Growth Response, Apparent Nutrient Digestibility, Ileal Digesta Viscosity and Economy of Feed Conversion Ratio of Broiler Chickens Fed *Zymomonas mobilis* Treated Soybean Hulls

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Summary

This study was conducted for 56 days using 375 one-day-old Marshal broiler chicks (34.20 g ± 0.06) to evaluate the dietary inclusion of untreated soybean hulls (SH) and *Zymomonas mobilis* treated soybean hulls (SHZ) on growth response, apparent nutrient digestibility, ileal digesta viscosity and economy of feed conversion ratio. The broiler chicks were randomly allotted to five dietary treatments with 75 birds per treatment and were replicated 5 times with 15 birds each. The SH and SHZ replaced wheat offal at 0, 50 and 100% levels both at the starter and finisher phases. The experimental design was completely randomized. At the starting phase, the broiler chickens fed 100% SHZ had the lowest ($P < 0.05$) value of feed conversion ratio while those fed 100% SH had significantly ($P < 0.05$) highest protein efficiency ratio (PER). At the finishing phase, the birds fed 50% SH and 100% SH had statistically similar ($P > 0.05$) and the highest ($P < 0.05$) values of PER while birds fed 50% SHZ had the lowest value. The crude fibre digestibility highest value was observed at 100% SH while the lowest value recorded in the control diet was similar ($P > 0.05$) to the values obtained in 50% SH and 50% SHZ at the finishing phase. Birds fed 50% SHZ had increased ($P < 0.05$) ileal digesta viscosity at 100rpm. The broiler chickens fed SH and SHZ had the highest ($P < 0.05$) values of gross profit, rate of return on investment, economic efficiency and relative cost benefit. Therefore, it was concluded that 100% SHZ could promote the growth response and economic efficiency of broiler chickens.

Key words

apparent nutrient digestibility, economy of feed conversion ratio, growth response, ileal digesta viscosity, soybean hulls, *Zymomonas mobilis*

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Introduction

In commercial poultry, the production of broiler feed contributes up to 70% of the total production cost. The unprecedented global increase in prices of feedstuffs has led stakeholders to consider unconventional or alternative feedstuffs. This move is, however, limited by several issues: high and low fibre and protein contents and the presence of antinutritional factors (ANF) in unconventional feed ingredients that can reduce feed digestibility (Sugiharto and Ranjitkar, 2019).

Fermentation involves the combination of substrates, microorganisms and environmental conditions to break down complex substrates into simpler compounds (Niba et al., 2009). The highly variable fermented products depend on the characteristics and nature of the substrates utilized in fermentation (Canibe and Jensen, 2012, Subramaniyam and Vimala, 2012).

It has been reported in the literature that fermented products have been used for feeding pigs for a long time (Canibe and Jensen, 2012). However, nutritionists have increased interest in including fermented feedstuff in broiler rations to take advantage of its positive influences, particularly on gut health and production parameters (Alshelmani et al., 2016, Zhang et al., 2016). Soybean hulls are the by-products of soybean seeds after the extraction of oil and a very valuable feed ingredient available on the farm for feeding cattle and other species including poultry birds. Soybean hulls contain different quantities of celluloses (29 – 51%), hemicelluloses (10 – 25%), proteins (11 – 15%), lignin (1 – 4%), and pectins (4 – 8%) (Mielenz et al., 2009). The fibrous nature of the soybean hulls makes them readily available for feeding ruminants but they are not used as food for man (Ipharraguerre and Clark, 2003).

The utilization of wheat offal as a major dietary fibre source in most parts of poultry-producing areas of the tropics has escalated its price, thereby necessitating a search for non-convectional feedstuff which is readily available in the community (Lamidi et al., 2008). Therefore, soybean hulls may likely be a suitable alternative in the diet of broiler chickens.

The soybean hulls are good sources of carbohydrates, but they have some drawbacks. Soybean hulls are poorly digested by non-ruminant animals due to their high fibre contents (Dourado et al., 2011) but, they have potential as an alternative feed ingredient for poultry birds (Chee et al., 2005). Excessive levels of fibre in poultry diets can lead to antinutritive effects, including reduced nutrient absorption, energy utilization and feed intake, as well as digestive disorders and impaired gut health (Jha and Mishra, 2021). Balancing fibre levels is crucial to ensure optimal nutrient utilization and overall performance of poultry while maintaining gastrointestinal health. To enhance their utilization and other high fibre non-conventional feedstuffs, nutritionists have resorted to using exogenous enzyme supplementation (Esonu et al., 2010) to improve the nutritive value of feedstuffs (Adeola and Olukosi, 2009). However, the fermentation approach can improve the quality of unconventional feed ingredients for broiler chickens. The replacement of expensive conventional feedstuffs with cheaper unconventional fermented feedstuffs will lead to a low cost of production. (Sugiharto and Ranjitkar, 2019).

