were formulated to replace wheat offal at 0, 50 and 100 % levels on weight for weight basis. A total of three hundred and seventy-five 1-day-old unsexed Marshall broiler chickens were randomly allotted to the five dietary treatments in a Completely Randomized Design (CRD). Results showed that the biodegradation of corn cobs resulted in improved ($p < 0.05$) nutrient composition, crude protein increased by 63.90 % while the crude fibre decreased by 137.89 % after fermentation with *Zymomonas mobilis*. The broiler chickens fed 100 % CCZ had the lowest ($p < 0.05$) values for feed conversion ratio (FCR) at both phases. The 50 % CCZ improved ($p < 0.05$) crude fibre digestibility (CFD) at the finisher phase. However, 50 % and 100 % CCZ reduced ($p < 0.05$) the ileal digesta viscosity of the broiler chickens. The birds fed 100 % CCZ had the highest ($p < 0.05$) values of rate of return on investment, economic efficiency and relative cost-benefit. The study concluded that wheat offal could be replaced with 50 % and 100 % CCZ in the ration of broiler chickens with positive economic returns.

Key words: corn cobs; cost-benefit; digestibility; growth response; *Zymomonas mobilis*

INTRODUCTION

The cost of conventional protein and energy sources like groundnut, fish meal, and soya beans for monogastric animal production has been on the increase around the world since the last decade. This was a result of competition with the man over few available cereals, grains and legumes with resultant scarcity and increase in price. It is expensive to use them to feed poultry birds (Esonu *et al.*, 2004; Oduguwa *et al.*, 2004). Aside from this, feed accounts for 65 – 75 % of the cost of production of non-ruminant animals (Esonu *et al.*, 2002). The escalating cost of conventional feedstuffs motivated nutritionists to search for alternative

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Received: June 8, 2022
Accepted: March 22, 2023

https://doi.org/10.36547/sjas.821

feedstuffs (Adeniji, 2001). There is an urgent need to search for affordable locally non-conventional feed ingredients to formulate balanced rations for non-ruminant animals (Esonu, 2008).

The lignocellulosic materials (rice hull, sawdust, corn husk, corn cobs, wood-chips, barks, rice straw, etc.) have been identified as some of the by-products of industries and farms. Efforts are being made by animal scientists to explore the possibilities of utilizing them as alternative feed resources. However, microbial treatment of lignocellulosic materials will improve their nutrients (Anigbogu, 2011). Corn cobs can be defined as the waste products of maize grain shelling. They litter the surroundings, streets, and markets and constitute a public nuisance. They can block drainage canals and cause flooding (Ndubuisi *et al.*, 2008). Several million tons of corn cobs that had no immediate use to humans accumulate on-farm processing units contributing to land and air pollution as a sizeable percentage are burnt to provide space for other useful purposes and ashes are used as fertilizer in crop farming (Oladeinde, 2000).

The incorporation of wheat offal as a major fibre in poultry ration has led to an unprecedented increase in its price and perennial scarcity, therefore there is a need to search for low-cost agro-industrial by-products (Lamidi *et al.*, 2008). The utilization of corn cobs will reduce the competition between man and animals for conventional feedstuffs, especially in monogastric animal nutrition (Oke *et al.*, 2007). It has been reported in the literature that broiler chickens fed fermented feed have improved production, immunity, nutrient utilization and intestinal microecological balance (Sun *et al.*, 2022). *Zymomonas mobilis* has a hetero-fermentative ability to produce gas from glucose, fructose and sucrose. It has a shorter fermentation time (300 – 400 %) than yeast, and higher ethanol yield of 92 – 94 % efficiency, a high level of ethanol tolerance, non-toxic, locally available and its ability to be genetically and mutationally altered (Jeon *et al.*, 2005). The treatment of fibrous feedstuffs with *Zymomonas mobilis* microbes is proposed to break down the polysaccharide and lignin contents into simpler carbohydrates, which the poultry birds can utilize for better productivity. Also, the utilization of degraded fibrous feedstuffs for farm animals will reduce the cost of production, encourage the production of cheap animal protein for Nigerians, increase foreign reserves and greatly reduce environmental hazards/pollution (Anigbogu and Anosike, 2010). Therefore, this study was carried out to determine the effects of treated and untreated corn cobs on growth performance, apparent nutrient digestibility, ileal digesta viscosity and cost benefits of broiler chickens.

MATERIALS AND METHODS

Research station and test ingredient

The experiment was conducted at the Poultry Unit of the Directorate of University Farms, Federal University of Agriculture, Abeokuta, Nigeria. It is located at 7°10'N and 3°2'E, 76 m above sea level. It lies within the South-Western part of Nigeria with a prevailing tropical climate, mean annual rainfall of 1,238 mm and an average temperature of 27.1 ºC (Climate-data.org Nigeria Ogun, 2020).

