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https://dx.doi.org/10.4314/afsjg.v16i1.4

The Effects of Life-Enzyme (*Zymomonas mobilis*) Treated Sawdust on Growth Performance, Apparent Nutrient Digestibility and Ileal Digesta Viscosity and Economics of Broiler Chickens

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Received: 8 June 2020 Accepted: 21 April 2023

Abstract
A 56-day study investigated the effects of *Zymomonas mobilis* treated sawdust on growth and economics of broiler chickens. Three hundred and seventy-five (375) day old unsexed marshal broiler chicks were allotted to five dietary treatments with 75 broiler chicks per treatment in a completely randomised designed experiment. Diets were formulated to include untreated sawdust (SD) and *Zymomonas mobilis* treated sawdust (ZSD) at 0, 50% and 100%. At the finishing phase (5-8 weeks), dietary treatments with 50% ZSD had higher daily weight gain and protein efficiency ratio (PER) and the lowest feed conversion ratio (FCR). Overall growth response (0 - 8 weeks) showed similar values for FCR and PER. There was improved crude fibre digestibility; however, there was no influence on crude protein, ether extract and ash digestibility at the finishing phase (5-8 weeks). Dietary inclusion of SD and ZSD decreased the values of the ileal digesta viscosity and economic efficiency. Therefore, 50% SD and 100% ZSD could be incorporated in broiler chickens' diets without compromising the growth response.

Keywords: Apparent nutrient digestibility; Broiler chickens; Economic analysis; Growth response; Ileal digesta viscosity; Sawdust

Les Effets de la Sciure De Bois Traitée à L'enzyme de Vie (*Zymomonas Mobilis*) sur la Performance de Croissance, la Digestibilité Apparente des Nutriments, la Viscosité du Digesta Iléal et L'analyse Coût-Bénéfice Chez les Poulets de Chair

Résumé
Une étude de 56 jours a examiné les effets de la sciure de bois traitée au Zymomonas *mobilis* sur la croissance et l'analyse coût-bénéfice des poulets de chair. Trois cent soixante-quinze (375) poulets de chair marshal non sexés, âgés d'un jour, ont été répartis en cinq traitements

alimentaires, avec 75 poulets de chair par traitement, dans le cadre d'une expérience complètement randomisée. Les régimes alimentaires ont été formulés de manière à inclure de la sciure de bois non traitée (SD) et de la sciure de bois traitée au *Zymomonas mobilis* (ZSD) à 0, 50 et 100 %. Lors de la phase de finition (5-8 semaines), les traitements alimentaires avec 50% de ZSD ont eu un gain de poids quotidien et un ratio d'efficacité protéique (PER) plus élevés et le ratio de conversion alimentaire (FCR) le plus bas. La réponse globale à la croissance (0 - 8 semaines) a montré des valeurs similaires pour le FCR et le PER. La digestibilité des fibres brutes a été améliorée, mais il n'y a pas eu d'influence sur la digestibilité des protéines brutes, des extraits d'éther et des cendres lors de la phase de finition (5-8 semaines). L'inclusion alimentaire de SD et de ZSD a diminué les valeurs de la viscosité du digesta iléal et de l'efficacité économique. Par conséquent, 50 % de SD et 100 % de ZSD peuvent être incorporés dans l'alimentation des poulets de chair sans compromettre la réponse à la croissance.

Mots Clés: Digestibilité apparente des nutriments; Poulets de chair; Analyse coût-bénéfice Réponse à la croissance; Viscosité du digesta iléal; Sciure.

Introduction

In the past, agro-industrial by-products such as brewers spent grains, wheat and maize offals, and molasses were either being burnt or improperly disposed on land or in water bodies, which resulted in environmental pollution (Onyeonagu & Njoku, 2010). It is necessary to alleviate the negative impact of indiscriminate disposal of these organic materials in the environment by diverting them for livestock feeding, bio-fertilizer production, bioenergy generation, etc. (Kivaisi *et al*., 2010).

