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GROWTH RESPONSE OF RABBITS TO RUMEN LIQUOR–FERMENTED SUGAR BY-PRODUCT MEAL DIETS WITH MULTIGRAIN ENZYME SUPPLEMENTATION

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ABSTRACT
The global demand for animal protein necessitates the exploration of sustainable feed alternatives in livestock production. Rabbit farming is considered a promising avenue due to the high reproductive rate and their ability to thrive on diverse feedstuffs. This study investigated effect of rumen-liquor fermented solid waste product of sugar industry (FSWAPSI) supplemented with enzyme on the performance of rabbits. The experiment used 72 weaner rabbits assigned to a 3x2 factorial arrangement fitted into Completely Randomized Design and replicated four times with 3 rabbits each. Six diets were formulated to be isonitrogenous and iso-caloric, supplementing FSWAPSI at 20, 30, and 40 % for weaners and 40, 50 and 60 % for growers, with enzyme supplementation at 0 and 200 ppm. Rumen liquor was used to inoculate SWAPSI and fermented before sun-drying. In the grower phase the result shows that higher level of the test ingredient was tolerated, 20 % FSWAPSI inclusion group showed a significant ($P<0.05$) increase in final weight (1426.70 g). Enzyme supplementation at 200 ppm significantly ($P<0.05$) depressed final weight (1240.60 g) as compared to the 0 ppm group (1398.90 g). There was significant ($P<0.05$) increase in average feed intake (52.61 g) and protein intake (9.5g) due to interactive effects of FSWAPSI and enzyme supplementation in the weaner phase. Conclusively, FSWAPSI can be safely incorporated up to 40 % for weaner rabbits and up to 60 % for grower rabbits. However, enzyme supplementation at 200 ppm proved unnecessary for grower rabbits as the fermentation itself effectively enhanced nutrient utilization.

Keywords: Rabbit, rumen-liquor, fermentation, sugar industry waste, enzyme supplementation, growth performance

INTRODUCTION

The escalating global demand for animal protein necessitates the exploration of sustainable and cost-effective feed alternatives in livestock production (FAO, 2020). Rabbit farming, in particular, offers a promising avenue due to the high reproductive rate, rapid growth, and efficient feed conversion of rabbits, alongside their ability to thrive on diverse feedstuffs (Lukefahr & Cheeke, 1991, Anyaegbu *et al.*, 2020). However, the economic viability of rabbit production is often challenged by the fluctuating costs and limited availability of conventional feed ingredients (Tewolde & Ebro, 2017). This underscores the critical need for identifying and evaluating novel feed resources that are both nutritionally adequate and economically sustainable.

One such potential resource is solid waste products from the sugar industry (SWAPSI). These by-products, including bagasse, molasses, and filter cake, are often discarded; leading to environmental pollution, but possess significant nutritional value that could be harnessed for animal feeding (Onyeonagu & Ugwu, 2012). While rich in fermentable carbohydrates, the direct inclusion of raw SWAPSI in animal diets may be limited by factors such as high fiber content and the presence of anti-nutritional factors (McDonald *et al.*, 2011). Fermentation, particularly with rumen liquor, has been demonstrated as an effective strategy to improve the nutritional quality of fibrous agricultural by-products by breaking down complex carbohydrates and reducing anti-nutritional compounds, thereby enhancing nutrient availability and digestibility (Kumar *et al.*, 2012). Furthermore, enzyme supplementation, such as cellulases and xylanases, can complement fermentation by further degrading indigestible fiber components, thereby improving nutrient utilization and overall animal performance (Adeola & Cowieson, 2011; Anyaegbu *et al.*, 2020).

Previous studies have explored the utilization of various agro-industrial by-products in rabbit diets, with varying degrees of success (Dairo *et al.*, 2005; Lebas, 1983). However, there is a paucity of comprehensive research specifically investigating the combined effects of rumen-liquor fermented sugar industry waste and enzyme supplementation on the growth performance of both weaner and grower rabbits (Olaruntola *et al.*, 2020).

Given the imperative to develop sustainable and cost-effective animal feed strategies, coupled with the underutilized potential of sugar industry waste products, this study aims to evaluate the efficacy of rumen-liquor fermented SWAPSI, with and without enzyme supplementation, on key growth performance parameters, including initial and final weights, weight gain, feed intake, protein intake, and feed conversion ratio among others in weaner and grower rabbits.

The findings from this research will contribute to a better understanding of optimal dietary formulations for rabbits using unconventional feed resources, potentially leading to improved economic returns for rabbit farmers and reduced environmental burden from industrial waste. This research is vital for advancing sustainable animal agriculture practices in regions where sugar industry by-products are readily available (Alu *et al.*, 2024).