The corn cobs used for the study were obtained from the maize shelling unit of Obasanjo Farm Nigeria Ltd., Breeder farms, Igboora, Nigeria. The corn cobs were crushed using a hammer mill and screened using a 3.5 cm sieve before storage on pallets. Pure strains of *Zymomonas mobilis* used in this study were extracted from fresh palm wine. The *Zymomonas mobilis* suspension was used to inoculate the ground corn cobs to obtain starter inoculum for the study. The corn cobs were biologically treated in the traditional setting according to Anigbogu *et al.* (2009) using 50 kg ground corn cobs placed in a fermentation vat (Volume = 200 litres) with 100 litres of water added to 5 kg previously fermented dough containing *Zymomonas mobilis,* which acted as starter inoculums. The sample was homogeneously mixed and kept to ferment for a period of 20 days at room temperature of between 23.1 ºC to 24.6 ºC. After this, the fermented product was sun-dried, analysed and stored as a life enzyme (corn cobs treated *Zymomonas mobilis* microbes) for the experimental study.

Management of birds and experimental diets

Three hundred and seventy-five 1-day old unsexed Marshal broiler chicks were obtained from Obasanjo Farms Nigeria Limited, Lanlate, Nigeria. They were weighed individually weighed and randomly allotted to five dietary treatments. A total of 75 birds were used per treatment and were replicated 5 times with 15 birds each. The chicks were brooded for 2 weeks. All routine vaccinations and necessary medication were administered to the birds. The test diets were formulated to include untreated and *Zymomonas mobilis* treated corn cobs at varying levels of 0, 50 and 100 % replacing wheat offal weight for weight basis. The coarse and uniform mash feed was presented in dry form to the birds in the morning at 8.00am daily. Mash feed and water were supplied to the broiler chickens *ad libitum*. The birds were raised for eight weeks (0 – 4 weeks for the starter phase and 4 – 8 weeks for the finisher phase).

The percentage and chemical composition of the experimental diets is shown in Table 1.

Chemical analysis

The crude protein, crude fibre, ether extract and ash contents of the ground samples and experimental diets were determined according to the standard procedures of AOAC (2015). The fibre fraction: neutral detergent fibre (NDF), acid detergent fibre (ADF) and acid detergent lignin (ADL) were determined by the method of Van Soest *et al.* (1991). The calcium and phosphorus of the ground samples and diets were determined by the methods of Gruelling (1966). The gross energy of the ground corn cobs was determined using a Gallenkamp Ballistic bomb calorimeter (Cam Metric Ltd., Cambridge, UK).

Data collection

Performance characteristics

The weekly feed intake and the body weight were measured with a weighing scale in the morning before feeding and the average weight gain and feed conversion ratio were calculated. A record of mortality was kept as it occurred throughout the feeding trial.

Metabolic Trial

The metabolic trial was carried out during the 4th and 8th weeks of the experiments, 3 broiler chickens per replicate were randomly selected and kept separately in appropriate metabolic cages equipped with individual feeders, water troughs and a facility for separate excreta collection. A 3-day acclimatization period was allowed before the commencement of the metabolic trial. The weight of feed supplied to each broiler chicken was recorded. The total droppings voided per bird were collected separately in a labelled aluminum foil daily, weighed wet and dry in the oven at 65 °C to constant weight. The dried droppings from the same replicate were pooled and ground. The ground corn cobs were analyzed for ash, ether extract, crude fibre and crude protein, according to standard procedures of AOAC (2015).

Measurement of ileal digesta viscosity

Ileal digesta viscosity was determined by the Stowarld method as described by Habibi (1999) at 100 rpm. At the end of the experiment (8 weeks), a total of 15 broiler chickens per treatment (3 birds per replicate) were slaughtered for each experiment to examine the ileal digesta viscosity using a viscometer. The abdomen of each of the birds was opened immediately after death and the intestinal content was exposed. The ileal digesta content was collected from Merkel's diverticulum to the ileocaecal junction. The ileal digesta for each replicate was emptied into a sample bottle and properly labelled. A uniform weight of the sample was taken from each sample bottle using a sensitive scale and was diluted to a volume of 50 ml. The ileal digesta contents for each replicate were placed in a centrifuge tube and centrifuged at 6000 rpm for 20 minutes. The supernatant was withdrawn and viscosity was determined in a Torsion VHA-205-F viscosity using a torsion wire of 36 swg and an 11/16 in a cylinder.

Experimental design and Statistical analysis

The experimental design was a completely randomized design (CRD). All data collected were subjected to a one-way analysis of variance (ANOVA) as outlined by Daniel (1995) with the aid of SAS (2001) and the significant means were separated by Duncan's multiple range test at a 5 % level of significance (Steel and Torrie, 1980).

RESULTS

The result of the proximate composition of treated corn cobs and untreated corn cobs is shown in Table 2. The biodegradation of corn cobs resulted in improved ($p < 0.05$) nutrient composition, crude protein increased by 63.90 % while the crude fibre, neutral detergent fibre, acid detergent fibre and acid detergent lignin decreased by 137.89, 38.50, 64.64 and 197.50 % respectively after fermentation with *Zymomonas mobilis.*

Table 1: Percentage and Chemical Composition of Experimental Broiler Chicken Diets (DM-Basis)

