Trop J Nat Prod Res, January 2026; 10(1): 6952 - 6957

**ISSN 2616-0684 (Print)**
**ISSN 2616-0692 (Electronic)**

# Tropical Journal of Natural Product Research

Available online at https://www.tjnpr.org

*Original Research Article*

# Yeast-Mediated Solid-State Fermentation Enhances the Additive Quality of *Dialium Guineense* Stem Bark on the Performance of Broilers Aged from 1 to 21 days

Ifeanyichukwu P. Ogbuewu*, Oparaugo C. Ezra, Blessing A. Okoye, Godswill C. Ikeagwu, Mary E. Egwu, Emeka A. Anyigor, Innocent Ejiofor, Linda C. Ikpamezie, Emmanuel U. Ahiwe, Tobechukwu C. Iwuji, Nnanyere O. Aladi, Ifeanyi C. Okoli

*Department of Animal Science and Technology, Federal University of Technology, P.M.B. 1526, Owerri, Imo State, Nigeria*

ARTICLE INFO

*Article history:*
Received 26 November 2025
Revised 15 December 20255
Accepted 27 December 2025
Published online 01 February 2026



ABSTRACT

The stem bark of Tamarind is a rich source of fibre and phytochemicals, making it a potential feed additive for chickens. The study assessed the effect of yeast-mediated solid-state fermentation (SSF) on the chemical composition of tamarind stem bark and the impact of fermented tamarind bark (FTB) on the growth performance of broilers aged from 1 to 21 days. Two hundred broilers were partitioned into four groups (T0, T0.5, T1.0, and T1.5) of 50 chicks, and each group was replicated five times. Birds on T0 received a diet without FTB supplementation and served as the control, while birds on T0.5, T1.0, and T1.5 received the same control diet but supplemented with FTB at 0.5, 1.0. and 1.5 g/kg feed, respectively, in a completely randomized design. A quadratic optimisation model was used to determine the FTB supplementation levels for optimal growth performance. Results revealed that yeast-mediated SSF improved ($p<0.05$) dry matter, crude protein, ether extract, ash, flavonoids, phenol content, and DPPH activity in tamarind bark. In contrast, fermentation decreased ($p<0.05$) the fibre, oxalate, phytate, alkaloids, and saponins content in tamarind bark. Broilers on T0.5, T1.0, and T1.5 had higher ($p < 0.05$) final live weight (FLW), average daily gain (ADG), and average daily feed intake (ADFI) than the T0, and were optimised at 3.05 and 3.03 g FTB/kg feed, respectively. In conclusion, yeast-mediated SSF improved the feed additive quality of tamarind bark, and FTB should be supplemented in the starter broiler diet at 3.05 and 3.03 kg feed for the best FLW, ADG, and ADFI.

***Keywords:*** Tamarind bark, Fermentation, Broilers, Daily gain, Feed intake, Quadratic function.

## Introduction

Feed makes up around 60-70% of total costs in intensive broiler farming.[1] As a result, nutrient optimization plays an important part in maximizing broiler productivity. One such strategy to optimize nutrient uptake in broilers is the use of in-feed antibiotics.[2] However, the association of in-feed antibiotics with the development of resistant strains of bacteria has burdened researchers in developing countries to search for alternatives. Among the alternatives usually available in the study region are yeast, organic acids, ginger, turmeric, and tamarind bark.[3-5] Specifically, tamarind (*Dialium guineense*) belongs to the family *Leguminosae* and subfamily *Caesalpinioideae*, and the bark is not used as food by humans and is little known in poultry nutrition. A recent study in our station[5] showed that tamarind bark is high in important phytochemicals such as total phenols (2.02%) and flavonoids (0.34%). The authors also noticed that tamarind bark is moderate in trypsin inhibitors (0.05%), and low in saponins (0.004%), cyanogenic glycosides (0.009%), and alkaloids (0.006%). Trypsin inhibitor reduces protein digestion by hindering the activity of trypsin activity.[6]

*Corresponding author. Email: dr.ogbuewu@gmail.com; Ifeanyi.ogbuewu@futo.edu.ng
Tel: +2348035441864

