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Original Research Article

SOLID-STATE FERMENTATION OF RICE MILLING WASTE WITH *PLEUROTUS OSTREATUS* FOR PARTIAL REPLACEMENT OF GROWER PIGS DIETS: PERFORMANCE AND ECONOMIC VIABILITY

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ABSTRACT
High feed costs remain a critical constraint in pig production across developing countries. This study evaluated the effect of solid-state fermented rice milling waste (FRMW) with *Pleurotus ostreatus* as a partial replacement for conventional feed ingredients in grower pigs' diets. Fresh rice milling waste was collected, pasteurized, and then subjected to solid-state fermentation with *P. ostreatus* for three weeks. The FRMW was subsequently used to replace varied percentages (15%, 25% and 50%) of conventional diet formulated with maize, soybean cake, and other standard ingredients, with or without enzyme (Enerzyme®) supplementation. Seven groups of weaners (n = 3/group) were fed the experimental diets (containing a percentage of the conventional diet and a percentage of the fermented rice milling waste with or without enzyme) for eight weeks after a two-week acclimatization. Performance parameters, apparent energy and protein digestibility, and benefit-cost ratio were evaluated. Results showed that pigs fed 15% and 25% FRMW with and without enzyme supplementation recorded improved feed conversion ratios and economic efficiency compared to control and 50% FRMW groups. Solid-state fermentation using *P. ostreatus* effectively improved the feeding value of rice milling waste, providing a sustainable alternative to conventional feedstuffs.

Keywords: Weaners, feed cost, *Pleurotus ostreatus*, rice milling waste, solid-state fermentation

INTRODUCTION
Global demand for animal protein continues to rise, driven by population growth and urbanization (Latino *et al*., 2020). In Nigeria, animal protein intake is still very low, averaging about 6.0 - 8.4 g per person per day, which is well below the 13.5 g per day recommended by the World Health Organization (Mailafia *et al*., 2010). By 2100, the global population is projected to reach 11 billion, with over 90% in developing regions (Dorling, 2021). Meeting the increasing demand for meat, particularly pork, necessitates cost-effective production strategies. Pig production offers advantages such as high feed efficiency, prolificacy, and short generation intervals (Oguniyi & Omoteso, 2011). However, rising costs of conventional feed ingredients like maize and soybean meal hinder profitability. Feed costs account for up to 75% of total production expenses, with energy sources being the most expensive component (Uddin & Osasogie, 2016). Exploring alternative feed resources, especially agro-industrial by-products, is essential to enhance profitability and sustainability. Rice milling waste (RMW), a by-product of rice processing, is abundant in Nigeria, but underutilized due to high lignocellulose content limiting digestibility (Ifeanyichukwu *et al*., 2019). Biological treatments of lignocellulosic biomass using white-rot fungi like *Pleurotus ostreatus* offer a safer and cost-effective alternative, degrading lignin and improving feed quality (Vasco-Correa & Shah, 2019). Solid-state fermentation enhances nutrient availability, reduces anti-nutritional factors, and improves feed palatability (Mussatto & Teixeira, 2010). This study investigated the performance and economic implications of incorporating FRMW with or without enzyme supplementation in weaned pig diets.

MATERIALS AND METHODS
EXPERIMENTAL SITE AND ANIMALS
The research was conducted at the Research Farm of the College of Veterinary Medicine (CVM), Michael Okpara University of Agriculture, Umudike. (Coordinates:

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5.5250ºN; 7.4931ºE). The protocol for this research was reviewed and approved by the Ethical Committee of the College of Veterinary Medicine, Michael Okpara University of Agriculture, Umudike, Abia State, Nigeria (Ref. No: MOUAU/CVM/REC/202411).

A total of twenty-one 7-week-old Yorkshire weaners, 7 males and 14 females were sourced from a reputable pig farm in Umuahia, Abia State, and used for the study. Freshly produced RMW was obtained from the Uzuakoli rice milling center in Abia State, and conveyed to the study center for fermentation, and subsequently for partial replacement of the basal diet. Spawns of *Pleurotus ostreatus* were sourced from a commercial dealer; multiplied, and used as RMW fermentation agent, while Enerzyme® (a cocktail of cellulase 10,000 IU; Beta-glucanase 200 IU; Xylanase 10,000 IU, and Phytase 2,500 IU), was purchased from the dealer for the enrichment of some groups' diets.