Ingredients	Starter Diets					Finisher Diets				
	0 %	50 % CCZ	100 % CCZ	50 % CC	100 % CC	0 %	50 % CCZ	100 % CCZ	50 % CC	100 % CC
Maize	53.60	53.60	53.60	53.60	53.60	54.60	54.60	54.60	54.60	54.60
Soyabean meal	29.50	29.50	29.50	29.50	29.50	23.50	23.50	23.50	23.50	23.50
Fish meal	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Groundnut cake	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50
Wheat offal	5.00	2.50	0.00	2.50	0.00	10.00	5.00	0.00	5.00	0.00
Corn cobs	0.00	2.50	5.00	2.50	5.00	0.00	5.00	10.00	5.00	10.00
Bone meal	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Limestone	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50
Broiler premix[ab]	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Lysine	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Methionine[c]	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Toxin binder	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Salt	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
TOTAL	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Metabolizable energy (MJKg^{-1})	12.00	12.10	12.20	11.94	11.88	11.92	12.12	12.31	11.81	11.69
Chemical composition:										
Crude Protein (%)	23.38	23.19	23.01	23.04	22.70	21.68	21.31	20.93	21.00	20.32
Crude Fibre (%)	3.62	3.88	4.14	4.54	5.45	3.67	4.20	4.72	5.51	7.34
Ether Extract (%)	3.83	3.95	4.08	3.76	3.69	3.83	4.08	4.33	3.69	3.55
Ash (%)	2.60	2.65	2.70	2.80	3.00	2.26	2.36	2.46	2.65	3.05
Nitrogen Free Extract (%)	50.57	50.32	50.07	49.86	49.16	52.56	52.06	51.56	51.14	49.73
Calcium (%)	1.48	1.54	1.59	1.55	1.63	1.47	1.58	1.69	1.62	1.76
Phosphorus (%)	0.57	0.59	0.61	0.59	0.61	0.54	0.57	0.61	0.57	0.61

[a] Starter Vitamin-Mineral Premix: (Rotinol) based on 2.5 kgton^{-1} (Thiamine, 2000 mg, riboflavin, 7000 mg, pyridoxine, 5000 mg, cyanocobalamine, 1700 mg, niacin, 30,000 mg, D-panthotenate, 10,000 mg, folic acid, 800 mg, biotin, 2000 mg, Retinyl acetate, 12,000 iu., cholecalciferol, 2,400,000 iu., tocopherol acetate, 35,000 iu., menadione, 4,000 mg, ascorbic acid, 60,000 mg, manganese, nill, iron, 70,200 mg, zinc, nill, copper, nill, cobalt, 200 mg, iodine, 400 mg, selenium, 80 mg, choline chloride, 500,000 mg.

[b] Finisher Vitamin-Mineral Premix: (Rotinol) based on 2.5 kgton^{-1} (Thiamine, 1000 mg, riboflavin, 6000 mg, pyridoxine, 5000 mg, cyanocobalamine, 25 mg, niacin, 60,000 mg., D-panthotenate, 20,000 mg, folic acid, 200 mg, D-biotin, 8 mg, Retinyl acetate, 40 mg, cholecalciferol, 500 mg, tocopherol acetate, 40,000 mg., menadione, 800 mg, ascorbic acid, 60,000 mg, manganese, nill, iron, 80,000 mg, zinc, nill, copper, nill, cobalt, 80 mg, iodine, 400 mg, selenium, 40 mg, choline chloride, 80,000 mg.

[c] Methionine Hydroxyl Analog (MHA): (Novus International Inc.St. Charles, MO), feed supplement providing 84 % Methionine activity.

Table 2. Proximate analysis of treated and untreated corn cobs* (DM-basis)

Components (%)	Treated Corn cobs	Untreated Corn cobs	t-test (P-value)
Dry matter	88.00	88.30	2.16 (0.0967)
Moisture	12.00	11.66	-2.45 (0.0705)
Crude protein	9.45^{a}	3.41^{b}	-43.51 (0.0001)
Crude fibre	19.00^{b}	45.20^{a}	188.76 (0.0001)
Ether extract	8.50^{a}	0.70^{b}	-56.19 (0.0001)
Nitrogen free extract	49.05^{a}	31.11^{b}	-129.25 (0.0001)
Ash	2.00^{b}	7.92^{a}	42.65 (0.0001)
Neutral detergent fibre	65.00^{b}	90.03^{a}	180.33 (0.0001)
Acid detergent fibre	42.00^{b}	69.15^{a}	195.60 (0.0001)
Acid detergent lignin	10.00^{b}	29.75^{a}	142.29 (0.0001)
Calcium (gKg^{-1} DM)	2.32^{b}	3.05^{a}	5.26 (0.0063)
Phosphorus (gKg^{-1} DM)	0.84	0.84	0.000 (1.0000)
Gross energy (MJKg^{-1})	41.39^{a}	39.11^{b}	-16.43 (0.0001)
**Metabolizable energy (MJKg^{-1})	11.68^{a}	5.41^{b}	-45.17 (0.0001)

^{ab} Means on the same row having different superscripts are significantly different ($P < 0.05$).
* = Average of three determinations (n = 3).
**Metabolizable energy values were calculated using the method:
37 x % CP + 81 x % EE + 35.5 x % NFE for poultry birds (Fisher and Boorman, 1986).