Sawdust, produced in very large quantities in most developing nations, is a by-product of sawmilling industries due to ever rising demand for building materials and furniture (El-Ladan & Olofin, 2013). A general attribute of this and other wastes is the large quantity generated and the high costs of effective disposal, especially if long hauls are undertaken (El-Ladan & Olofin, 2013). Studies in the management of sawdust as waste are not new worldwide. However, most of these studies have focused on utilising the waste as a soil amendment material, with promising results. Ibrahim (2003) attempted a study to explore the potential of sawdust as a livestock feed and reported encouraging results.

However, there is scarce information concerning the utilisation of sawdust by chickens (Oke & Oke, 2007); these authors suggested biological and chemical treatment of sawdust to improve its digestibility by broiler chickens. *Zymomonas mobilis* has a hetero-fermentative ability to produce gas from glucose, fructose and sucrose and a shorter fermentation time (300 – 400%) than yeast, is non-toxic, locally available and its ability to be genetically and mutational altered (Jeon *et al*., 2005). Utilising degraded fibrous feedstuffs for farm animals will reduce production costs, encourage the production of cheap animal protein for man, increase foreign reserve and greatly reduce environmental hazards/pollution (Anigbogu & Onyejekwe, 2010).

Alade *et al*. (2020) reported that *Zymomonas mobilis* treated sawdust contained 7.13% crude protein, 50.51% crude fibre, 5.00% ether extract, 20.87% nitrogen-free extract and 1410.20 Kcal/Kg metabolisable energy. Little information is available in the literature on the effects of feeding *Zymomonas mobilis* fermented sawdust-based diets. Hence, this study investigated the effects of untreated sawdust and *Zymomonas mobilis* treated sawdust on growth performance, apparent nutrient digestibility and ileal digesta viscosity of broiler chickens. A comparative economic analysis was also conducted on the formulated feeds.

Materials and Methods

The study was conducted at the Poultry Unit, Directorate of University Farms (DUFARMS), and Animal Nutrition Laboratory, Federal University of Agriculture, Abeokuta, Ogun State, Nigeria, 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 °C (Climate-data.org Nigeria Ogun, 2020).

The assorted sawdust was collected at the Lafenwa Sawmill, Lafenwa, Abeokuta, Nigeria. Pure strains of *Zymomonas mobilis* extracted from fresh palm wine was used to inoculate the sawdust (SD). It was prepared in the traditional setting under laboratory condition as stated by Anigbogu *et al*. (2009). Assorted sawdust (substrate) of 500g weight, 100 ml of *Zymomonas mobilis* suspension and 2 litres of water were poured into the fermentation vat (3.5 litres) and stirred with a plastic rod to obtain a homogeneous mixture at a room temperature (23.1 °C to 24.6 °C) for 20 days. It was turned on 24-hourly basis to produce starter inoculum.

The life enzyme was prepared as in Anigbogu *et al*. (2009) using 25 kg assorted sawdust placed in the fermentation vat (capacity = 100 litres) with 50 litres of water added to 2.5 kg fermented dough (starter inoculum). The sample was homogeneously mixed and kept to ferment for 20 days. The fermented product was sun-dried, analysed and stored as life-enzyme sawdust.

Management of broiler chickens and experimental diets

Three hundred and seventy-five (375) day-old unsexed marshal broiler chicks were obtained from Obasanjo Farms Nigeria Limited, Lanlate, Nigeria. They were weighed and randomly allotted to five dietary treatments with 75 broiler chicks per treatment. They were replicated five times with 15 birds each. The chicks were brooded for two weeks, routine vaccinations and necessary medications were administered. Feed and water were given *ad libitum*. The birds were raised for eight weeks (0 – 4 weeks for the starter phase and 5-8 weeks for the finisher phase). The diets were formulated to include untreated sawdust and *Zymomonas mobilis* treated sawdust at 0, 50 and 100% to replace wheat offal weight for weight. The composition of the experimental broiler chicken diets is shown in Table 1.

Data collection

Chemical analysis

The materials (untreated and treated SD) used in Alade et al. (2020) are the same materials used in the present study. Therefore, the methods of analyses and the proximate composition of the untreated and treated SD (Table 2) were described in Alade et al. (2020).