FERMENTATION PROCEDURE AND DIET FORMULATION

Freshly produced rice milling waste was collected, pasteurized and subjected to solid-state fermentation with *Pleurotus ostreatus* for three weeks following standard procedure (Jahromi *et al*., 2010; Olagunju *et al*., 2023). Basal diet was formulated using maize, soybean cake, palm kernel cake (PKC), lysine, methionine, salt, and premix to contain 20.1% crude protein and 2,985 Kcal/kg metabolizable energy. Fermented RMW replaced conventional diet at 15%, 25%, and 50%, with or without Enzyme (Enerzyme®) at 1g/10 kg (0.01%) of formulated feed.

EXPERIMENTAL DESIGN

The experiment followed a completely randomized design (CRD) with seven treatments (A - G), and were assigned diets as follows: A (Control): 100% conventional diet, B: 85% conventional diet + 15% FRMW, no enzyme, C: 75% conventional diet + 25% FRMW, no enzyme, D: 50% conventional diet + 50% FRMW, no enzyme, E: 85% conventional diet + 15% FRMW + enzyme, F: 75% conventional diet + 25% FRMW + enzyme, G: 50% conventional diet + 50% FRMW + enzyme.

ANIMAL MANAGEMENT AND DURATION

The pigs were acclimatized for two weeks, during which albendazole was administered orally at a dosage of 10 mg/kg body weight as a single dose. At the end of the acclimatization period, they were weighed, and the initial body weights were recorded. The weaners were then assigned to the treatments described above using a completely randomized design. Each treatment group consisted of three weaners (n = 3), with each weaner serving as a replicate. They were provided feed and portable water ad libitum throughout the experiment, and the feeding trial lasted for eight weeks.

DATA COLLECTION AND ANALYSIS

Parameters measured included weight gain (WG)(kg), feed intake (FI) (kg), feed conversion ratio (FCR) = Feed intake/Weight gain), apparent energy digestibility (AED, %), apparent protein digestibility (APD, %), and benefit-cost ratio (BCR) = Net returns/Total cost of production). Data generated were analyzed using one-way analysis of variance (ANOVA) to determine significant differences across treatment means for each parameter. Tukey's Honestly Significant Difference (HSD) test was used for post-hoc comparisons at $p \leq 0.05$.

RESULTS

PERFORMANCE EVALUATION

Table I shows the performance responses of pigs to dietary treatments (conventional ration partially replaced with graded levels of FRMW with or without enzyme supplementation.

Table I: Performance parameters of pigs fed conventional diet partially replaced with FRMW with or without enzyme supplementation

Group	IW	FW	WG	FI	FCR	AED	APD
A	6.33± 0.44	20.25± 1.52	13.92 ± 1.88_a	32.11 ± 0.10_e	2.31 ± 0.04_d	44.88 ± 0.08_g	43.04 ± 0.03_f
B	6.42± 0.22	19.92± 0.46	13.5 ± 1.00_a	33.9 ± 0.10_b	2.58 ± 0.07_c	52.56 ± 0.06_d	50.59 ± 0.1_d
C	6.83± 0.67	18.92± 2.29	12.08 ± 3.06_a	32.27 ± 0.05_d	2.79 ± 0.03_b	53.84 ± 0.04_c	55.69 ± 0.04_b
D	6.50± 0.29	15.00± 0.76	8.5 ± 1.32_b	29.7 ± 0.10_g	3.48 ± 0.03_a	48.22 ± 0.02_f	38.44 ± 0.05_g
E	6.33± 0.85	19.58± 1.47	13.25 ± 1.09_a	33.03 ± 0.06_c	2.57 ± 0.06_c	54.21 ± 0.02_b	51.65 ± 0.05_c
F	6.34± 0.71	18.92± 0.55	12.58 ± 0.38_a	34.63 ± 0.06_a	2.76 ± 0.05_b	54.52 ± 0.02_a	57.51 ± 0.01_a
G	6.67± 0.74	15.84± 1.39	9.17 ± 1.13_b	31.87 ± 0.06_f	3.48 ± 0.07_a	51.16 ± 0.01_e	44.22 ± 0.02_e

Means within the same column with different subscripts are significantly different ($P \leq 0.05$)

IW: Initial weight (kg), FW: Final weight (kg), WG: Weight Gain (kg), FI: Feed Intake (kg), FCR: Feed Conversion Ratio, AED: Apparent Energy Digestibility (%), and APD: Apparent Protein Digestibility (%).

Results from Table I indicated that there was no significant difference in weight gain between the control (Group A) and the groups fed experimental diets containing either 15% or 25% of the FRMW with or without enzyme (Groups B, C, E, F). However, there was a significant increase in weight in the groups fed with experimental diet containing 15% or 25% of the FRMW, with or without enzyme compared to the group fed with experimental diets containing 50% of the FRMW with (Group G) or without (Group D) enzyme.