Table 3. Performance characteristics of starting broiler chickens (0 – 4 weeks) fed diets containing treated and untreated corn cobs

Parameters	Dietary treatments					SEM
	1 Control diet	2 50 % CCZ	3 100 % CCZ	4 50 % CC	5 100 % CC	
Initial body weight (g/bird)	43.00	43.00	44.00	43.00	44.00	0.35
Final body weight (g/bird)	736.00^{a}	724.00^{b}	738.00^{a}	643.00^{d}	680.00^{c}	9.92
Average weight gain (g/bird)	693.00^{a}	681.00^{b}	694.00^{a}	600.00^{d}	636.00^{c}	9.91
Daily weight gain (g/bird)	24.75^{a}	24.32^{b}	24.79^{a}	21.43^{d}	22.71^{c}	0.35
Average feed intake (g/bird)	1454.00^{b}	1504.00^{a}	1335.00^{e}	1440.00^{c}	1401.00^{d}	15.11
Daily feed intake (g/bird)	53.85^{b}	55.70^{a}	49.44^{e}	53.33^{c}	51.89^{d}	0.56
Feed conversion ratio	2.10^{c}	2.21^{b}	1.92^{d}	2.40^{a}	2.20^{b}	0.04
Protein efficiency ratio	2.29	2.02	2.43	2.02	2.18	0.10
Cost of the feed/Kg (€/Kg)	0.33	0.30	0.30	0.33	0.33	0.01
Total cost of feed consumed/bird (€)	0.48	0.47	0.43	0.47	0.46	0.01
Cost of feed/Kg weight gain (€/Kg)	0.69^{ab}	0.72^{ab}	0.63^{b}	0.78^{a}	0.72^{ab}	0.02
Mortality (%)	0.80^{a}	0.80^{a}	0.00^{b}	0.00^{b}	0.00^{b}	0.11

^{abcde} Means on the same row having different superscripts are significantly different ($P < 0.05$); SEM: Standard Error of Mean; n = 5; Exchange rate: 1 Euro = 492.05 NGN.

The performance characteristics of starting broiler chickens fed diets containing treated and untreated corn cobs are shown in Table 3. The broiler chickens fed 100 % *Zymomonas mobilis* treated corn cobs (100 % CCZ) and control diet had higher values ($p < 0.05$) for final body weight, average weight gain and daily weight gain respectively while they recorded the least feed intake and feed conversion ratio.

The dietary treatments did not influence ($p > 0.05$) the cost of feed consumed/bird and cost of feed/kg weight gain with 100 % CCZ having the least cost of feed/kg weight gain.

The performance characteristics of finishing broiler chickens fed diets containing treated and untreated corn cobs are shown in Table 4. The birds fed the 100 % CCZ and control diet had similar values

Table 4. Performance characteristics of finishing broiler chickens (4 – 8 weeks) fed diets containing treated and untreated corn cobs

Parameters	Dietary treatments 1 Control diet	 2 50 % CCZ	 3 100 % CCZ	 4 50 % CC	 5 100 % CC	SEM
Initial body weight (g/bird)	736.00^a	724.00^b	738.00^a	643.00^b	680.00^c	9.92
Final body weight (g/bird)	2133.00^a	1913.00^d	2130.00^a	1963.00^b	1920.00^c	26.53
Average weight gain (g/bird)	1397.00^a	1189.00^e	1392.00^b	1320.00^c	1240.00^d	22.01
Daily weight gain (g/bird)	49.89^a	42.46^e	49.71^b	47.14^c	44.29^d	0.79
Average feed intake (g/bird)	4055.00^a	3479.00^e	3488.00^d	3771.00^c	3806.00^b	57.83
Daily feed intake (g/bird)	144.82^a	124.25^e	124.57^d	134.68^c	135.93^b	2.07
Feed conversion ratio	2.90^b	2.93^b	2.51^d	2.86^c	3.07^a	0.05
Protein efficiency ratio	1.59	1.48	1.80	1.65	1.69	0.05
Cost of the feed/Kg (€/Kg)	0.35	0.35	0.35	0.35	0.35	0.01
Total cost of feed consumed/bird (€)	1.42^a	1.22^c	1.22^c	1.33^b	1.32^b	0.02
Cost of feed/Kg weight gain (€/Kg)	1.02^a	1.03^a	0.87^b	1.01^a	1.07^a	0.02
Mortality (%)	4.80^a	2.40^b	0.80^c	0.80^c	2.40^b	0.41

^{abcde}Means on the same row having different superscripts are significantly different ($P < 0.05$); SEM: Standard Error of Mean; n = 5; Exchange rate: 1 Euro = 492.05 NGN.