MATERIALS AND METHODS

Experimental Site

The experiment was conducted at the Livestock Complex of the Department of Animal Science, Faculty of Agriculture, Shabu-Lafia Campus, Nasarawa State University, Keffi. The farm is located in the Southern Guinea Savannah Zone, in the middle belt of Nigeria, at coordinates Latitude 8°35'N and Longitude 8°33'E. The area experiences an average minimum temperature of 23°C and a maximum temperature of 36.9°C. The average monthly relative humidity was 74% (NiMeT, 2024). The annual average rain falls measured in 821 mm during the experimental period was recorded. Temperature, humidity, and precipitation data were sourced from the weather station of the Faculty of Agriculture, Shabu Lafia Campus, Nasarawa State University, Keffi, Nigeria.

Sources of Experimental Feeds Ingredients

Solid waste product of sugar industry (SWAPSI) was sourced from Dangote sugar processing industry in Numan LGA of Adamawa State and was sorted for fermentation. Other ingredients such as bone meal, fish meal, lysine, methionine, salt and premix were purchased from GLOBAL feed Ltd. Mararaba, Nasarawa State of Nigeria. Whole maize, maize offal, rice offal and ground nut cake were sourced from Lafia metropolitan city.

Sources of Experimental Animal

Seven-two weaner rabbits were purchased from National Animal Production Research Institute (NAPRI), Shika, ABU, Zaria, Nigeria. The rabbits were given 7-day acclimatizationperiod before commencing the feeding trial. About 0.1 ml of ivermectin was given subcutaneously per rabbit against ecto and endo parasites. Vitacoccs was also used as prophylactic treatment against coccidiosis while Oxytrox L.A was provided at 0.2 ml subcutaneously also for prophylactic treatment. Light was provided at night using electric bulb throughout the period of the experiment. Weighed amount of experimental diet and water were provided *ad-libitum* and other routine management practices were adapted as outlined by Alu *et al*. (2009).

Rumen Liquor

The bovine rumen fluid was collected by squeezing and sieving the rumen contents generated from slaughtering of cattle at Lafia Municipal abattoir. The rumen liquor was mixed, homogenized and filtered through 100 mm meshnet. The solid materials were discarded while the fluid (liquor) part of the content was transferred into insulated flasks and stored until use. The stored rumen liquor was them used as the source of inoculums.

Inoculation of SWAPSI with Rumen Liquor

The stored rumen liquor was used to inoculate the SWAPSI by spraying 6 L of rumen liquor per 30 kg of SWAPSI on weight bases. The sprayed SWAPSI was thoroughly mixed and transferred into an airtight plastic container to initiate the fermentation process that lasted for 72 hours. The fermented samples were sundried, hammer-milled and analyzed for nutrient and anti-nutrient composition according to the methods outlined by AOAC (2006).

Experimental Diets

The experimental diets were formulated to be iso-nitrogenous (18 and 15% crude protein) and isocaloric (2700 and 2500 kcal/kg) where the test ingredients (Fermented SWAPSI meal) were added at 20, 30, and 40% for weaner rabbits and 40, 50 and 60% for grower rabbits. The treatment diets had two levels of enzyme supplementations at 0 and 200 ppm for both phases. The six (6) experiment diets were tagged T1, T2, T3, T4, T5 and T6 respectively. T1 and T2 contained 20 percent fermented FSWAPSI meal with 0 and 200 ppm, T3 and T4 contained 30% fermented SWAPSI meal with 0 and 200 ppm while T5 and T6 contained 40% FSWAPSI meal with 0 and 200 ppm, respectively. The same arrangement was done for grower diets with little adjustment in the percentage inclusion of FSWASPI meal at 40, 50 and 60% (Tables 1 and 2).