Feed intake was significantly lowest ($p < 0.05$) in pigs fed 50% FRMW diets, while the highest feed intake was recorded in pigs fed 25% FRMW with enzyme supplementation (Group F), followed by those fed 15% FRMW (Group B). The control group exhibited the lowest feed conversion ratio (FCR), followed closely by pigs fed 15% FRMW, whereas pigs fed 50% FRMW diets had the highest FCR, indicating poorer feed efficiency.

Apparent energy digestibility (AED) was significantly highest ($p < 0.05$) in pigs fed 15% and 25% FRMW with enzyme supplementation (Groups F and E) compared to pigs fed diets without enzyme supplementation and the control diet. In contrast, apparent protein digestibility (APD) was highest in pigs fed 25% FRMW without enzyme supplementation (Group C), followed by those fed 25% FRMW with enzymes (Group F).

ECONOMIC VIABILITY

Production cost components, revenue, and net returns of pigs fed conventional diet partially replaced with graded levels of FRMW with and without enzyme supplementation.

Table II: Production Cost Components, Revenue, and Net Returns of Pigs Fed Conventional Diet Partially Replaced with Graded Levels of FRMW with and without Enzyme Supplementation

Group	Feed Cost (₦)	Fixed Cost (₦)	Miscellaneous Cost (₦)	Total Cost of Production (₦)	Returns (₦)	Net Returns (₦)
A	75,965	103,500	17,945	197,410	243,000	45,590
B	68,730	103,500	17,225	189,455	239,040	49,585
C	59,800	103,500	16,325	179,625	227,040	47,415
D	36,520	103,500	14,000	154,020	180,000	25,800
E	66,950	103,500	17,050	187,500	234,040	46,540
F	62,600	103,500	16,600	182,700	227,040	44,340
G	39,150	103,500	16,150	159,150	190,080	30,920

Total Cost of Production (₦) = Feed Cost + FRMW Processing Cost + Enzyme Cost + Fixed Cost (Weaners Cost + Labour Cost + Medication Cost) + Miscellaneous Cost
Returns (₦) = Final Live Weight (kg) × Market Price per kg Live Weight
Net Returns (₦) = Revenue − Total Cost of Production

BENEFIT-COST RATIO (BCR)

The benefit-cost ratio (BCR) of pigs fed conventional diet partially replaced with graded levels of fermented rice milling waste (FRMW), with and without enzyme supplementation is presented in Table III.

Table III: Benefit-Cost Ratio (BCR) of Pigs Fed Conventional Diet Partially Replaced with Graded Levels of FRMW with and without Enzyme Supplementation

Group	Benefit-Cost Ratio (BCR)
A	$1.23 \pm 0.003_b$
B	$1.26 \pm .0.006_a$
C	$1.26 \pm 0.006_a$
D	$1.17 \pm 0.006_c$
E	$1.25 \pm 0.003_a$
F	$1.24 \pm 0.006_b$
G	$1.18 \pm 0.008_c$

Means within the same column with different subscripts are significantly different (P≤0.05)
Benefit-Cost Ratio (BCR) = Revenue ÷ Total Cost of Production

Results from Table III indicated that the benefit-cost ratio (BCR) values of pigs fed conventional diet partially replaced with graded levels of fermented rice milling waste (FRMW) with and without enzyme supplementation ranged from 1.17 to 1.26, indicating that all dietary treatments yielded returns above production costs (BCR > 1).

Groups B (1.26 ± 0.006), C (1.26 ± 0.006), and E (1.25 ± 0.003) recorded the highest (P ≤ 0.05) BCR values and are statistically similar. Groups A (1.23 ± 0.003) and F (1.24 ± 0.006) had intermediate BCR values, which are significantly lower than Groups B, C, and E, but significantly higher than Groups D and G. The lowest (P ≤ 0.05) BCR values were observed in Groups D (1.17 ± 0.006) and G (1.18 ± 0.008), and not significantly different from each other.

DISCUSSION

The comparable final body weight and body weight gain observed in pigs fed 15% and 25% FRMW diets relative to the control indicate that conventional pig diets can be partially replaced with FRMW up to 25% without adverse effects on growth performance. This finding supports earlier reports by Wang *et al*., (2011) and Sun *et al*., (2024), who documented improved nutrient digestibility and growth performance in pigs fed solid-state fermented feed ingredients.