Table 5. Performance characteristics of broiler chickens (0 – 8 weeks) fed diets containing treated and untreated corn cobs

Parameters	Dietary treatments 1 Control diet	 2 50 % CCZ	 3 100 % CCZ	 4 50 % CC	 5 100 % CC	SEM
Initial body weight (g/bird)	43.00	43.00	44.00	43.00	44.00	0.35
Final body weight (g/bird)	2133.00^a	1913.00^d	2130.00^a	1963.00^b	1920.00^c	26.53
Average weight gain (g/bird)	2090.00^a	1870.00^e	2086.00^b	1920.00^c	1876.00^d	26.50
Daily weight gain (g/bird)	37.32^a	33.39^c	37.25^a	34.29^b	33.50^c	0.48
Average feed intake (g/bird)	5509.00^a	4983.00^d	4823.00^e	5211.00^b	5207.00^c	62.17
Daily feed intake (g/bird)	98.38^a	88.98^c	86.13^d	93.05^b	92.98^b	1.11
Feed conversion ratio	2.64	2.66	2.31	2.71	2.78	0.09
Protein efficiency ratio	1.94	1.75	2.12	1.84	1.94	0.09
Cost of the feed/Kg (€/Kg)	0.68	0.65	0.65	0.68	0.68	0.01
Total cost of feed consumed/bird (€)	1.90^a	1.71^b	1.65^c	1.80^b	1.78^b	0.03
Cost of feed/Kg weight gain (€ /Kg)	1.71^a	1.75^a	1.50^b	1.79^a	1.79^a	0.03
Mortality (%)	5.60^a	3.20^b	0.80^d	0.80^d	2.40^c	0.48

^{abcde}Means on the same row having different superscripts are significantly different ($P < 0.05$); SEM: Standard Error of Mean; n = 5; Exchange rate: 1 Euro = 492.05 NGN.

($p > 0.05$) for final body weight but had significantly ($p < 0.05$) the lowest feed conversion ratio and cost of feed/kg weight gain.

The overall performance characteristics of broiler chickens (0 – 8 weeks) fed diets containing treated and untreated corn cobs are shown in Table 5. The broiler chickens in the control group had significantly ($p < 0.05$) the highest values for average weight gain, daily weight gain, average feed intake, daily feed intake and mortality. However, broiler chickens fed 100 % CCZ had similar ($p > 0.05$) values of daily weight gain with the control group but the lowest values ($p < 0.05$) of average feed intake and daily feed intake. The dietary treatments did not influence ($p > 0.05$) the feed conversion ratio and protein efficiency ratio.

The apparent nutrient digestibility of starting broiler chickens fed diets containing treated and untreated corn cobs are shown in Table 6. It revealed that the replacement of wheat offal with treated and untreated corn cobs improved the nutrient digestibility of starting broiler chickens. The starting broiler chickens fed 50 % CC had the highest values ($p < 0.05$) for nutrient digestibility except for nitrogen-free extract digestibility. However, the values obtained in 100 % CCZ were comparable with the control diet.

The apparent nutrient digestibility of finishing broiler chickens fed diets containing treated and untreated corn cobs is shown in Table 7. Broiler chickens fed 50 % CCZ had the superior highest values ($p < 0.05$) for dry matter, crude protein, crude fibre, ash and other parameters.

The viscosity of ileal digesta of broiler chickens fed diets containing treated and untreated corn cobs are shown in Table 8. The dietary treatments significantly ($p < 0.05$) influenced the ileal digesta viscosity of the broiler chickens. At 100rpm, the highest value was observed in 100 % CC while the lowest value was recorded in the control diet.

The economy of feed conversion of broiler chickens fed diets containing treated and untreated corn cobs is shown in Table 9. The gross profit was higher ($p < 0.05$) for birds fed 100 % CCZ but a lower value was obtained for 100 % CC. The birds fed 100 % CCZ had the highest ($p < 0.05$) values of rate of return on investment, economic efficiency and relative cost-benefit while the least values for the rate of return on investment and economic efficiency were recorded in 100 % CC.

Table 6. Apparent nutrient digestibility of starting broiler chickens (0 – 4 weeks) fed diets containing treated and untreated corn cobs

	Dietary treatments					
Parameters	1	2	3	4	5	
	Control diet	50 % CCZ	100 % CCZ	50 % CC	100 % CC	SEM
Dry matter digestibility	76.50^{a}	69.00^{b}	65.92^{b}	79.91^{a}	69.00^{b}	1.48
Crude protein digestibility	75.38^{a}	72.63^{ab}	69.25^{b}	76.75^{a}	73.42^{ab}	0.84
Crude fibre digestibility	61.25^{b}	46.67^{c}	47.46^{c}	68.31^{a}	46.67^{c}	2.46
Acid detergent fibre digestibility	75.59^{a}	72.50^{a}	68.46^{b}	76.62^{a}	74.36^{a}	0.91
Neutral detergent fibre digestibility	68.18^{a}	62.50^{b}	60.34^{b}	72.07^{a}	61.72^{b}	1.28
Acid detergent lignin digestibility	42.50^{bc}	35.67^{d}	43.46^{b}	52.73^{a}	39.00^{cd}	1.78
Ether extract digestibility	74.05^{ab}	70.00^{bc}	72.31^{abc}	74.55^{a}	69.09^{c}	0.75
Ash digestibility	75.31^{ab}	69.33^{c}	71.35^{bc}	76.52^{a}	68.39^{c}	0.99
Nitrogen free extract digestibility	71.01^{a}	62.50^{b}	63.80^{b}	70.17^{b}	64.01^{b}	1.07
Calcium digestibility	78.43^{b}	73.52^{d}	83.48^{a}	74.25^{d}	75.92^{c}	0.99
Phosphorus digestibility	81.59^{a}	73.66^{c}	76.26^{b}	80.39^{a}	76.17^{b}	0.80
Apparent metabolizable energy digestibility	69.57^{b}	65.15^{c}	61.33^{c}	73.89^{a}	64.30^{c}	1.27

^{abcd} Means on the same row having different superscripts are significantly different ($P < 0.05$);
SEM: Standard Error of Mean; n = 5.