Zymomonas mobilis is a bacterium belonging to the genus Zymomonas that is known for its bio-ethanol production efficiency (Seo et al., 2005) with activities that surpass yeast in some aspects. It is generally found in African palm wine and Mexican pulque. It is a rod-shaped gram-negative bacterium. It is 2-6 μm long and 1-1.4 μm wide but can vary significantly (Yanase et al., 2005; Cazetta et al., 2007). Its ability to efficiently ferment carbohydrates using the Entner-Doudoroff pathway makes it an attractive option for life enzyme for animal feed (Onyejekwe, 2010).

Esonu et al. (2010) reported that a 30% dietary level of soybean hull meal (SHM) with/without Safzyme® supplementation could be used in laying birds' diets without any deleterious effects on birds; however, 20% dietary levels of SHM with exogenous enzyme Safzyme® at 1.0% could not improve the nutritive value of SHM for broiler finishing birds, besides negative percentage of feed cost savings. The substitution of wheat offal with soybean hulls in broiler chicken diets has not been reported in the literature. Therefore, this study was conducted to investigate the replacement of wheat offal with soybean hulls treated with *Zymomonas mobilis* on growth response, apparent nutrient digestibility, ileal digesta viscosity and economy of feed conversion ratio of broiler chickens.

Materials and Methods

Ethical Approval

All animal protocols for this study were approved by the Animal Care and Use Committee of the Department of Animal Nutrition, College of Animal Science and Livestock Production, Federal University of Agriculture Abeokuta, Nigeria.

Research Station and Test Ingredient

The study was carried out at the Poultry Unit, Directorate of University Farms and Animal Nutrition Laboratory, Federal University of Agriculture, Abeokuta, Nigeria, located at 7°10´N and 3°2´E, 76 m above sea level. It lies within the southwestern part of Nigeria with a prevailing tropical climate, mean annual rainfall of 1,238 mm and an average temperature of 27.1 °C (Climate-data.org Nigeria Ogun, 2020).

The soybean hulls were collected from Nestle Plc., Agbara Estate, Ogun State, Nigeria. They were milled using a grinding machine because of their slippery nature and stored on pallets.

Pure strains of *Zymomonas mobilis* used in this study were extracted from fresh palm wine using the methods of Anigbogu et al. (2009) using a 3.5 L sized fermentation vat. 500 g soybean hulls as substrate with 100 mL of extracted *Zymomonas mobilis* suspended in defined cultured media in the fermentation vat were weighed and homogeneously mixed. Two litres of water were poured into the vat and stirred to obtain a homogeneous mixture. The mixture was under room temperature of between 23.1 °C to 24.6 °C for 20 days and was properly turned using a plastic rod on 24-hourl basis. After this, the fermented product was used as starter inoculums (fermented dough) for the study.

The ground soybean hulls were biologically treated in the traditional setting according to Anigbogu et al. (2009) using 25 kg ground soybean hulls placed in a fermentation vat (Volume = 100 litres) with 50 litres of water added to 2.5 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°C to 24.6 °C. After this, the fermented product was sun-dried, analysed and stored as a life enzyme (soybean hulls treated *Zymomonas mobilis* microbes) for the experimental study.

Management of Birds and Experimental Diets

Three hundred and seventy-five unsexed one-day-old Marshal broiler chicks (34.20g ± 0.06) were obtained from Obasanjo Farms Nigeria Limited, Lanlate, Nigeria. They were allotted to five dietary treatments on a weight equalization basis. A total of 75 birds were used per treatment and were replicated 5 times with 15 birds each. The initial rearing temperature was 35 °C, measured 1 m above floor level for the first two days after hatch. The temperature decreased gradually until day 14 when they were reared in an open-sided deep-litter poultry house. All routine vaccinations and necessary medication were administered to the birds. 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 test diets were formulated to include untreated and *Zymomonas mobilis* treated soybean hulls at varying levels of 0, 50 and 100% replacing wheat offal weight for weight basis.