Performance Characteristics

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

Metabolic Trial

The metabolic trial was carried out on the 4 and 8 weeks of the experiments. Ten

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

Ingredients	%	Starter 50% SD	Diets 100% SD	50% ZSD	100% ZSD	%	Finisher 50% SD	Diets 100% SD	50% ZSD	100% ZSD
Rmaize	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
Sawdust	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	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**
Metabolisable energy (MJ/Kg)	12.00	11.88	11.76	11.95	11.91	11.92	11.68	11.44	11.83	11.74
Determined analysis:										
Crude protein (%)	22.55	21.58	21.71	23.05	22.79	21.43	20.11	20.75	20.09	20.35
Crude Fibre (%)	4.81	5.24	6.16	5.85	5.89	5.34	6.69	7.54	5.91	6.49
Ether Extract (%)	4.17	4.13	4.09	4.18	4.20	4.67	4.35	4.02	4.21	4.74
Ash (%)	3.15	3.26	3.37	3.16	3.20	2.26	3.29	3.50	3.13	3.18
Nitrogen Free Extract (%)	52.59	53.03	51.82	50.98	51.14	52.64	51.88	51.42	51.97	51.54
Calcium (%)	1.22	1.24	1.30	1.25	1.21	1.16	1.19	1.21	1.17	1.15
Phosphorus (%)	0.51	0.52	0.55	0.53	0.57	0.50	0.49	0.56	0.52	0.55

[a]Starter Vitamin-Mineral Premix: Rotinol based on 2.5 kgton^{-1}; Thiamine, 2000 mg; Riboflavin, 7000 mg; Pyridoxine, 5000 mg; cyanocobalamin, 1700 mg; Niacin, 30,000 mg; D-Pantothenate, 10,000 mg; Folic acid, 800 mg; D-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-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;Methionine Hydroxyl Analog (MHA): (Novus International Inc. St. Charles, MO), feed supplement providing 84% Methionine activity

experimental birds per treatment (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 for each experiment. A 3-day acclimatisation period was allowed before a 3-day metabolic trial commenced. The weight of feed given to each bird was recorded. The total droppings voided from the birds was collected in a labelled aluminium foil daily. The fresh weight was recorded and later oven dried at 65 °C to constant weight. The dried droppings from the same replicate were pooled and ground. The dried, pooled, and ground samples were analysed for crude protein, crude fibre, ether extract and ash according to standard procedures of AOAC (2015).

Measurement of Ileal digesta viscosity

Ileal digesta viscosity was determined by Stowarld method, as described by Habibi (1999). At the end of the experiment (8 weeks), a total of 50 broiler chickens (10 birds per treatment) were slaughtered by decapitation, and the ileal digesta viscosity was determined using a viscometer. Each bird's abdomen was opened immediately after death, exposing the intestinal content. The ileal digesta content was collected from the Merekel's diverticulum to the ileo-caecal junction. The ileal digesta for each replicate was emptied into a sample bottle and properly labelled. A uniform weight of sample was taken from each sample bottle using a sensitive scale and s diluted to 50 ml. The ileal digesta contents for each replicate were placed in a centrifuge tube and centrifuged at 6,000 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 cylinder.

Economic Analysis

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

Experimental design and Statistical analysis

The treatments were arranged in a completely randomised designed (CRD) experiment. Data collected were subjected to one-way analysis of variance (ANOVA) as outlined by Daniel (1995) with the aid of SAS (SAS Institute, 2001). The Duncan's multiple range test was used to separate means at 5% level of significance (Steel & Torrie, 1980).

Results

The results of proximate composition of untreated and treated SD were reported by Alade *et al*. (2020) (Table 2).

The broiler chickens fed 50% SD had the highest average weight gain, daily weight gain and protein efficiency ratio and the lowest ($p<0.05$) feed conversion ratio. The highest value of average and daily feed intake was observed in birds fed 50% ZSD while the lowest value was recorded for birds fed 100% ZSD and the control (Table 3). Percentage mortality was highest in 50% SD treatment. In contrast, no mortality was recorded in the control and 50% ZSD during the starter phase (Table 3).

Broiler finishers fed 50% ZSD had the highest ($p<0.05$) final body weight, average weight gain and daily weight gain. However, differences in average and daily feed intake among 50% SD, 50% ZSD and 100% ZSD were similar. The birds on the control diet had the least values of average feed and daily feed intake. The lowest ($p<0.05$) protein efficiency ratio was recorded for birds fed on 50% SD (Table 4).