The depressed growth performance and poorer feed efficiency observed at the 50% inclusion level may be attributed to the high fiber and lignin content of FRMW, which can limit nutrient digestibility in monogastric animals. Excess dietary fiber reduces energy availability and nutrient utilization efficiency, thereby negatively affecting growth performance. Although enzyme supplementation improved feed conversion ratio and nutrient digestibility at moderate inclusion levels, its effect appeared insufficient to counteract the negative impact of excessive fibre at 50% inclusion. This observation corroborates the findings of Yang *et al*., (2021), who emphasized the synergistic benefits of combining fermentation and exogenous enzymes to enhance feed utilization efficiency.

The significantly higher apparent energy digestibility in enzyme-supplemented groups suggests improved fibre degradation and nutrient release, while the superior apparent protein digestibility in pigs fed 25% FRMW without enzymes may indicate that fermentation alone effectively enhanced protein availability. Fermentation has been widely reported to reduce anti-nutritional factors, degrade complex fibre components, and improve amino acid availability, thereby enhancing nutrient utilization (Frias *et al*., 2008; Niba *et al*., 2009).

Generally, moderate inclusion levels of FRMW, whether supplemented with enzymes or not (Groups B, C, and E), produced significantly higher economic efficiency than both the control diet and the higher inclusion treatments, demonstrating a more favourable balance between cost-reduction and productive performance.

The benefit-cost ratio (BCR) is a critical economic indicator in livestock production, reflecting the relationship between total revenue and total production cost, and ultimately determining the profitability of a feeding strategy (Gittinger, 1982; FAO, 2011). In the present study, the BCR showed values greater than 1.0 across all treatments; which indicate that pig production under all dietary regimens was economically viable, as revenue exceeded total production cost.

The significantly higher BCR observed in Groups B, C, and E suggests that moderate inclusion levels of FRMW improved profitability. This outcome may be attributed to partial replacement of expensive conventional feed ingredients with FRMW, thereby reducing feed cost without compromising growth performance; aligning with Sime & Duguma, (2025), who highlighted the potential of alternative feedstuffs in reducing production costs. Feed accounts for approximately 60 - 75% of total production cost in pig enterprises, and any reduction in feed cost without adverse performance effects substantially improves economic returns (FAO, 2011; NRC, 2012).

The relatively improved BCR in enzyme-supplemented groups may be associated with enhanced nutrient digestibility and better feed utilization. Exogenous enzymes are known to improve the breakdown of non-starch polysaccharides and fibre components in unconventional feedstuffs, thereby enhancing nutrient availability and growth efficiency (Adeola & Cowieson, 2011). Improved nutrient digestibility is closely associated with enhanced feed efficiency and economic performance in monogastric animals, particularly when fibrous agro-industrial by-products are incorporated into their diets. Enhanced digestibility significantly increases nutrient availability, thereby promoting improved feed conversion ratio (FCR) and overall productive performance (Ravindran, 2013).

Conversely, the significantly lower BCR recorded in Groups D and G suggests that higher inclusion levels of FRMW may have negatively influenced economic efficiency. This reduction may be due to diminished growth performance or suboptimal nutrient utilization at excessive replacement levels, offsetting any feed cost savings. Similar observations have been reported where high inclusion levels of fibrous by-products in pig diets reduced performance and profitability due to lower energy density and increased gut fill (Noblet & Le Goff, 2001).

The intermediate BCR values in the control group (A) and Group F indicate that while conventional diets remain profitable, strategic incorporation of moderate levels of FRMW offers superior economic advantage. Therefore, moderate inclusion of FRMW, with or without enzyme supplementation, appears to provide the most favourable balance between cost reduction and productive performance.

CONCLUSION

The findings demonstrated that partial replacement of conventional feed ingredients with moderate levels of fermented rice milling waste (FRMW) significantly enhanced economic efficiency in pig production. Also, solid-state fermentation of rice milling waste using *Pleurotus ostreatus* improved its nutritive and feeding value, making it a viable alternative feed resource. However, excessive inclusion levels may reduce profitability, highlighting the importance of optimal diet formulation that carefully balances cost-reduction with nutrient adequacy and animal performance. Generally, this strategy offers a sustainable and cost-effective approach to feeding pigs, particularly suited to resource-constrained environment and developing countries.

REFERENCES

Adeola, O. & Cowieson, A. J. (2011). Board-invited review: Opportunities and challenges in using exogenous enzymes to improve non-ruminant animal production. *Journal of Animal Science*, 89(10), 3189–3218. https://doi.org/10.2527/jas.2010-3715

Dorling, D. (2021). World population prospects at the UN: our numbers are not our problem? In The struggle for social sustainability (pp. 129-154). Policy Press.