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

Chemical Analysis

The crude protein, crude fibre, ether extract and ash contents of the milled samples of SH, SHZ 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 methods of Van Soest et al. (1991). The calcium and phosphorus of the experimental diets were determined by the methods of Grueling (1966).

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, 2 broiler birds 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 3-day metabolic trial. The quantity of the feed supplied to each broiler bird was weighed and recorded in a record book. The total droppings voided per bird were collected separately in a labelled aluminum foil daily and 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 samples were analyzed for crude protein, crude fibre, ether extract and ash contents 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 25 broiler chickens (5 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 the Merekel 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 36swg and an 11/16 in the cylinder.

The Economy of Feed Conversion Ratio

The prevailing market prices of the ingredients per kg at the time of the study were used to calculate the cost of feed per kilogram diet ($), the total cost of feed consumed per bird ($) and the cost of feed per kilogram weight gain ($ per Kg) both for the starter and finisher phases. The cost-benefit analysis was based on the methods applied by Anigbogu and Anosike (2010).

Experimental Design and Statistical Analysis

The experimental design used for this study was a completely randomized design (CRD). All data collected were subjected to one-way analysis of variance (ANOVA) as contained in SAS 9.0 (SAS Institute 2001). The significant means were separated using Duncan's multiple range test at a 5% level of significance (Steel and Torrie, 1980).

Results

The result of the proximate composition of *Zymomonas mobilis* untreated and treated soybean hulls is shown in Table 2. The biodegradation of the soybean hulls increased ($P < 0.05$) crude protein, nitrogen-free extract, and ash and decreased crude fibre content.

The performance characteristics of starting broiler chickens fed diets containing untreated and treated soybean hulls is shown in Table 3. The dietary treatments increased ($P < 0.05$) the final body weight, daily weight gain and daily feed intake. The broiler chickens fed 100% *Zymomonas mobilis* treated soybean hulls (100% SHZ) had the lowest value of feed conversion ratio while those fed 100% untreated soybean hulls (100% SH) had significantly ($P < 0.05$) highest value of protein efficiency ratio (PER). The mortality was significantly influenced ($P < 0.05$) across the dietary treatments.

Table 1. Ingredients and Chemical Composition of Experimental Broiler Chicken Diets (DM- Basis)

Ingredients	0%	Starter 50% SH	Diets 100% SH	50% SHZ	100% SHZ	0%	Finisher 50% SH	diets 100% SH	50% SHZ	100% SHZ
Maize	53.60	53.60	53.60	53.60	53.60	54.60	54.60	54.60	54.60	54.60
Soyabean meal (44% CP)	29.50	29.50	29.50	29.50	29.50	23.50	23.50	23.50	23.50	23.50
Fish meal (72% CP)	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Groundnut cake (45% CP)	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50
Wheat offal (17% CP)	5.00	2.50	0.00	2.50	0.00	10.00	5.00	0.00	5.00	0.00
Soyabean hulls	0.00	2.50	5.00	2.50	5.00	0.00	5.00	10.00	5.00	10.00
Bone meal (0% CP)	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; Jubaili[Ltd]Agrotec	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 (MJ/Kg)	13.09	13.05	13.01	13.09	13.07	13.10	13.04	13.07	13.10	13.05
Determined Chemical composition:										
Crude Protein (%)	22.70	22.68	22.75	22.93	22.75	20.60	20.59	20.64	20.73	20.96
Crude Fibre (%)	4.81	5.15	5.49	4.96	5.10	4.84	5.52	5.20	5.13	5.41
Ether Extract (%)	3.67	3.73	3.83	3.79	3.88	3.72	3.93	3.94	3.98	3.99
Ash (%)	2.55	2.59	2.63	2.60	2.65	2.43	2.45	2.57	2.48	2.58
Nitrogen Free Extract (%)	55.77	55.35	54.80	55.22	55.12	57.91	57.01	57.15	57.18	56.56
Calcium (%)	1.29	1.30	1.32	1.31	1.32	1.26	1.28	1.31	1.29	1.33
Phosphorus (%)	0.51	0.54	0.57	0.55	0.58	0.52	0.56	0.59	0.57	0.59

Note: SH – untreated soyabean hull; SHZ – *Zymomonas mobilis* treated soyabean hull

[a] Starter Vitamin-Mineral Premix: (Rotinol) based on 2.5 kg/t (Thiamine, 2000 mg, riboflavin, 7000 mg, pyridoxine, 5000 mg, cyanocobalamine, 1700 mg, niacin, 30,000 mg, D-pantothenate, 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 kg/t (Thiamine, 1000 mg, riboflavin, 6000 mg, pyridoxine, 5000 mg, cyanocobalamine, 25 mg, niacin, 60,000 mg., D-pantothenate, 20,000 mg, folic acid, 200 mg, D-biotin, 8 mg, Retinyl acetate, 40 mg, cholecalciferol, 500mg, 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; Toxin binder: Jubaili[Ltd] Agrotec made in Spain.