There were significant ($p<0.05$) differences in mortality across the dietary treatments, with the highest value recorded in 50% SD. The dietary treatments significantly increased ($p<0.05$) the final body weight, daily weight gain, daily feed intake and mortality of the finishing broiler chickens (Table 5). In contrast, the dietary treatments did not significantly influence their feed conversion and protein efficiency ratios (Table 5).

The dietary inclusion of 100% SD, 50% and 100% *Zymomonas mobilis* treated sawdust based diets significantly ($p<0.05$) increased the crude fibre digestibility more than the control. However, there was no significant difference in crude fibre digestibility among 50% SD, 50% ZSD and 100% ZSD. The 100% ZSD treatment recorded the lowest values for all the other parameters (Table 6).

The apparent nutrient digestibility of finishing broiler chickens fed sawdust based diets is shown in Table 7. Except for 100% SD, the crude fibre digestibility was significantly lower in the finishing broiler chickens fed on a 50% ZSD treated diet. The crude fibre digestibility was comparable among 50% SD, 100% SD and 100% ZSD (Table 7).

The viscosity of ileal digesta was significantly higher ($p<0.05$) for birds on a control diet than 00% SD, 50% ZSD and 100% ZSD. Differences among 50% SD, 50% ZSD and 100% ZSD were not significant (Table 8).

The cost of feed per kilogram remained constant at $0.50 across all dietary treatments and the price per kilogram of live weight was consistent at $2.14 for all treatments. The cost of production per broiler ranged from $3.25 for the control to $3.40 for the 50% ZSD. The gross revenue per broiler ranged from $3.90 for 100% ZSD to $4.19 for 50% ZSD with gross profit ranging from $0.60 for 100 ZSD to $0.79 for 50% ZSD. The rate of return on investment and economic efficiency were significantly lower in 100% ZSD. The birds fed control diet, 50% SD, 100% SD and 50% ZSD had a similar ($p>0.05$) rate of return on investment and economic efficiency (Table 9).

Discussion

The higher final body weight, average and daily weight gain in birds fed with 50% SD compared with 100% ZSD (Table 3) might be due to the milling and partial fermentation of the sawdust in the saw mill before collection and sun drying, which might have had positive effect on its intake (Oke & Oke, 2007). Including untreated and *Zymomonas mobilis* treated sawdust did not depress the final body weight, average weight gain and daily weight gain of the broiler chickens at the starter phase, probably due to the altering of endogenous losses by supplementary enzymes and other compounds, for example, tannins, due to the release of contents of the cells of dietary components by enzyme action (Acamovic, 2001). This observation agrees with the findings of Lawal *et al*. (2012), who also reported that body weights of broiler chickens fed degraded wheat offal improved at the starter phase. The result also agreed with the report of Yunusa *et al*. (2015), who reported significant differences in the daily weight gain and feed conversion ratio of chicks at the end of the starter phase. Generally, there was higher feed intake in the SD and *Zymomonas mobilis* treated SD than the control. This observation may be due to the energy levels of the diets, which other ingredients might have compensated for to meet the energy requirement of the broiler

Table 2: Results of proximate analysis on untreated and treated sawdust[*] (SD) (DM-basis)

Components (%)	Untreated SD	Treated SD	t-test (P-value)
Dry matter	89.51[a]	86.50[b]	21.69 (0.0001)
Moisture	10.49[b]	13.50[a]	-21.69 (0.0001)
Crude protein	2.14[b]	7.13[a]	-35.95 (0.0001)
Crude fibre	62.48[a]	51.50[b]	79.10 (0.0001)
Ether extract	0.60[b]	5.00[a]	-31.70 (0.0001)
Nitrogen free extract	15.82[b]	20.87[a]	-36.38 (0.0001)
Ash	8.47[a]	2.00[b]	46.61 (0.0001)
Neutral detergent fibre	89.31[a]	66.00[b]	167.93 (0.0001)
Acid detergent fibre	76.76[a]	48.00[b]	207.20 (0.0001)
Acid detergent lignin	40.51[a]	14.00[b]	191.00 (0.0001)
Calcium (g/Kg DM)	0.05	0.04	1.23 (0.2879)
Phosphorus (g/Kg DM)	0.85	0.83	0.144 (0.8924)
**Metabolisable energy (MJ/Kg)	2.90[b]	5.92[a]	-21.76 (0.0001)