Table 1: Percent ingredients composition of experiment diets for weaner rabbits

Ingredients	T1 20% FSWAPSI +0 ppm	T2 20% SWAPSI +200 ppm	T3 30% SWAPSI +0 ppm	T4 30% SWAPSI +200 ppm	T5 40% SWAPSI +0 ppm	T6 40% SWAPSI +200 ppm
Maize	29.00	29.00	29.63	29.63	29.70	29.70
FSWAPSI	**20.00**	**20.00**	**30.00**	**30.00**	**40.00**	**40.00**
Maize bran	19.00	19.00	12.00	12.00	1.70	1.70
Groundnut cake	24.50	24.50	25.00	25.00	26.60	26.60
Rice offal	3.63	3.63	0.00	0.00	0.00	0.00
Bone meal	1.00	1.00	1.00	1.00	0.20	0.20
Blood meal	1.00	1.00	1.00	1.00	0.50	0.50
Lysine	0.20	0.20	0.20	0.20	0.20	0.20
Methionine	0.20	0.20	0.20	0.20	0.20	0.20
Premix	0.25	0.25	0.25	0.25	0.20	0.20
Salt	0.22	0.22	0.22	0.22	0.20	0.20
Palm oil	1.00	1.00	0.50	0.50	0.50	0.50
Total	**100**	**100**	**100**	**100**	**100**	**100**
Enzyme (ppm)	**+0**	**+200**	**+0**	**+200**	**+0**	**+200**
	Calculated Nutrients Composition					
Energy	2707.72	2707.72	2707.90	2707.90	2708.76	2708.76
Protein	18.29	18.29	18.24	18.24	18.07	18.07
Crude fibre	8.06	8.06	9.35	9.35	10.43	10.43
Ether Extract	6.05	6.05	5.87	5.87	6.40	6.40
Ash	3.44	3.44	3.14	3.14	3.54	3.54
Calcium	0.64	0.64	0.68	0.68	0.47	0.47
Phosphorus	1.20	1.20	1.57	1.57	1.83	1.83
Lysine	0.93	0.93	1.02	1.02	1.11	1.11
Methionine	0.46	0.46	0.50	0.50	0.54	0.54

FSWAPSI= fermented solid waste product of sugar industry. * The premix (vitamin-mineral) supplied the following per 100 kg of diet: Vitamin A 15,00 I.U, Vitamin D3 300,00 I.U, Vitamin E 3,000 I.U, Vitamin K 2.50 mg, Thiamine (B1) 200 mg, Riboflavin (B2) 600 mg, Pyridoxine (B6) 600 mg, Niacin 40.0 mg, Vitamin (B12) 2 mg, Pantothenic acid 10.0 mg, Folic acid 100 mg, Biotin 8 mg, Choline chlorine 50 g, Anti-oxidant 12.5 g, Manganese 96 g, Zinc 6 g, Iron 24 g, Copper 0.6 g, Iodine 0.14 g, Selenium 24 mg and Cobalt 214 mg

Table 2: Percent ingredients composition of experiment diets for grower rabbits

Ingredients	T1 40% SWAPSI +0 ppm	T2 40% SWAPSI +200 ppm	T3 50% SWAPSI +0 ppm	T4 50% SWAPSI +200 ppm	T5 60% SWAPSI +0 ppm	T6 60% SWAPSI +200 ppm
Maize	20.00	20.00	17.00	17.00	15.00	15.00
SWAPSI	**40.00**	**40.00**	**50.00**	**50.00**	**60.00**	**60.00**
Maize bran	11.25	11.25	4.30	4.30	3.00	3.00
GNC	18.00	18.00	19.00	19.00	19.70	19.70
Rice offal	7.00	7.00	6.00	6.00	0.00	0.00
Bone meal	0.90	0.90	0.90	0.90	0.50	0.50
Blood meal	1.00	1.00	1.00	1.00	0.50	0.50
Lysine	0.20	0.20	0.20	0.20	0.20	0.20
Methionine	0.20	0.20	0.20	0.20	0.20	0.20
Premix	0.25	0.25	0.20	0.20	0.20	0.20
Salt	0.20	0.20	0.20	0.20	0.20	0.20
Palm oil	1.00	1.00	1.00	1.00	0.50	0.50
Total	**100**	**100**	**100**	**100**	**100**	**100**
Enzyme (ppm)	**+0**	**+200**	**+0**	**+200**	**+0**	**+200**
Calculated Nutrients Composition						
Energy	2544.50	2544.50	2509.61	2509.61	2521.60	2521.60
Protein	15.28	15.28	15.29	15.29	15.24	15.24
Crude fibre	11.08	11.08	12.38	12.38	14.11	14.11
Ether Extract	6.27	6.27	6.63	6.63	6.32	6.32
Ash	4.37	4.37	4.55	4.55	3.80	3.80
Calcium	0.75	0.75	0.83	0.83	0.72	0.72
Phosphorus	1.91	1.91	2.29	2.29	2.57	2.57
Lysine	0.98	0.98	1.07	1.07	1.13	1.13
Methionine	0.49	0.49	0.53	0.53	0.56	0.56