Table 7. Apparent nutrient digestibility of finishing broiler chickens (5 – 8 weeks) fed diets containing treated and untreated corn cobs

Parameters	Dietary treatments 1 Control diet	 2 50 % CCZ	 3 100 % CCZ	 4 50 % CC	 5 100 % CC	SEM
Dry matter digestibility	53.29^{c}	74.00^{a}	50.54^{c}	62.68^{b}	50.54^{c}	2.47
Crude protein digestibility	68.06^{bc}	75.24^{a}	68.13^{bc}	71.14^{ab}	66.67^{c}	0.96
Crude fibre digestibility	55.45^{b}	65.00^{a}	59.02^{b}	47.11^{c}	41.54^{d}	2.29
Acid detergent fibre digestibility	60.77^{c}	71.29^{a}	54.85^{d}	66.84^{b}	53.90^{d}	1.87
Neutral detergent fibre digestibility	49.30^{c}	65.76^{a}	47.95^{cd}	55.12^{b}	44.74^{d}	2.04
Acid detergent lignin digestibility	60.16^{c}	70.63^{b}	76.15^{a}	68.04^{b}	62.52^{c}	1.61
Ether extract digestibility	69.01^{bc}	73.75^{a}	65.21^{cd}	70.43^{ab}	61.54^{d}	1.23
Ash digestibility	66.61^{b}	72.50^{a}	55.64^{c}	70.31^{ab}	57.38^{c}	1.88
Nitrogen free extract digestibility	44.29^{e}	70.68^{a}	58.36^{c}	64.97^{b}	48.88^{d}	2.66
Calcium digestibility	66.80^{d}	86.99^{a}	81.25^{b}	70.88^{c}	66.52^{d}	2.20
Phosphorus digestibility	72.78^{b}	86.05^{a}	65.57^{c}	74.07^{b}	73.29^{b}	1.77
Apparent metabolizable energy digestibility	65.44^{b}	76.90^{a}	57.94^{c}	65.50^{b}	60.22^{c}	1.81

^{abcde} Means on the same row having different superscripts are significantly different ($P < 0.05$);
SEM: Standard Error of Mean; n = 5.

Table 8. Viscosity of ileal digesta of broiler chickens fed diets containing treated and untreated corn cobs

Parameters	Dietary treatments 1 Control diet	 2 50 % CCZ	 3 100 % CCZ	 4 50 % CC	 5 100 % CC	SEM
100rpm	3.03^{c}	3.90^{bc}	3.30^{c}	4.22^{b}	7.40^{a}	0.43

^{abc} Means on the same row having different superscripts are significantly different ($P < 0.05$);
SEM: Standard Error of Mean; n = 5.

Table 9. Economy of feed conversion ratio of broiler chickens fed diets containing treated and untreated corn cobs

Parameters	Dietary treatments 1 Control diet	 2 50 % CCZ	 3 100 % CCZ	 4 50 % CC	 5 100 % CC	SEM
Cost of the feed/Kg (€/Kg)	0.35	0.35	0.35	0.35	0.35	0.01
Price/Kg live weight (€)	1.82	1.82	1.82	1.82	1.82	0.01
Cost of production/broiler (€/broiler)	2.86^{a}	2.66^{c}	2.66^{c}	2.77^{b}	2.76^{b}	0.02
Gross revenue/broiler (€/broiler)	3.88^{a}	3.61^{b}	3.88^{a}	3.57^{b}	3.50^{b}	0.07
Gross profit (€)	1.02^{ab}	0.95^{bc}	1.22^{a}	0.80^{bc}	0.73^{c}	0.07
Rate of return on Investment (%)	35.64^{b}	30.71^{c}	46.07^{a}	28.83^{bc}	26.51^{c}	2.02
Economic efficiency	0.71^{bc}	0.77^{b}	0.99^{a}	0.59^{bc}	0.55^{c}	0.05
Relative cost benefit (%)	0.00^{b}	5.47^{b}	13.92^{a}	0.73^{b}	5.14^{b}	1.51

^{abc} Means on the same row having different superscripts are significantly different ($P < 0.05$); SEM: Standard Error of Mean; n = 5; Exchange rate: 1 Euro = 492.05 NGN.

DISCUSSION

The experimental diets met the nutrient requirements of the starting and finishing broiler chickens in the tropics as stated by Klasing (2022).