[ab]Means on the same row having different superscripts are significantly different (P<0.05)
* = Average of three determinations
**Metabolisable energy values were calculated using the method
37x %CP + 81x % EE + 35.5 x % NFE for poultry birds (Fisher and Boorman, 1986)
Source: Alade *et al*. (2020)

Table 3: Performance characteristics of starting broiler chickens (0 – 4weeks) fed diets containing untreated and treated sawdust-basis)

Parameters	Dietary Treatment 1 Control Diet	2 50% SD	3 100% SD	4 50% ZSD	5 100% ZSD	SEM
Initial body weight (g/bird)	35.00	33.00	33.00	35.00	35.00	0.59
Final body weight (g/bird)	527.00[c]	666.00[a]	534.00[c]	553.00[b]	510.00[d]	14.96
Average weight gain (g/bird)	492.00[d]	633.00[a]	501.00[c]	518.00[b]	475.00[e]	15.07
Daily weight gain (g/bird)	17.57[b]	22.61[a]	17.89[b]	17.50[b]	16.96[b]	0.58
Average feed intake (g/bird)	1141.00[d]	1165.00[b]	1153.00[c]	1223.00[a]	1138.00[d]	8.30
Daily feed intake (g/bird)	42.26[d]	43.15[b]	42.70[c]	45.30[a]	42.15[d]	8.30
Feed conversion ratio	2.32[a]	1.84[b]	2.30[a]	2.36[a]	2.40[a]	0.06
Protein efficiency ratio	2.21[c]	2.81[a]	2.30[b]	2.13[d]	1.99[e]	0.08
Cost of feed/Kg ($/Kg)	0.43	0.43	0.42	0.43	0.42	0.04
Cost of feed/Kg weight gain ($/Kg)	1.00	0.79	0.96	1.01	1.02	0.04
Mortality (%)	0.00[c]	2.00[a]	0.67[b]	0.00[c]	0.67[b]	0.20

[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 USD = 462.00 NGN; 1 USD = 11.86 GHS

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

Parameters	Dietary Treatment 1 Control Diet	2 50% SD	3 100% SD	4 50% ZSD	5 100% ZSD	SEM
Initial body weight (g/bird)	527.00[c]	666.00[a]	534.00[c]	553.00[b]	510.00[d]	14.96
Final body weight (g/bird)	1869.00[c]	1915.00[b]	1858.00[d]	1954.00[a]	1822.00[e]	12.32
Average weight gain (g/bird)	1342.00[b]	1249.00[e]	1324.00[c]	1401.00[a]	1312.00[d]	13.11
Daily weight gain (g/bird)	47.93[b]	44.61[e]	47.29[c]	50.04[a]	46.86[d]	0.47
Average feed intake (g/bird)	3561.00[c]	3760.00[ab]	3729.00[b]	3880.00[a]	3833.00[ab]	32.45
Daily feed intake (g/bird)	127.18[d]	134.29[ab]	133.18[c]	138.57[a]	138.57[ab]	1.11
Feed conversion ratio	2.65	3.01	2.82	2.77	2.92	0.09
Protein efficiency ratio	1.91[a]	1.46[c]	1.69[b]	1.85[a]	1.81[a]	0.04
Cost of feed/Kg ($/Kg)	0.50	0.50	0.50	0.50	0.50	0.04
Cost of feed/Kg weight gain ($/Kg)	1.23	1.37	1.26	1.26	1.31	0.04
Mortality (%)	0.67[c]	3.33[a]	0.67[c]	2.67[ab]	2.00[b]	0.30

[abcd] Means on the same row having different superscripts are significantly different (P<0.05)
SEM: Standard Error of Mean n = 5; Exchange rate: 1 USD = 462.00 NGN; 1 USD = 11.86 GHS

Table 5: Overall Performance characteristics of finishing broiler chickens (0 – 8weeks) fed diets containing untreated and treated sawdust