FSWAPSI= fermented solid waste product of sugar industry, * The premix (vitamin-mineral) supplied the following per 100 kg of diet: Vitamin A 15,00 I.U, Vitamin D3 300,00 I.U, Vitamin E 3,000 I.U, Vitamin K 2.50 mg, Thiamine (B1) 200 mg, Riboflavin (B2) 600 mg, Pyridoxine (B6) 600 mg, Niacin 40.0 mg, Vitamin (B12) 2 mg, Pantothenic acid 10.0 mg, Folic acid 100 mg, Biotin 8 mg, Choline chlorine 50 g, Anti-oxidant 12.5 g, Manganese 96 g, Zinc 6 g, Iron 24 g, Copper 0.6 g, Iodine 0.14 g, Selenium 24 mg and Cobalt 214 mg

Experiment design

Rabbits were randomly assigned totest diets T1(20% FSWAPSI,+0ppm), T2 (20% FSWAPSI +200 ppm), T3 (30% FSWAPSI+0ppm), T4 (30 FSWAPSI +200ppm), T5 (40% FSWAPSI +0 ppm) and T6 (40% +200 ppm) weaners, and diets T1 (40% FSWAPSI,+0 ppm), T2 (40% FSWAPSI +200 ppm), T3 (50% FSWAPSI +0 ppm), T4 (50 FSWAPSI +200 ppm), T5 (60% FSWAPSI +0 ppm) and T6 (60% +200 ppm) for growers respectively for 3x2 factorial arrangement fitted into Completely Randomized Design (CRD) with each treatment replicated 4 timeswith three rabbits per replicate T1, T2, T3, T4, T5 and T6 for 3x2 factorial arrangement fitted into Completely Randomized Design (CRD) with each treatment replicated 4 times with three per replicate.

Management of Experimental Animals

Seventy-two (72), 5-weeks old composite weaner rabbits of live weight of about 500 to 600 grams were purchased and reared in an open-sided wire mesh hutch. The rabbits were given 14-day adjustment period before commencing feeding trial. About 0.1 ml of ivermectin was given subcutaneously per rabbit against ecto and endo parasites. Vitacoccs was used as prophylactic treatment against coccidiosis while Oxytrox L.A was given at 0.2 ml subcutaneously also for prophylactic treatment. Light was provided at night using electric bulb throughout the period of the experiment. Weighed amount of experimental diet and water were provided *at-libitum* and other routine management practices adapted as outlined by Alu *et al.* (2009).

Data Collection

Weaner phase: The weaner rabbits were weighed at the beginning of the experiment and body weight changes taken thereafter on weekly basis. Daily feed intake was determined by obtaining the difference between the quantity of feed given and the quantity leftover. Body weight gain was determined weekly while Feed Conversion Ratio was calculated by dividing feed intake by body weight gain. Protein efficiency ratio (PER) was determined as the gain in body weight to the alternative amount of protein consumed by the animal.

Performance parameters

Daily feed intake: The required quantity of feed was weighed daily with a scale before given to the animals. Left over was measured and subtracted from feed offered and the actual feed intake gotten.

$$\text{Feed intake (g)} = \text{Feed offered (g)} - \text{Feed left over (g)}$$

Weekly weight gain: Rabbits were weighed at the end of each week using a digital scale. Weight gain was determined by subtracting the Initial weight from the final weight.

$$\text{Weight gain (g)} = \text{Final weight(g)} - \text{Initial weight (g)}$$

Feed conversion ratio: The feed conversion ratio is the ratio between feed intake per week and body weight gain per week. This was calculated using this formular:

$$\text{FCR} = \frac{\text{Feed intake}}{\text{Body weight gain}}$$

Protein efficiency ratio (PER): This is the ratio between body weight gain in grams and protein intake in the diets. Where protein intake = Feed intake (DM) × Percentage Protein in diet.

$$\text{Protein efficiency ratio} = \frac{\text{Body weight gain}}{\text{Protein intake}}$$

Energy efficiency ratio: This is the ratio between body weight gain in grams and metabolizable energy in the diets where Metabolizable Energy is calculated using ME=37 x % CP+81.1 x % EE+35.5 x % NFE as described by Pauzenga (1985).

Energy Efficiency Ratio

$$= \frac{\text{Body weight gain}}{\text{Total Metabolizable energy intake}} \text{x } 100$$

Data Analysis

Data collected were subjected to two-way analysis of variance (ANOVA) for factorial experiment using SPSS version 20.0IBM Corp. (2011). Significant differences were considered at P< 0.05 and using Duncan's Multiple Range Test (DMRT) as described by Steel and Torries (1980).

The following statistical model was used:

$$Y_{ijk} = \mu + A_i + B_{ii} + (A \text{ x } B)_{ij} + e_{ijk}$$

Where: Y_{ijk}= is the j^{th} observation of the i^{th} treatment
μ = population mean; A_i= effect of the FSWAPSI
B_i= effect of the enzyme; $(A \text{ x } B)_{ii}$= effects of the SWAPSI & enzyme combined; e_{ijk}= is the random error.