Food and Agriculture Organization (FAO). (2012). Pig sector Kenya. FAO Animal Production and Health Livestock Country Reviews. FAO.

Food and Agriculture Organization of the United Nations (FAO). (2011). Guide to business planning for farming enterprises. FAO Animal Production and Health Guidelines. Rome: FAO.

Frias, J., Song, Y. S., Martínez-Villaluenga, C., González de Mejia, E. & Vidal-Valverde, C. (2008). Immunoreactivity and amino acid content of fermented soybean products. *Journal of Agricultural and Food Chemistry*, 56(1), 99–105. https://doi.org/10.1021/jf072177j

Gittinger, J. P. (1982). Economic analysis of agricultural projects (2nd ed.). Johns Hopkins University Press.

Ifeanyichukwu, N. P., Sule, E., Adebisi, O. F. & Uchele, O. (2019). A Review on the Availability and Economics of Rice Milling Waste as Animal Feeding Stuff in Nigeria. *Journal of Applied Sciences*, 19(8), 747–755.

Jahromi, M. F., Liang, J. B., Rosfarizan, M., Goh, Y. M., Shokryazdan, P. & Ho, Y. W. (2010). Effects of *Aspergillus niger* (K8) on nutritive value of rice straw. *African Journal of Biotechnology*, 9(42), 7043-7047.

Latino, L. R., Pica-Ciamarra, U. & Wisser, D. (2020). Africa: The livestock revolution urbanizes. *Global Food Security*, 26, 100399.

Mailafia, S., Onakpa, M. M. & Owoleke, O. E. (2010). Problems and prospects of rabbit production in Nigeria-A review. *Bayero Journal of Pure and Applied Sciences*, 3(2), 20-25.

Mussatto, S. I. & Teixeira, J. A. (2010). Increase in the fructooligosaccharides yield and productivity by solid-state fermentation with *Aspergillus japonicus* using agro-industrial residues as support and nutrient source. *Biochemical Engineering Journal*, 53(1), 154-157

National Research Council (NRC). (2012). Nutrient requirements of swine (11th rev. ed.). Washington, DC: National Academies Press.

Niba, A. T., Beal, J. D., Kudi, A. C. & Brooks, P. H. (2009). Potential of bacterial fermentation as a biosafe method of improving feeds for pigs and poultry. *African Journal of Biotechnology*, 8(9), 1758–1767.

Noblet, J. & Le Goff, G. (2001). Effect of dietary fibre on the energy value of feeds for pigs. *Animal Feed Science and Technology*, 90(1–2), 35–52. https://doi.org/10.1016/S0377-8401(01)00195-X

Oguniyi, L. T. & Omoteso, O. A. (2011). Economic analysis of swine production in Nigeria: A case study of

Ibadan zone. *Journal of Human Ecolog*y, 35(2), 137–142.

Olagunju, L. K., Isikhuemhen, O. S., Dele, P. A., Anike, F. N., Essick, B. G., Holt, N. & Anele, U. Y. (2023). *Pleurotus ostreatus* can significantly improve the nutritive value of lignocellulosic crop residues. *Agriculture*, 13(6), 1161.

Ravindran, V. (2013). Feed enzymes: The science, practice, and metabolic realities. *Journal of Applied Poultry Research*, 22(3), 628–636.

Sime, A. G. & Duguma, B. S. (2025). The Role of Non-Conventional Feeds in Small Ruminant Production and Their Implication for Feed Cost Reduction in Ethiopia-A Mini Review. *Veterinary Medicine and Science*, 11(5), e70554.

Sun, H., Jiang, Z., Chen, Z., Liu, G. & Liu, Z. (2024). Effects of fermented unconventional protein feed on pig production in China. *Frontiers in Veterinary Science*, 11, 1446233.

Uddin, I. O. & Osasogie, D. I. (2016). Constraints of pig production in Nigeria: A case study of Edo Central Agricultural Zone of Edo State. *Asian Research Journal of Agriculture*, 2(4), 1-7.

Vasco-Correa, J. & Shah, A. (2019). Techno-economic bottlenecks of the fungal pre-treatment of lignocellulosic biomass. *Fermentation*, 5(2), 30.

Wang, J. J., Wang, S. X. & Lu, W. Q. (2011). Effects of antibiotic-free microbial fermented feed on immune and antioxidant function of piglets. *China Feed*, 16, 25–27.

Yang, L., Zeng, X. & Qiao, S. (2021). Advances in research on solid-state fermented feed and its utilization: The pioneer of private customization for intestinal microorganisms. *Animal Nutrition*, 7(4), 905–916. https://doi.org/10.1016/j.aninu.2021.06.002.