Proximate composition of *Zymomonas mobilis* treated corn cobs

The proximate composition of the treated corn cobs used in the study was close to the previous results reported in the literature. The crude protein of fermented corn cobs of 9.45 % reported in the study was lower than the 12.80 % reported by Mafimidiwo *et al.* (2022) for urea-molasses-treated corn cobs. The crude fibre of the fermented corn cobs of 19.00 % was within the range of values obtained from bio-activators fermented corn cobs reported by Arwinsyah *et al.* (2018). However, the difference between the reported value in the study and the literature may be due to the length of storage, the drying period and the species of maize from which the cobs were harvested. The values of ash and nitrogen-free extract were lower than the values reported for fermented corn cobs by Adedire *et al.* (2012) and Olagunju *et al.* (2013). The difference in the values may be due to the microorganisms used for fermentation. The metabolizable energy of fermented corn cobs (11.68 $MJKg^{-1}$) was comparable to the value (11.61 $MJKg^{-1}$) for wheat offal (Aduku, 1993), therefore, it implies that it can replace wheat offal energy for energy in broiler chicken diet. The fermentation of corn cobs with *Zymomonas mobilis* improved its crude protein content. This could be attributed to the possible degradation of the substrate and microbial growth. This agreed with the reports of Olagunju *et al.* (2013) who reported that fermentation of corn cobs with white rot fungi improved its protein content, fibre level, ash and some mineral elements like calcium, potassium and zinc. However, the reduced calcium and phosphorus content of the fermented corn cobs when compared with the non-fermented product suggested the utilization of the constituent minerals by *Zymomonas mobilis* during fermentation as observed by Oso *et al.* (2015).

Performance characteristics of starting broiler chickens fed corn cobs based diets

At the starter phase, the birds fed 100 % *Zymomonas mobilis* treated corn cobs (100 % CCZ) had the highest values for final body weight, average weight gain, daily weight gain and improved feed conversion ratio. The increased body weight might be due to the proper utilization of *Zymomonas mobilis*-treated corn cobs. This agreed with the reports of Hartinger *et al.* (2022), who reported higher body weight, average daily gain and improved feed conversion ratio when *Hermetia illucens* defatted larvae meal-based diets were fed to Ross 308 broiler chickens as a protein source. Several similar reports have been observed in earlier studies (Janocha *et al.,* 2022 and Mulvenna *et al.*, 2022). The reduced feed intake in broiler chickens fed 100 % CCZ could indicate the adequacy of the energy content of the diet because birds feed to satisfy their energy need. The total cost of feed consumed/bird and cost of feed/kg weight gain in 100 % CCZ were lower than the values obtained in the control and other diets. This may be due to the low cost of fermented corn cobs compared to the cost of wheat offal at the time of the study.

Although, higher mortality was recorded in the control group and 50 % *Zymomonas mobilis* treated corn cobs (50 % CCZ), the result of post-mortem autopsy revealed that mortality may be due to systemic infection from the hatchery.

Performance characteristics of finishing broiler chickens fed corn cobs based diets

At the finisher phase, the birds fed 100 % CCZ had the lowest value for feed conversion ratio and the highest value of protein efficiency ratio. This might be attributed to the potential role of *Zymomonas mobilis* making more nutrients available for growth. This was in agreement with the observation of Mulvenna *et al.* (2022) who reported that a traditional soya-based diet with commercial exogenous phytase resulted in the best growth response in broiler chickens. However, this report was contrary to the observation of Biesek *et al.* (2020) who reported that broiler finishers fed legume seeds and rape seed meal have significantly reduced body weight gain and increased feed conversion ratio in the experimental groups than the control group fed soyabean meal based diet. Although the crude fibre of the dietary treatments was within the recommended range for finishing broiler chickens (NRC, 1994), the performance of the birds fed 100 % CCZ may be because as the birds grow older, they adapted to the high fibre diets, digested and utilized them better. However, the total cost of feed consumed/bird and cost of feed/kg weight gain was lower than the values obtained in the control and other diets. This may have compensated for the reduced daily weight gain and feed intake. There was the highest value for mortality in the control diet while similar values were obtained in 100 % CC and 50 % CCZ with the lowest value in 50 % CC. Although Ózsvári *et al.* (2017) reported lower values of mortality in the control and experimental groups for ROSS 308, mortality may not, however, be related to the dietary treatments. Therefore, *Zymomonas mobilis*-treated corn cobs can be incorporated into the feeds for broiler chickens.

Apparent nutrient digestibility of broiler chickens fed corn cobs-based diets

There were significant differences in all the parameters evaluated for the starting broiler chickens fed corn cobs-based diets. However, Otu *et al.* (2021) observed significant differences in ether extract, nitrogen-free extract, ash and crude fibre digestibility when wheat offal was replaced with watermelon rind in the diets of broiler chickens. The birds fed 50 % CC have the highest values except in nitrogen-free extract digestibility. This improved nutrient digestibility showed that ground corn cobs can promote the growth of broiler chickens.

Moreover, Ndelekwute *et al.* (2018) reported an improved digestibility of fibre, protein and ether extract with organic acids. The nutrient digestibility values obtained in 50 % CCZ were comparable to the values recorded in 100 % CCZ. This may be due to the fermentation of the corn cobs with *Zymomonas mobilis*. It might have reduced the possible non-starch polysaccharides in the corn cobs. Life-enzyme produced during fermentation could have brought unexpected benefits as observed by Adebiyi *et al.* (2009) for fermented cowpea seed hull.