Table 2. Proximate analysis of untreated and treated Soybean hulls* (SH) (DM-basis)

Components (%)	Untreated soybean hulls (SH)	Treated soybean hulls (SHZ)	T-test (*P*-value)
Dry matter	87.94^{b}	89.00^{a}	-7.64 (0.002)
Crude fibre	35.64^{a}	20.00^{b}	112.68 (0.0001)
Crude protein	17.06^{b}	19.68^{a}	-18.88 (0.0001)
Ether extract	9.90	10.00	-0.72 (0.51)
Ash	2.87^{b}	4.00^{a}	-8.14 (0.0012)
Nitrogen free extract	31.38^{b}	35.32^{a}	-28.39 (0.0001)
Acid detergent fibre	57.43^{a}	28.00^{b}	212.03 (0.0001)
Neutral detergent fibre	81.09^{a}	50.00^{b}	223.98 (0.0001)
Acid detergent lignin	18.81^{a}	10.00^{b}	63.47 (0.0001)
Phosphorus (g/Kg DM)	2.27	2.16	0.79 (0.4724)
Calcium (g/Kg DM)	1.00^{b}	1.39^{a}	-2.81 (0.0483)
**Metabolizable energy (MJ/Kg)	7.67^{b}	11.73^{a}	-29.25 (0.0001)
Gross energy (MJ/Kg)	16.10^{a}	15.31^{b}	5.69 (0.0047)

Note: Means on the same row having different superscripts are significantly different ($P < 0.05$)
* = Values are the average of three determinations (n =3)
** Metabolizable energy values were calculated using the method 37x % CP + 81x % 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 untreated and treated soybean hulls

Parameters	Dietary treatments					
	1	2	3	4	5	
	Control diet	50% SH	100% SH	50% SHZ	100% SHZ	SEM
Initial body weight (g/bird)	35.00	33.00	35.00	35.00	33.00	0.60
Final body weight (g/bird)	525.00^{e}	565.00^{d}	621.00^{b}	605.00^{c}	675.00^{a}	13.61
Average weight gain (g/bird)	490.00^{e}	532.00^{d}	586.00^{b}	570.00^{c}	642.00^{a}	13.75
Daily weight gain (g/bird)	17.50^{d}	19.00^{c}	20.93^{b}	20.36^{b}	22.93^{a}	0.51
Average feed intake (g/bird)	1181.00^{c}	1142.00^{c}	1195.00^{c}	1470.00^{a}	1282.00^{b}	32.87
Daily feed intake (g/bird)	43.74^{c}	42.30^{d}	44.26^{c}	54.40^{a}	47.48^{b}	1.16
Feed conversion ratio	2.41^{b}	2.15^{c}	2.04^{cd}	2.58^{a}	2.00^{d}	0.06
Protein efficiency ratio	2.24^{d}	2.53^{c}	2.85^{a}	1.94^{e}	2.65^{b}	0.09
Cost of feed/Kg ($/Kg)	0.43	0.43	0.42	0.43	0.43	0.04
Cost of feed/Kg weight gain ($/Kg)	1.04	0.92	0.87	1.11	0.85	0.04
Mortality (%)	4.00^{b}	0.67^{c}	0.67^{c}	6.00^{a}	3.33^{b}	0.57

Note: Means on the same row having different superscripts are significantly different ($P < 0.05$)
SEM: Standard Error of Mean; n = 5
Exchange rate: $1.00 = #1,392.96

The performance characteristics of finishing broiler chickens fed diets containing untreated and treated soybean hulls are shown in Table 4. The dietary treatments significantly ($P < 0.05$) influenced the final body weight, average and daily weight gain. The dietary treatments did not statistically affect ($P > 0.05$) the daily feed intake and the feed conversion ratio. The protein efficiency ratio (PER) was significantly ($P < 0.05$) influenced by the dietary treatments. The birds fed 50% SH and 100% SH had statistically similar ($P > 0.05$) and highest value of PER while birds fed the control diet had the lowest value. There was a significant ($P < 0.05$) influence observed in mortality across the dietary treatments.