Citation: Ifeanyichukwu P. Ogbuewu, Oparaugo C. Ezra, Blessing A. Okoye, Godswill C. Ikeagwu, Mary E. Egwu, Emeka A. Anyigor, Innocent Ejiofor, Linda C. Ikpamezie, Emmanuel U. Ahiwe, Tobechukwu C. Iwuji, Nnanyere O. Aladi, Ifeanyi C. Okoli. Yeast-mediated solid-state fermentation enhances the additive quality of *Dialium guineense* stem bark on the performance of broilers aged from 1 to 21 days. Trop J Nat Prod Res. 2026; 10(1): 6952 – 6957 https://doi.org/10.26538/tjnpr/v10i1.68

Official Journal of Natural Product Research Group, Faculty of Pharmacy, University of Benin, Benin City, Nigeria

Recent feeding experiments in our station[5,7] revealed that diets supplemented with unfermented tamarind bark at 1.0-1.5 g/kg negatively impacted Ross 308 broiler performance, resulting in decreased growth, blood values, carcass yield, cut-part weights, and intestinal characteristics. These deleterious impacts were partly caused by its high lignocellulosic biomass (>25%), and the existence of trypsin inhibitors[5,8] demonstrated to limit nutrient digestibility and availability in poultry.[7] The ability of enzymes such as cellulases, hemicellulases, and ligninases to degrade cell wall components of fibrous materials into their monomers has been demonstrated.[9] However, most poultry species cannot produce cellulases, hemicellulases, and ligninases in their gastrointestinal tract, and as a result, their potential ability to digest tamarind bark is hindered. To maximize the adoption of tamarind bark as an additive source, strategies are required to degrade its lignocellulosic biomass and antinutrients while improving their nutrient and phytochemical content to increase their supplementation levels in broiler diets. Studies have revealed that Solid-state fermentation (SSF) can be used to improve nutrient and decrease antinutrient content of lignocellulosic biomass.[10-11]

Yeast (*Saccharomyces cerevisiae*) was chosen in this experiment trial for its production of hydrolytic enzymes, including invertase, lactase, lipase, raffinase, pectinases, amylases, cellulases, ligninase, and xylanase[12] and its established use in feed applications.[3] These enzymes break down lignocellulosic biomass, thereby improving nutrient and additive values. Presently, no study has examined the impact of yeast-mediated SSF on the additive value of tamarind bark and its supplementation effect on broiler growth. Therefore, the impacts of FTB supplementation on the growth characteristics of broilers aged from 1 to 21 days were also studied.

## Materials and Methods

This experiment was done at the Poultry Unit of FUTO, Nigeria, and was approved by the University Animal Ethics committee with ethics number: FUTO/2024/24. FUTO lies between latitudes 5°20'N - 5°25'N and longitudes 7°00'E - 7°05'E with 2400 mm mean rainfall. The mean

ISSN 2616-0684 (Print)
ISSN 2616-0692 (Electronic)

daily temperature ranges from 19-24°C (minimum) to 28-35°C (maximum).[13] Proximate and phytochemical composition of unfermented VB and fermented BV (FVB) were conducted at the Precision Food and Feed Analysis Laboratory, Ibadan, Nigeria.

*Production of unfermented and fermented tamarind bark*

The tamarind bark was harvested in FUTO, Nigeria, cut into bits, sundried, and milled as described by Ogbuewu and Mbajiorgu.[5] A portion was mixed with dried baker's yeast (STK Royal®) at a 10 kg:1g ratio.[5] Thereafter, the sample was fermented for 8 days[14] and sun-dried for 3 days to 14% moisture content.[15] The other portion, unfermented and without yeast, served as a control. Fermented and unfermented tamarind bark were analysed for proximate, fibre, and phytochemical composition.