Parameters	Dietary Treatment 1 Control Diet	2 50% SD	3 100% SD	4 50% ZSD	5 100% ZSD	SEM
Initial body weight (g/bird)	35.00	33.00	33.00	35.00	35.00	0.26
Final body weight (g/bird)	1869.00[c]	1915.00[b]	1858.00[d]	1954.00[a]	1822.00[e]	12.31
Average weight gain (g/bird)	1834.00[c]	1882.00[b]	1825.00[d]	1919.00[a]	1787.00[e]	12.32
Daily weight gain (g/bird)	32.75[c]	33.61[b]	32.59[d]	34.27[a]	31.91[e]	0.22
Average feed intake (g/bird)	4702.00[e]	4925.00[c]	4882.00[d]	5103.00[a]	4971.00[b]	34.85
Daily feed intake (g/bird)	83.96[e]	87.95[c]	87.18[d]	91.13[a]	88.77[b]	0.62
Feed conversion ratio	2.56	2.62	2.68	2.66	2.78	0.04
Protein efficiency ratio	1.73	1.74	1.75	1.70	1.65	0.04
Cost of feed/Kg ($/Kg)	0.93	0.93	0.92	0.93	0.92	0.04
Cost of feed/Kg weight gain ($/Kg)	2.23	2.16	2.22	2.27	2.33	0.04
Mortality (%)	0.67[d]	5.33[a]	1.34[c]	2.67[b]	2.67[b]	0.43

[abcde] Means on the same row having different superscripts are significantly different (P<0.05)
SEM: Standard Error of Mean n = 5
Exchange rate: $1.00 = #462.00; 1 USD = 11.86 GHSD

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

Parameters	Dietary Treatment 1 Control Diet	2 50% SD	3 100% SD	4 50% ZSD	5 100% ZSD	SEM
Dry matter digestibility	77.64^a	72.59^c	77.50^a	75.71^b	66.27^d	1.14
Crude protein digestibility	74.78^a	72.76^b	75.29^a	74.63^a	70.45^c	0.48
Crude fibre digestibility	59.17^c	66.28^b	77.50^a	66.86^b	66.27^b	1.57
Acid detergent fibre digestibility	72.11^a	68.42^b	72.53^a	71.90^a	62.47^c	1.02
Neutral detergent fibre digestibility	68.82^a	64.01^c	68.97^a	67.57^b	57.27^d	1.18
Acid detergent lignin digestibility	71.48^d	72.43^c	76.17^a	74.46^b	69.18^e	0.65
Ether extract digestibility	73.91^a	70.43^d	71.24^c	72.85^b	66.57^e	0.68
Ash digestibility	73.72^a	71.09^c	73.61^a	72.62^b	67.30^d	0.64
Nitrogen free extract digestibility	73.36^a	70.25^c	73.68^a	72.34^b	63.69^d	0.99
Calcium digestibility	81.21^b	77.63^c	70.68^d	86.06^a	64.46^e	2.05
Phosphorus digestibility	83.97^a	80.91^b	81.75^b	83.71^a	77.48c	0.65
Apparent metabolisable energy digestibility	78.10^a	72.66^c	76.20^b	76.04^b	69.57^d	0.81

^{abcde} 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 – 8weeks) fed diets containing untreated and treated sawdust – 4weeks) fed diets containing untreated and treated sawdust

Parameters	Dietary Treatment 1 Control Diet	2 50% SD	3 100% SD	4 50% ZSD	5 100% ZSD	SEM
Dry matter digestibility	74.41^a	76.00^a	72.59^{ab}	68.89^b	75.46^a	0.88
Crude protein digestibility	77.93	78.29	77.55	76.28	78.49	0.59
Crude fibre digestibility	75.94^a	76.00^a	74.24^{ab}	70.12^b	75.00^a	0.80
Acid detergent fibre digestibility	75.98^{ab}	76.86^a	74.50^{ab}	71.67^b	77.02^a	0.76
Neutral detergent fibre digestibility	75.13^{ab}	76.68^a	73.62^{ab}	70.85^b	75.49^{ab}	0.77
Acid detergent lignin digestibility	67.15^b	74.50^a	70.37^{ab}	59.63^c	69.54^b	1.42
Ether extract digestibility	77.41	78.00	76.44	73.72	77.92	0.69
Ash digestibility	76.40	77.94	76.83	75.80	77.42	0.58
Nitrogen free extract digestibility	75.95	77.27	75.16	73.13	76.56	0.67
Calcium digestibility	85.71^b	85.28^b	84.83^b	78.53^c	88.29^a	0.88
Phosphorus digestibility	87.11^a	86.53^{ab}	85.45^b	82.85^c	87.09^a	0.46
Apparent metabolisable energy digestibility	75.50^a	76.64^a	73.94^{ab}	69.78^b	76.42^a	0.86