The apparent nutrient digestibility of starting broiler chickens fed diets containing untreated and treated soybean hulls is shown in Table 5. The dietary treatments increased ($P < 0.05$) the apparent nutrient digestibility except for the crude fibre digestibility. The highest value of crude protein digestibility (CPD) was recorded in 100% SHZ, which was similar ($P > 0.05$) to the values observed in 50% SH, 100% SH and 50% SHZ. Significantly ($P < 0.05$) lowest CPD value was recorded in the control diet.

The apparent nutrient digestibility of finishing broiler-fed diets containing untreated and treated soybean hulls is shown in Table 6. The dietary treatments significantly ($P < 0.05$) increased the nutrient digestibility of the finishing broiler chickens. The highest value of CPD recorded in 100% SHZ was similar ($P > 0.05$) to the value obtained in 100% SH while the lowest value was recorded in birds fed 50% SHZ. The crude fibre digestibility highest value was observed in 100% SH while the lowest value recorded in the control diet was similar ($P > 0.05$) to the values obtained in 50% SH and 50% SHZ.

The viscosity of ileal digesta of broiler chickens fed diets containing untreated and treated soybean hulls is shown in Table 7. The dietary treatments significantly ($P < 0.05$) increased the ileal digesta of broiler chickens fed 50% SHZ and 100% SHZ experimental diets whereas reduced in 100% SH experimental diets at 100 rpm.

The economy of feed conversion ratio of broiler chickens fed diets containing untreated and treated soybean hulls is shown in Table 8. The finishing broiler chickens fed 100% SH and 50% SHZ had higher values ($P < 0.05$) of gross revenue and gross profit compared to the control group. Moreover, the dietary inclusion of SH and SHZ increased ($P < 0.05$) the rate of return on investment and economic efficiency.

Table 4. Performance characteristics of finishing broiler chickens (5 – 8 weeks) fed diets containing untreated and treated soybean hulls

Parameters	Dietary treatments					
	1	2	3	4	5	
	Control diet	50% SH	100% SH	50% SHZ	100% SHZ	SEM
Initial body weight (g/bird)	525.00^{e}	565.00^{d}	621.00^{b}	605.00^{c}	675.00^{a}	13.63
Final body weight (g/bird)	2100.00^{b}	2072.00^{b}	2248.00^{a}	2300.00^{a}	2128.00^{b}	26.08
Average weight gain (g/bird)	1575.00^{bc}	1507.00^{c}	1627.00^{ab}	1695.00^{a}	1453.00^{d}	25.05
Daily weight gain (g/bird)	56.25^{c}	53.82^{d}	58.11^{b}	60.54^{a}	51.89^{e}	0.83
Average feed intake (g/bird)	4346.00^{a}	3836.00^{c}	4144.00^{b}	4241.00^{ab}	3920.00^{c}	54.97
Daily feed intake (g/bird)	155.21	137.00	148.00	151.46	140.00	3.27
Feed conversion ratio	2.76	2.55	2.55	2.50	2.71	0.04
Protein efficiency ratio	1.86^{c}	2.16^{a}	2.14a	1.99^{b}	2.01^{b}	0.03
Cost of feed/Kg ($/Kg)	0.46	0.46	0.45	0.46	0.45	0.04
Cost of feed/Kg weight gain ($/Kg)	1.28	1.16	1.14	1.14	1.22	0.04
Mortality (%)	6.00^{a}	2.67^{b}	0.67^{c}	6.67^{a}	4.00^{b}	0.62

Note: Means on the same row having different superscripts are significantly different ($P < 0.05$)
SEM: Standard Error of Mean; n = 5
Exchange rate: $1.00 = #1,392.96

Table 5. Apparent nutrient digestibility of starting broiler chickens (0 – 4 weeks) fed diets containing untreated and treated soybean hulls