However, the finishing broiler chickens fed 50 % CCZ has the highest values of the apparent nutrient digestibility which deviated from the result of the starting phase. The improved nutrient digestibility implied that the experimental broiler chickens were able to effectively digest and utilize the treated corn cobs which could have been excreted and decomposed in the soil. The value of crude fibre digestibility obtained in 100 % CCZ was comparable with the control diet. This may be due to the development of the gastrointestinal tract of the broiler chickens which led to the breakdown of the highly fibrous diet. The industrial treatment of wheat offal and the crushing of the corn cobs might have contributed to the better utilization of the diets. This was contrary to the findings of Ghasemi-Sadabadi *et al.,* 2022 who reported decreased apparent nutrient digestibility when 8 % of pomegranate peels were fed to broiler chickens and Ndelekwute *et al.* (2018) who observed that organic acids (citric acid, butyric acid, formic acid and acetic acid) significantly reduced dry matter and nitrogen free extract digestibility of the birds.

The crude fibre digestibility and its component values were higher in the test diets than in the control. It indicated that the anti-nutritional factor (ANFs) levels in the test diets did not significantly impair the utilization of these nutrients. In the present study, nutrient digestibility was significantly influenced by life-enzyme-based diets. This did not agree with the reports of Salehi *et al.* (2021) who stated that the digestibility of calcium, phosphorus and ash were not significantly affected by Kombucha treatments on broiler chickens. The poor nutrient digestibility recorded in broiler chickens fed 100 % CC (untreated corn cobs-based diet) can be attributed to the gel-forming capacity (viscosity) of non-starch polysaccharides which was responsible for low nutrient digestibility and/or availability (Jha and Mishra, 2021).

The viscosity of ileal digesta of broiler chickens fed corn cobs-based diets

The corn cobs-based diets exerted influence on the ileal digesta viscosity of broiler chickens.

However, El-Wahab *et al.* (2020) reported no significant differences among broiler chickens fed rye-supplemented diets besides lower values of ileal digesta viscosity. Birds fed 100 % untreated corn cobs (CC) had higher values at 100rpm but the lowest values were obtained in the control diet. This may be responsible for the depressed performance of the birds on 100 % CC because of the possible reduction in feed passage rate throughout the gastrointestinal tract (Shuaib *et al.,* 2022). The inclusion of treated corn cobs in the diets of broiler chickens reduced ileal digesta viscosity in 50 % CCZ and 100 % CCZ. This observation agreed with the reports of the previous studies of Smeets *et al.* (2018) and Alade *et al.* (2019). Smeets *et al.* (2018) reported that the utilization of enzyme mixtures in broiler chicken diets significantly decreased the ileal viscosity of the diets. Their reported values were lower than the values obtained in this study.

The economy of feed conversion ratio of broiler chickens fed corn cobs-based diets

The cost of feed/kg lowest value recorded in 50 % CC was similar to the values obtained in the control diet and 100 % CCZ. This may be due to the cost of treated and untreated corn cobs compared to the cost of wheat offal. The highest cost of feed/kg observed in 50 % CC and 50 % CCZ may be due to the combination of wheat offal and untreated and/or treated corn cobs in the diets. The gross revenue/broiler recorded in the control diet was similar to the value in 100 % CCZ but was higher than other values in 50 % CC, 100 % CC and 50 % CCZ. The value of gross profit/broiler obtained in 100 % CCZ was greater than the value obtained in the control diet. This agreed with the findings of Ózsvári *et al.* (2017) when mixtures of vitamins and nutrient supplements were administered in drinking water for broiler chickens. This may be due to the nutritional adequacy of *Zymomonas mobilis*-treated corn cobs which supported the growth performance of broiler chickens. The additional cost of purchasing enzymes and incorporating them into feeds had been removed by the production of life-enzyme-based feed.

CONCLUSION

The replacement of wheat offal with 100 % CCZ improved the feed conversion ratio, protein efficiency ratio and apparent nutrient digestibility of the broiler chickens at both phases. 50 % and 100 % CCZ reduced the ileal digesta viscosity of the broiler chickens. Therefore, untreated and *Zymomonas mobilis* treated corn cobs can replace wheat offal on weight for weight basis in broiler chicken diets without deleterious effects on the growth response and health status.

ACKNOWLEDGEMENTS

We thank Professor Anigbogu, N. M. for the provision of *Zymomonas mobilis* suspension and technical support during the fermentation of the fibrous agro-industrial by-product.

Mr. Obadina Folorunso James of the Government Science and Technical College, Abeokuta, Nigeria for the technical contributions to the study.

ETHICAL APPROVAL

This study was approved by the Animal Care and Use Committee of the College of Animal Science and Livestock Production, the Federal University of Agriculture, Abeokuta, Nigeria with Reference number PG020054.

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All authors have read and agreed to the published version of the manuscript.

INFORMED CONSENT STATEMENT

Not applicable.

DATA AVAILABILITY STATEMENT

The data presented in this study are available on request from the corresponding author.

CONFLICTS OF INTEREST

There is no conflict of interest with any individual or organization regarding the materials discussed in this manuscript.

FUNDING

The authors are grateful for the research grant received from the World Bank Africa Centre of Excellence in Agricultural Development and Sustainable Environment, Federal University of Agriculture, Abeokuta, Nigeria.

We appreciate the financial contribution of Mrs. Felicia Omolara Alade of the ASUU-UNAAB Cooperative Multipurpose Society Limited, Federal University of Agriculture, Abeokuta, Nigeria towards the success of the research work.

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