RESULTS AND DISCUSSION

Effect of Rumen-liquor Fermented SWAPSI on Growth Performance of Weaner Rabbits

Table 3 showed the effect of rumen – liquor fermented SWAPSI on the growth performance of weaner rabbits. The inclusion of rumen-liquor fermented SWAPSI at varying levels (20, 30, 40%) in the diets of weaner rabbits had no significant differences (P>0.05) in average daily gain, feed intake, or feed conversion ratio (FCR). All performance parameters were statistically similar across treatments except average feed intake.

The absence of significant differences suggests that up to 40% inclusion of fermented SWAPSI did not show any significant difference on the growth performance of weaner rabbits. This aligns with previous findings that agro-industrial by-products, when properly processed (e.g., via fermentation), can replace conventional feed ingredients without negative effects on growth (Adeyemi *et al*., 2014; Oloruntola *et al*., 2016). This could indicate that FSWAPSI is a palatable and digestible feedstuff for weaner rabbits, providing adequate nutrients for maintenance and growth without causing adverse effects on these specific parameters. The significant difference observed in average feed intake, where the 30% FSWAPSI group consumed less feed, yet showed no significant difference in weight gain, might suggest a slightly better nutrient utilization or possibly a palatability issue at that specific inclusion level. However, since final weight and weight gain were not significantly affected, the differences in feed intake might not be biologically impactful on the overall growth. The observed results in this study could mean that fermentation likely reduced anti-nutritional factors and improved the digestibility of SWAPSI, making nutrients more available to the rabbits. Adeyemi *et al.* (2014) observed that fermentation improves nutrient availability by breaking down complex fibers and reducing anti-nutritional factors (Adeyemi *et al.*, 2014) and rabbits' ability to utilize fibrous feeds may explain the lack of negative effects on growth.

Table 3: Effect of rumen-liquor fermented SWAPSI on the growth performance of weaner rabbits

Parameters	Inclusion Levels of FSWAPSI			P–value	SEM	LOS
	20 %	30 %	40 %			
Initial weight (g/rabbit)	644.67	603.33	543.50	0.5664	66.19	NS
Final weight (g/rabbit)	936.67	820.67	730.67	0.1280	67.16	NS
Av. daily weight gain (g/rabbit/day)	6.62	5.22	4.46	0.1687	0.77	NS
Av. daily feed intake (g/rabbit/day)	49.42^{ab}	42.92^{b}	51.81^{a}	0.0465	2.37	*
Av. protein efficiency ratio	0.74	0.67	0.47	0.0903	0.08	NS
Av. feed conversion ratio	0.17	0.20	0.29	0.2084	0.05	NS
Av. protein intake (g/rabbit/day)	9.04	7.83	9.37	0.0558	0.43	NS
Av. energy efficiency ratio	0.27	0.19	0.16	0.0971	0.03	NS

SWAPSI= solid waste products of sugar industry; SEM= Standard error means, NS= No significant (P>0.05), LOS= Level of significant, a, b = Means on the same row bearing different superscript differ significantly (P<0.05)

Table 4: Effect of enzymes supplementation on the growth performance of weaner rabbits

Parameters	Inclusion Levels of Enzymes (ppm)		P-value	SEM	LOS
	0 %	200 %			
Initial weight (g/rabbit)	634.00	560.33	0.3383	52.77	NS
Final weight (g/rabbit)	905.67	753.00	0.0655	54.59	NS
Av. daily weight gain (g/rabbit/day)	6.25	4.62	0.0841	0.63	NS
Av. daily feed intake (g/rabbit/day)	49.15	46.95	0.5014	2.26	NS
Av. protein efficiency ratio	0.70	0.55	0.1666	0.07	NS
Av. feed conversion ratio	0.19	0.25	0.4333	0.04	NS
Av. protein intake (g/rabbit/day)	8.98	8.51	0.4219	0.41	NS
Av. energy efficiency ratio	0.25	0.17	0.0610	0.03	NS

SWAPSI= Solid waste products of sugar industry; SEM= Standard error means, NS= No significant (P>0.05), LOS= Level of significant, a, b = Means on the same row bearing different superscript differ significantly (P<0.05) SEM= Standard error means, NS= No significant (P>0.05), LOS= Level of significant, a, b = Means on the same row bearing different superscript differ significantly (P<0.05)

Effect of Enzyme Supplementation on the Growth Performance of Weaner Rabbits

Effect of enzyme supplementation on the growth performance of weaner rabbits is presented in Table 4. Enzyme supplementation (0 vs. 200 ppm) did not significantly affect (P>0.05) the growth performance parameters of weaner rabbits.