Parameters	Dietary treatments					
	1	2	3	4	5	
	Control diet	50% SH	100% SH	50% SHZ	100% SHZ	SEM
Dry matter digestibility	62.64[c]	73.88[a]	74.18[a]	67.07[b]	74.30[a]	1.29
Crude protein digestibility	65.94[b]	72.26[a]	72.93[a]	71.51[a]	73.67[a]	0.78
Crude fibre digestibility	63.52	64.88	63.95	65.38	65.30	0.32
Acid detergent fibre digestibility	70.24[a]	46.51[c]	49.54[b]	41.92[d]	46.28[c]	2.68
Neutral detergent fibre digestibility	55.31[d]	64.35[ab]	63.73[b]	58.80[c]	66.28[a]	1.11
Acid detergent lignin digestibility	69.61[a]	62.04[c]	50.36[d]	43.45[e]	62.04[b]	2.43
Ether extract digestibility	65.06[c]	68.86[b]	71.82[a]	68.19[b]	72.65[a]	0.77
Ash digestibility	66.42[b]	73.28[a]	73.19[a]	68.39[b]	71.79[a]	0.78
Nitrogen-free extract digestibility	63.58[d]	70.69[bc]	72.49[ab]	69.51[c]	73.12[a]	0.94
Calcium digestibility	70.40[bc]	70.06[c]	78.90[a]	71.83[b]	80.18[a]	1.18
Phosphorus digestibility	78.24[b]	81.49[a]	78.69[b]	79.62[b]	82.15[a]	0.45
Apparent metabolizable energy digestibility	64.33[b]	72.62[a]	73.23[a]	66.24[b]	73.63[a]	1.08

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

Table 6. Apparent nutrient digestibility of finishing broiler chickens (5 – 8 weeks) fed diets containing untreated and treated soybean hulls

Parameters	Dietary treatments					
	1	2	3	4	5	
	Control diet	50% SH	100% SH	50% SHZ	100% SHZ	SEM
Dry matter digestibility	59.00[d]	60.83[c]	71.00[a]	53.17[e]	66.27[b]	1.65
Crude protein digestibility	69.16[b]	69.17[b]	71.50[a]	65.98[c]	72.33[a]	0.63
Crude fibre digestibility	56.67[c]	58.33[c]	66.50[a]	57.60[c]	61.81[b]	0.99
Acid detergent fibre digestibility	59.00[c]	57.79[c]	62.82[b]	55.73[d]	66.23[a]	1.02
Neutral detergent fibre digestibility	50.24[d]	53.91[c]	64.49[a]	47.78[e]	59.90[b]	1.66
Acid detergent lignin digestibility	63.64[c]	66.48[b]	72.50[a]	61.30[d]	64.85[bc]	1.03
Ether extract digestibility	65.00[c]	60.28[d]	70.18[a]	56.71[e]	66.74[b]	1.29
Ash digestibility	61.61[d]	64.15[c]	71.00[a]	63.08[cd]	66.63[b]	0.90
Nitrogen-free extract digestibility	55.86[c]	51.11[d]	65.23[a]	54.90[c]	62.00[b]	1.38
Calcium digestibility	69.39[c]	69.51[c]	67.49[d]	71.84[b]	85.07[a]	1.71
Phosphorus digestibility	70.28[d]	72.66[c]	82.40[a]	72.41[c]	78.15[b]	1.20
Apparent metabolizable energy digestibility	66.12[c]	67.71[c]	74.37[a]	56.53[d]	70.30[b]	1.60

Note: Means on the s ame row having different superscripts are significantly different ($P < 0.05$)
SEM: Standard Error of Mean; n = 5

Table 7. Viscosity of Ileal digesta of broiler chickens fed diets containing untreated and treated soybean hulls

Parameters	Dietary treatments					
	1	2	3	4	5	
	Control diet	50% SH	100% SH	50% SHZ	100% SHZ	SEM
100 rpm	1.33[c]	1.31[c]	1.10[d]	1.56[a]	1.50[b]	0.04

Note: [abcde] Means on the same row having different superscripts are significantly different ($P < 0.05$)
SEM: Standard Error of Mean; n = 5

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

Parameters	Dietary treatments					
	1	2	3	4	5	
	Control diet	50% SH	100% SH	50% SHZ	100% SHZ	SEM
Cost of the feed/Kg ($/Kg)	0.46	0.46	0.45	0.46	0.45	0.04
Price/Kg live weight ($)	2.14	2.14	2.14	2.14	2.14	0.04
Cost of production/broiler ($/broiler)	3.63[ab]	3.34[b]	3.47[ab]	3.67[a]	3.41[ab]	0.05
Gross revenue/broiler ($/broiler)	4.50[c]	4.43[c]	4.82[ab]	4.93[a]	4.55[bc]	0.06
Gross profit ($)	0.87[b]	1.09[ab]	1.35[a]	1.26[a]	1.14[ab]	0.06
Rate of return on Investment (%)	23.94[c]	32.65[b]	38.88[a]	34.24[b]	33.48[b]	1.32
Economic efficiency	0.34[b]	0.49[a]	0.57[a]	0.49[a]	0.49[a]	0.02
Relative cost-benefit (%)	0.00[d]	9.31[b]	10.82[a]	2.39[c]	1.17[cd]	1.20