^{abc} 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 untreated and treated sawdust

Parameters	Dietary Treatment 1 Control Diet	 2 50% SD	 3 100% SD	 4 50% ZSD	 5 100% ZSD	SEM
100 rpm	1.49[a]	1.24[b]	1.15[c]	1.13[c]	1.14[c]	0.04

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

Table 9: Cost benefit analysis of broiler chickens fed diets containing untreated and treated sawdustsawdust

Parameters	1 Control Diet	2 50% SD	Dietary Treatment 3 100% SD	4 50% ZSD	5 100% ZSD	SEM
Cost of the feed/Kg ($/Kg)	0.50	0.50	0.50	0.50	0.50	0.04
Price/Kg live weight ($)	2.14	2.14	2.14	2.14	2.14	0.04
Cost of production/broiler ($/broiler)	3.25	3.31	3.26	3.40	3.30	0.04
Gross revenue/broiler ($/broiler)	4.01	4.10	3.98	4.19	3.90	0.04
Gross profit ($)	0.76	0.78	0.72	0.79	0.60	0.04
Rate of return on Investment (%)	23.28[a]	23.66[a]	22.09[a]	23.30[a]	18.23[b]	0.61
Economic efficiency	0.35[a]	0.35[a]	0.33[a]	0.34[a]	0.27[b]	0.01
Relative cost benefit (%)	0.00[d]	11.29[a]	2.09[c]	2.54[c]	6.24[b]	1.08

[abc] Means on the same row having different superscripts are significantly different (P<0.05)
SEM: Standard Error of Mean
Exchange rate: 1 USD = 462.00 NGN; 1 USD = 11.86 GHS

chickens as the diets were formulated to be isocaloric and isonitrogenous. The highest mortality obtained in the starting (Table 3) and finishing (Table 4) broiler chickens and the overall performance (Table 5) of the finishing broiler chickens fed with 50% SD could be due to other factors which we are unable to explain. The high mortality may not be linked with the sawdust-based diets as it occurred in all the dietary treatments, suggesting that a high amount of sawdust in the feed formulations does not appear to have any significant deleterious effect on the survival of the birds (Oke & Oke, 2007). The 2% mortality of the starting broiler chickens recorded in 50% SD (Table 3) was below the benchmark standard of 5% in broiler chicken production (ACP, 2006), probably due to good management practices employed in this study.

The higher final body weight, average weight gain and daily weight gain in the broiler chickens fed 50% ZSD might be due to the combination of wheat offal and *Zymomonas mobilis* treated sawdust, which might have resulted in weight gain in the broiler chickens, probably due to release of nutrients into the diet. Thus, the significant growth in the broiler chickens fed with 50% ZSD in our study might have also been caused by the release of certain phenolic compounds of lignin with antibiotic-like properties and unidentified growth promoters contributed by the sawdust (Oke & Oke, 2007). In addition, the broiler chickens on the 50% ZSD had higher average and daily feed intake, similar to those recorded in 50% SD and 100% ZSD. The moderately higher fibre contents of these diets might be responsible for high feed intake as the fibre levels increased across the dietary treatments. The increased feed intake might also be due to the increased passage rate of the more fibrous digesta in the small intestine.

At the starter phase (Table 6), apparent metabolisable energy digestibility and ether extract digestibility were higher in birds fed with the control diet, suggesting that the energy is more efficiently utilised by the birds. At the starting phase (Table 6), crude fibre digestibility and acid detergent lignin digestibility were higher in birds fed 100% SD, probably due to higher percentage of untreated sawdust, which had no deleterious effect on the birds. Dry matter, crude protein digestibility, acid detergent fibre digestibility, neutral detergent fibre digestibility, ash digestibility and nitrogen free extract digestibility did not differ in birds fed with control and 100% SD diets -the highest values were obtained in control and 100% SD treatment groups than the other treatment groups. In contrast, the protein efficiency ratio and average weight gain were lower in birds fed control than 100% SD diet, suggesting that birds in the control group utilised the protein for feather development rather than meat production.