The non-significant effect of enzyme supplementation on growth performance in weaner rabbits may be attributed to the already improved digestibility provided by the fermentation process. Enzyme addition may have had limited additional benefit because the substrate (fermented SWAPSI) was already highly digestible and this aligned with the report of Bedford (2000) and this could be that fermentation pre-digests the feed, possibly making exogenous enzyme supplementation redundant. Young rabbits' digestive systems may already be efficient at utilizing the improved feed, reducing the observable impact of enzymes.

The findings also agreed with the findings of Cowieson and Ravindran (2008) who reported that fermentation can break down some complex fibers, certain less accessible components which might still remain, requiring specific enzymatic activity not sufficiently provided by the supplementation used. Therefore, even with a fermented substrate, the absence of a significant effect could indicate a mismatch between the enzyme activity and the residual anti-nutritional compounds or undigested nutrients in the FSWAPSI.

Effect of rumen-Liquor fermented SWAPSI and enzymes on the growth performance of weaner rabbits

Table 5 reveals the interactive effect of rumen-liquor fermented SWAPSI and enzymes on the growth performance of weaner rabbits. There are no significant interactive effects (P>0.05) between SWAPSI inclusion level and enzyme supplementation on the growth performance of weaner rabbits except on average feed intake and protein intake.

The lack of significant interaction suggests that the effects of fermented SWAPSI and enzyme supplementation on growth performance are independent and do not synergize under the conditions tested. This aligns with findings from other studies where enzyme supplementation improved growth performance only when diets contained less digestible substrates, but offered limited additional benefits when the feed was already enhanced by fermentation (Bedford, 2000; Awad *et al*., 2017). Fermentation likely improved nutrient availability and digestibility of SWAPSI, reducing the need for exogenous enzymes to further enhance growth (Adeyemi *et al*., 2014). Moreover, the digestive system of weaner rabbits may have been sufficiently developed to utilize the fermented feed effectively without enzyme supplementation. Another reason for no significant difference could be that there is possible overlap in the mode of action between fermentation and enzyme supplementation, leading to no additive benefit.

However, one primary reason for variations in feed intake could be the palatability. The specific combination of 30% FSWAPSI and 200 ppm enzyme supplementation might have resulted in a feed mixture with undesirable sensory properties (taste, odor, texture) for the weaner rabbits, leading to reduced voluntary consumption. Rabbits are known to be selective feeders, and even subtle changes in feed characteristics can significantly influence their intake patterns. If the enzymes altered the flavor profile of the fermented SWAPSI in an unappealing way at this particular inclusion level, it could explain the observed decrease in feed intake.

Table 5: Effect of rumen – liquor fermented SWAPSI and enzymes on the growth performance of weaner rabbits

Parameters	T1 (20% SWAPSI, 0 ppm)	T2 (20% SWAPSI, 200 ppm)	T3 (30% SWAPSI, 0 ppm)	T4 (30% SWAPSI, 200 ppm)	T5 (40% SWAPSI, 0 ppm)	T6 (40% SWAPSI, 200 ppm)	P-value	SEM	LOS
Initial weight (g/rabbit)	666.00	623.33	612.66	594.00	578.00	509.00	0.9269	103.27	NS
Final weight (g/rabbit)	942.67	930.67	843.67	797.67	788.00	673.33	0.4839	103.12	NS
Weight gain (g/rabbit/day)	6.59	6.65	5.50	4.93	5.00	3.91	0.5850	1.19	NS
Average feed intake (g/rabbit/day)	48.89	49.95^a	48.61^a	37.22^b	52.61^a	51.01^a	0.0326	2.91	*
Average protein efficiency ratio	0.75	0.74	0.62	0.71	0.51	0.51	0.4367	0.1287	NS
Feed conversion ratio	0.19	0.15	0.25	0.15	0.25	0.25	0.432	0.0694	NS
Protein intake (g/rabbit/day)	8.94^a	9.13^a	8.87^a	6.79^b	9.5^a	9.5^a	0.0367	0.5300	*
Energy efficiency ratio	0.24	0.29	0.20	0.18	0.18	0.18	0.4043	0.0491	NS

SWAPSI = Solid waste products of sugar industry; SEM= Standard error means, NS= No significant (P>0.05), LOS= Level of significant, a, b = Means on the same row bearing different superscript differ significantly (P<0.05)

Table 6: Effect of rumen – liquor fermented SWAPSI on the growth performance of grower rabbits