Means on the same row having different superscripts are significantly different ($P < 0.05$)
SEM: Standard Error of Mean; n = 5
Exchange rate: $1.00 = #1,392.96

Discussion

The soybean hulls treated with *Zymomonas mobilis* had increased ash, crude protein, nitrogen-free extract and decreased crude fibre. This observation agreed with earlier studies that fermentation led to decreased crude fibre, antinutritional factors and toxic compounds (Xu et al., 2012) but increased crude protein content in feed ingredients (Sugiharto et al., 2016a).

The soybean based diets influenced the weight, feed intake, feed conversion ratio, and protein efficiency ratio of the starting broiler chickens. This observation agreed with the findings of Opoola et al. (2016) who reported that the final weight, body weight gain, feed intake and feed conversion ratio were significantly affected by dietary treatments. The improvement in the growth performance of the starting broiler chickens fed the *Zymomonas mobilis* treated soybean hulls (SHZ) may be due to the reduction of antinutritional factors as observed by Khattab and Arntfield (2009). They reported appreciable reductions in the tannin and phytic acid contents of cereals and legumes respectively. The starting birds fed 50% SHZ had higher values of daily feed intake than birds fed the control and other diets. Therefore, the compounded feeds were balanced to meet the nutrient requirements and tissue development of the broiler chickens. Moreover, starting birds fed 100% SHZ had the lowest value of feed conversion ratio which was similar to the value obtained in 100% untreated soybean hulls (SH). This may be due to the improvement in digestion and absorption of nutrients which led to improved growth response of the birds (Zhang et al., 2016).

Also, the inclusion of soybean based diets improved the protein efficiency ratio of the finishing broiler chickens. This might be due to increased activities of digestive enzymes such as lipases, trypsin, amylases and proteases in the birds fed fermented feeds which are responsible for growth improvement (Feng et al., 2007 and Sun et al., 2013a). This observation agreed with the findings of Odeh et al. (2016) who reported no differences in final weight gain and daily weight gain for broiler chickens fed rice milling waste-based diets. The values of daily weight gain obtained in this study were higher than the 42.95 - 46.39 g bird^{-1} reported by Odeh et al. (2016) although their broiler chicks had a similar initial body weight of 34.58 ± 0.31g like our Marshal broiler chicks. This may be attributed to the drying and fermentation of soybean hulls which improved its nutritive values. Moreover, a higher body weight observed in chicks fed 100% SHZ at day 28 which was not reflected at the finisher phase, might be because older poultry birds' nutrient requirements decrease with age (NRC. 1994). Adeyemo and Longe (2007) defined the protein efficiency ratio as a clear indicator of the quality of dietary protein. They further stated that dietary protein quality could be assessed by its availability for tissue deposition. The birds fed soybean hulls based diets at the finishing stage had significantly higher values of protein efficiency ratio than the value recorded in the control group. This further supports the adequacy of the SH and SHZ to replace wheat offal for improved growth response of broiler chickens.

At the finishing stage, mortality was recorded in all the dietary treatments, however, the values obtained in 100% SHZ and 50% SH were lower than the values recorded in control group. The high mortality recorded for birds fed with both SHZ and SH could not be attributed to *Zymomonas mobilis* treatment since the control group also recorded slightly high mortality. *Zymomonas mobilis* used for fermentation was extracted from fresh palm wine, which might have played pivotal roles in the degradation and biotransformation of mycotoxins to non-toxic compounds as observed by Okeke et al. (2015) for some strains of bacteria. The value of mortality recorded in 100% SHZ was lower than the value of 6.78% obtained for Anak 2000 broiler chickens by Awobajo et al. (2007).