The sawdust based diets influenced the viscosity of ileal digesta of broiler chickens. This result was contrary to the findings of Omidiwura & Agboola (2016) who did not observe differences in the digesta viscosities of different sections of the gastrointestinal tract (GIT) except for the duodenum. The inclusion of treated sawdust to replace wheat offal in the broiler chicken diets reduced the ileal digesta viscosity at 100 rpm. This observation agreed with the findings of Gunal *et al*. (2004), who reported that the supplementation of low or high viscous wheat-based diets with the enzyme preparations of amylase or xylanase activity led to reduction in ileal digesta viscosity. Also, Yasar & Forbes (2000) reported that enzyme supplementation of wheat-based diets markedly reduced digesta viscosity in broiler chickens. The birds in the control group had higher ileal digesta viscosity than those in other diets, probably due to the reduced feed passage rate throughout the GIT. Increased digesta viscosity may be involved in the slowdown of the passage rate of digesta within the gut (Yasar, 2003), although we did not determine the passage rate in this study. Van Der Klis *et al*. (1993) and Almirall *et al*. (1995) reported that increased digesta viscosity induced by viscous gel-forming dietary compounds reduced the rate of digestion and passage of digesta throughout the gut and may depress feed intake similar to the control diet.

The dietary treatments influenced the economic analysis of broiler chickens except in the cost of the feed/kg and price/kg live weight. The relative advantage or disadvantage of using any diet can be determined by the price of the feedstuffs at the time of use and the current prices of live and dressed chickens in such environment (Ojewola, 1993). The rate of return on investment and economic efficiency were significantly lower in 100% ZSD than other treatment groups suggesting that the high average feed intake did not result in higher final body weight. The decrease in the final body weight in birds fed with 100% ZSD, in addition to the cost of the feed, might have resulted in the reduction in the rate of investment and economic efficiency. Zakaria *et al*. (2008) also observed reductions in gross margins and cost-benefit ratio when BergazymP and Hemicell-D enzymes were added to broiler chicken diets compared to the control diet due to reductions in final body weight. Unconventional feedstuffs are cheap and locally available, treating them with *Zymomonas mobilis* before incorporation into broiler chicken diets might be necessary for maximum productivity.

Conclusion

The 50% untreated sawdust (SD) improved feed conversion and protein efficiency ratios at the starting phase while 50% and 100% ZSD promoted better protein efficiency ratio at the finishing phase. Replacing wheat offal by 50% and 100% ZSD improved the apparent nutrient digestibility in finishing broilers. The dietary inclusion of 100% SD, 50% and 100% ZSD reduced the viscosity of the ileal digesta of the broiler chickens. Replacing wheat offal with SD and 50% ZSD increased the gross profit and rate of return on investment. Therefore, 50% SD and 100% ZSD can be incorporated in the diets of broiler chickens without compromising the growth response.

Acknowledgements

World Bank Africa Centre of Excellence in Agricultural Development and Sustainable Environment, Federal University of Agriculture, Abeokuta, Nigeria, for research support.

Professor Anigbogu, N. M., Michael Okpara University of Agriculture, Umudike, Nigeria for the provision of *Zymomonas mobilis* suspension and technical assistance.

Mrs. Alade, Felicia Omolara, ASUU-UNAAB Cooperative Multipurpose Society Limited for financial support.

Mr. Obadina, James Folorunso, Government Science and Technical College, Abeokuta, Nigeria, for technical assistance.

Compliance with ethical standards

Conflict of interest

There was no conflict of interest.

Statement of animal rights

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

Authors' contributions

AAA & AMB were the lead investigators and the initiators of the study. They were involved in literature search. WAO, SAO & AAO were responsible for the study design, data collection and preparing the manuscript. AAA, AMB, AOO were responsible for overall study design, write up and provided critical feedback on the manuscript. AAA, MOF & AOO did the data entry, analysis and discussion. All the authors read and approved the final manuscript.

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