Parameters	Inclusion Levels of FSWAPSI			P–value	SEM	LOS
	20%	30%	40%			
Initial weight (g/rabbit)	961.67	820.67	730.67	0.0706	65.29	NS
Final weight (g/rabbit)	1426.70^a	1326.70^{ab}	1205.80^b	0.0149	46.58	*
Av. Daily weight gain(g/rabbit/day)	12.24	11.61	11.31	0.8238	1.06	NS
Av. Daily feed intake (g/rabbit/day)	62.47	59.16	61.93	0.8818	4.99	NS
Av. Protein efficiency ratio	0.45	0.45	0.41	0.8815	0.06	NS
Av. Feed conversion ratio	0.15	0.12	0.13	0.8083	0.02	NS
Av. Protein intake (g/rabbit/day)	9.54	9.01	9.44	0.8738	0.76	NS
Av. Energy efficiency ratio	0.28	0.21	0.18	0.1158	0.03	NS

SWAPSI = Solid waste products of sugar industry; SEM= Standard error means, NS= No significant (P>0.05), LOS= Level of significant, a, b = Means on the same row bearing different superscript differ significantly (P<0.05)

Effect of rumen-liquor fermented SWAPSI on the growth performance of grower rabbits

Effect of rumen-liquor fermented SWAPSI on the growth performance of grower rabbits is shown in Table 6. Similar to weaners, varying levels of fermented SWAPSI (40, 50, 60%) in grower rabbit diets did not result in significant differences (P>0.05) in growth performance parameters except on the final weight.

This result indicates that even at higher inclusion rates, fermented SWAPSI can be safely used in grower rabbit diets without compromising growth. This supports the sustainable use of agro-industrial by-products in animal feeding (Anyaegbu *et al.*, 2020). The reason could be that rabbits' tolerance for fibrous feeds and the effectiveness of fermentation in improving feed quality and nutrient adequacy of the diets even at higher SWAPSI inclusion rates.

The significant difference in final weight, with the 20% FSWAPSI group perform best, I significantly better than other groups. This implies that FSWAPSI can be well utilized at 20% inclusion level.There might be an optimal inclusion level beyond which its benefits plateau or even decline for overall body mass accumulation in grower rabbits (Adeyemi *et al*., 2014).

Effect of enzyme supplementation on the growth performance of grower rabbits

Table 7 shows the effect of enzyme supplementation on the growth performance of grower rabbits. The results showed that enzyme supplementation did not significantly affect (P>0.05) the growth performance of grower rabbits except on final weight where rabbits fed 0 ppm had significantly (P<0.05) higher final weight than those fed 200 ppm enzyme.

The lack of effect in growers may be due to their more developed digestive systems, which can efficiently utilize fibrous and fermented feeds without additional enzyme support (Oloruntola *et al.*, 2016). The reason for the observed results could be that mature digestive systems in grower rabbits reduce the need for exogenous enzymes and fermentation's effect may overshadow any marginal benefit from enzyme supplementation leading to the results obtained.

However, the possible reasons why grower rabbits fed 0 ppm enzyme had higher final weight than those fed 200 ppm could be that the mature digestive capacity in grower rabbits grower rabbits possess a relatively mature and efficient digestive system capable of producing endogenous enzymes sufficient for optimal nutrient digestion as reported by Oloruntola *et al.* (2016). Also, supplementing exogenous enzymes may not further enhance digestion and could potentially disrupt the natural enzyme balance or gut microbiota, leading to suboptimal nutrient utilization. Furthermore, enzyme-feed interaction and anti-nutritional factors certain enzyme preparations may not be fully compatible with fermented feed components, potentially leading to the formation of inhibitory compounds or reduced palatability, which can decrease feed intake and growth performance (Awad *et al.*, 2017).

Table 7: Effect of enzymes supplementation on the growth performance of grower rabbits

Parameters	Inclusion Levels of Enzymes		P-value	SEM	LOS
	0 % ppm	200 % ppm			
Initial weight (g/rabbit)	922.33	753.00	0.0509	53.84	NS
Final weight (g/rabbit)	1398.90^{a}	1240.60^{b}	0.0127	39.89	*
Av. daily weight gain(g/rabbit/day)	12.12	11.31	0.5053	0.84	NS
Av. daily feed intake (g/rabbit/day)	62.09	60.28	0.7511	3.96	NS
Av. protein efficiency ratio	0.45	0.43	0.7870	0.0486	NS
Av. feed conversion ratio	0.14	0.13	0.7093	0.020	NS
Av. protein intake (g/rabbit/day)	9.43	9.17	0.7227	0.61	NS
Av. energy efficiency ratio	0.26	0.18	0.0671	0.03	NS