The starting broiler chickens fed the experimental 100% SHZ had the highest values for dry matter (DM), crude protein digestibility (CPD), neutral detergent fibre digestibility (NDFD), ether extract digestibility (EED), nitrogen-free extract (NFED), calcium, phosphorus and apparent metabolizable energy digestibility (AMED) compared to the values from other diets. This might be due to the utilization of SHZ in the diet. This was supported by the reports of Canibe and Jensen (2012), who stated that fermentation of feedstuffs increased the digestibility of various nutrients such as organic matter, nitrogen, amino acids, crude fibre and calcium. Moreover, the observation agreed with the reports of Agboola et al. (2014) who reported that apparent nutrient digestibility in broiler chickens was significantly improved with enzyme supplementation. Also, Adeniji and Omonijo (2004) report that fibres are arranged in such a way that proteins are trapped within them, which makes it difficult for the enzyme to digest them in the gastrointestinal tracts of non-ruminant animals. The treatment of soybean hulls with *Zymomonas mobilis* to produce life enzyme-based diets assisted the broiler chickens at the starter phase to digest and promote optimum nutrient absorption from the GIT. The dietary treatments influenced the nutrient digestibility of finishing broiler chickens fed soybean hulls treated with *Zymomonas mobilis* based diets. This result did not agree with the reports of Manafi et al. (2011) who reported that there were no significant differences in the apparent nutrient digestibility in broiler chickens fed corn bran-based diets with or without polyzyme. The nutrient digestibility values observed in 50% SHZ and 100% SHZ for finishing broiler chickens were not superior to the values obtained in other diets. Moreover, McCracken and Bedford (2001) observed that the composition and form of diets could affect the performance response of broilers to enzyme supplementation. Biggs et al. (2007) stated that differences in responses might be due to the intrinsic properties of enzyme products. The birds fed 100% SH had the highest values for most of the nutrient digestibility parameters except in crude protein and acid detergent fibre digestibility.

However, this did not translate to the best productive performance; the reason for this observation could be attributed to inherent bias in animal experimentation (Alade et al., 2019). The observation was not in agreement with the reports of Adebiyi et al. (2009) who reported that poultry birds on the control diet had the highest apparent nutrient digestibility values when broiler chickens were fed different physically treated cowpea seed hulls. The result reported agreed with the reports of Fafiolu et al. (2015), who observed that palm kernel extraction residue (PKER) had a significantly higher apparent digestibility, digestive dry matter, crude protein, ether extract, ash, nitrogen-free extract and metabolizable energy in Marshal broiler chickens.

The dietary treatments influenced the ileal digesta viscosity of the broiler chickens. This was contrary to the reports of Alzawqari et al. (2010) who reported that the supplementation of glycine and desiccated ox bile to broiler chicken diet had no significant effect on ileal digesta viscosity. Moreover, the replacement of wheat offal with the SHZ in the diets of broiler chickens resulted in the highest values of viscosity of ileal digesta. The highest value recorded in 50% SHZ was within the values (2.50-140.00cps) reported by Józefiak et al. (2007), who observed that xylanase supplementation reduced ileal viscosity significantly only in broiler chickens fed with rye.

The dietary treatments influenced the economy of feed conversion of broiler chickens except in the cost of the feed/kg and price/kg live weight. The broiler chickens fed soybean hulls based diets had the highest values of gross profit, rate of return on investment, economic efficiency and relative cost-benefit which may be due to the final body weight of the broiler chickens and the ruling market price at the time of the study (Ewa et al., 2006). The observation was contrary to the summation of Esonu et al., (2006), who reported a negative percentage of feed cost savings when soybean hull meal was supplemented with exogenous cellulolytic enzyme for broiler finishing birds.

Conclusion

The replacement of wheat offal with untreated and treated soybean hulls improved the protein efficiency ratio thereby promoting the growth response of the broiler chickens. The apparent nutrient digestibility of the broiler chickens was improved by the replacement of wheat offal with 100% untreated and treated soybean hulls. 50% and 100% SH reduced the ileal digesta viscosity of the broiler chickens. The replacement of wheat offal with soybean hulls based diets promoted the highest rate of return on investment.

Therefore, 100% *Zymomonas mobilis* treated soybean hulls can be used to replace wheat offal in broiler chickens' diets without compromising the growth response of the birds.

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Conflict of Interest

There are no conflicts of interest in this research paper.

Statement of Animal Rights

All applicable international, national, and/or institutional guidelines for the care and use of animals were followed in the present study.

Code Availability

Not applicable

CRediT authorship contribution statement

Adelaja Alade, Adeyemi Bamgbose, Abimbola Oso, Babatunde Adewumi: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Supervision, Writing -original draft, Review and editing. **Adeboye Fafiolu, Oyegunle Oke, Babatunde Adewumi, Oluseyi Oluwatosin, Folorunso Obadina:** Funding acquisition, Project administration, Resources, Software, Validation and Visualization and Writing – review and editing.

Declaration of competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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