SWAPSI = Solid waste products of sugar industry; SEM= Standard error means, NS= No significant (P>0.05), LOS= Level of significant, a, b = Means on the same row bearing different superscript differ significantly (P<0.05)

Table 8: Effect of rumen – liquor fermented SWAPSI and enzymes on the growth performance of grower rabbits

Parameters	T1 (40% SWAPSI, 0 ppm)	T2 (40% SWAPSI, 200 ppm)	T3 (50% SWAPSI, 0 ppm)	T4 (50% SWAPSI, 200 ppm)	T5 (60% SWAPSI, 0 ppm)	T6(60% SWAPSI, 200 ppm)	P-value	SEM	LOS
Initial weight (g/rabbit)	942.67	980.67	843.67	797.67	788.00	673.33	0.3434	99.81	NS
Final weight (g/rabbit)	1386.70	1466.70	1343.30	1310.00	1210.00	1201.70	0.1411	71.47	NS
Av. daily weight gain (g/rabbit/day)	10.52	13.95	11.89	11.31	10.04	12.58	0.4624	1.43	NS
Av. daily feed intake (g/rabbit/day)	64.61	60.93	61.33	56.99	63.68	60.18	0.9882	7.38	NS
Av. protein efficiency ratio	0.39	0.51	0.45	0.46	0.35	0.48	0.8292	0.09	NS
Av. feed conversion ratio	0.17	0.12	0.13	0.12	0.15	0.12	0.8056	0.03	NS
Av. protein intake (g/rabbit/day)	9.78	9.30	9,37	8.65	9.70	9.17	0.9858	1.919	NS
Av. energy efficiency ratio	0.26	0.31	0.22	0.19	0.19	0.16	0.4566	0.05	NS

SWAPSI= Solid waste products of sugar industry; SEM= Standard error means, NS= No significant (P>0.05), LOS= Level of significant, a, b = Means on the same row bearing different superscript differ significantly (P<0.05)

Effect of Rumen-liquor Fermented SWAPSI and Enzymes on the Growth Performance of Grower Rabbits

The interactive effects of rumen-liquor fermented SWAPSI and enzymes on the growth performance of grower rabbits are presented in Table 8. The results observed showed no significant interactive effects (P>0.05) between SWAPSI inclusion and enzyme supplementation on the growth performance of grower rabbits in all the growth parameters considered in the study.

This outcome indicates that, as with weaner rabbits, the fermentation process alone was adequate to optimize nutrient release and utilization, rendering the additional inclusion of exogenous enzymes unnecessary. This finding is consistent with the observations of Awad *et* *al.* (2017), who noted that fermentation, especially when using rumen liquor as an inoculum, enhances the breakdown of complex carbohydrates and fibers, thereby improving the digestibility of agro-industrial by-products. Rumen microbes possess a broad spectrum of fibrolytic enzymes capable of degrading hemicellulose, cellulose, and lignin complexes in fibrous feedstuffs, making the nutrients more bioavailable to non-ruminants like rabbits (Akinfala *et al.*, 2012).

Moreover, the lack of additive or synergistic effects from exogenous enzymes suggests that the microbial fermentation process had already achieved maximal enzymatic degradation of anti-nutritional factors and structural polysaccharides. This aligns with the report of Oloruntola *et al.* (2016), who reported that once optimal fermentation is attained, the incremental benefit of supplementary enzymes becomes negligible due to saturation of enzymatic activity on substrate binding sites.

CONCLUSION

Rumen-liquor fermented sugar industry waste product (FSWAPSI) can be incorporated into weaner and grower rabbit diets up to 40 % and 60 %, respectively, without significantly hindering growth performance, indicating its potential as a sustainable feed alternative. In weaner rabbits, 40 % inclusion did not negatively affect growth parameters, while in grower rabbits, 40% inclusion yielded the best final weight, suggesting an optimal inclusion level. Enzyme supplementation at 200 ppm generally did not enhance growth and even reduced final weight in grower rabbits, likely due to fermentation already improving digestibility and possible enzyme-feed interactions. Overall, fermentation alone optimizes nutrient utilization, with no significant synergistic effects observed between FSWAPSI inclusion and enzyme supplementation.

For weaner rabbits, FSWAPSI can be safely included up to 40% in their diets. For grower rabbits, further research should focus on identifying the precise optimal inclusion level of FSWAPSI, given that the 20% inclusion showed the best final weight in this study, despite higher levels being tolerated. The routine supplementation of exogenous enzymes may not be necessary or beneficial when feeding rumen-liquor fermented sugar industry waste to rabbits, especially grower rabbits.

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