*Proximate composition and fibre fractions*

Dry matter (DM) (method no 930.15), crude protein (CP) (method 990.03), crude fibre (CF) (method 962.09), ether extract (EE) (method 960.39), and crude ash (method no 924.05) of fermented and unfermented tamarind bark were determined in triplicates and recorded in percentages according to the methods of AOAC.[16] The fibre fractions assessed were neutral detergent fibre (NDF), acid detergent fibre (ADF), acid detergent lignin (ADL), cellulose, and hemicellulose. Samples were oven-dried at 105°C to determine moisture content. EE content was extracted using a Soxhlet Extractor (DW-MSZF-M06C; Houston, Texas, USA) with petroleum ether. Ash content was determined by incinerating samples at 550°C in a muffle furnace. The samples were heated in a furnace at 550°C to quantify the ash value. Total organic nitrogen (TON) was assessed via the macro-Kjeldahl technique, and CP was derived as TON × 6.25. NDF and ADF values were assessed by serial reflux with neutral and acid detergent solutions.[17] The fibre fractions in the samples were measured via an ANKOM200 Fibre Analyzer (Model: ANKOM200 Fibre Analyzer, New York, USA). Fibre fractions were determined as follows: ADL content = ADF - cellulose; hemicellulose = NDF - ADF; Cellulose = ADF – ADL.

*Determination of phytochemical contents*

The phytochemical components analysed included DPPH, tannins, phenols, flavonoids, alkaloids, phytate, saponins, and oxalate. The tannins and saponins were measured using the standard methods.[18-19] Phytate concentration was evaluated using a modified colorimetric method[20], while total phenol, flavonoid, and antioxidant activity content were determined as described by others.[21-22] Alkaloid content was measured using Wagner's reagent test as described by Amaza[23], while the total oxalate was quantified using the method of Ruan et al.[24]

*Animal management and experimental design*

One day, 200 Ross 308 were distributed equally into four groups, with five birds per replication. Birds in the T0 group received a diet (Table 1) without FTB supplementation, which served as the control, while birds on T0.5, T1.0, and T1.5 groups received a control diet with FTB at 0.5, 1.0. and 1.5 g/kg feed, respectively. Broilers in each group were allotted to one of the diets in a completely randomised design. Each replicate was housed in a pen with dimensions of 1×2 m, in a dwarfed walled poultry house with an open side covered with wire mesh. The pens were cleaned and disinfected with Polidine® (Animal Care Nigeria) and thereafter covered with wood shavings to a depth of 2 cm. Drinkers and feeders were thoroughly cleaned and assembled a day before the commencement of the feeding study. A broiler diet (Table 1) was formulated to meet Ross 308 nutrition specifications[25]. The experimental birds were vaccinated following the standard method.[26] Birds were offered feed and clean water without restriction for three weeks. Metabolizable energy (ME) value of the ration was computed through the formula of Pauzenga[27]: ME (Kcal/kg) = 37 × %CP + 81.8 × %EE + 35.5 × %NFE, where NFE (nitrogen free extract) is calculated as 100 - %moisture - %CP - %EE - % ash - %CF.

**Table 1:** Ingredient and nutrient content of experimental diet

| Ingredients | percent |
|---|---|
| Maize (9% CP) | 55.00 |
| Soybean meal (44% CP) | 31.00 |
| Wheat offal | 2.00 |
| Palm kernel cake | 2.00 |
| Fish meal | 4.00 |
| Bone meal | 3.00 |
| Oyster shell | 2.00 |
| Common salt | 0.25 |
| Vitamin/mineral premix* | 0.25 |
| Lysine | 0.25 |
| Methionine | 0.25 |
| Total | 100 |
| Calculated nutrient composition (%) | |
| Crude protein | 23.00 |
| Crude fibre | 3.98 |
| Ether extract | 3.39 |
| Lysine | 0.97 |
| Methionine | 0.45 |
| Calcium | 1.63 |
| Phosphorus | 1.14 |
| Metabolizable energy (Kcal/kg) | 2965.10 |

*Having the following/ kg feed: Vitamin A (1,200,000 iu), cholecalciferol (350,000 iu), tocopherol (4000 mg), thiamine (250 mg), riboflavin (800 mg), pyridoxine (600 mg), cobalamin (3.2 mg), menadione (450 mg), nicotinic acid (4.5 g), calcium pantothenate (1.5 g), folic acid (120 mg), biotin (5 mg), choline chloride (55 g), iron (3 g), copper (2 g), manganese (10 g), zinc (8 g), iodine (120 mg), selenium (0.3 mg), and cobalt (40 mg).

*Data collection*

The birds' live weights were recorded at the start and weekly using an AG500 electronic scale (±0.5 g precision). Average daily feed intake (ADFI) was determined as the amount of feed offered on a particular day less the amount in the feeder the next morning. Average daily gain (ADG) was determined weekly, while feed conversion ratio (FCR) was calculated as ADFI/ADG per replicate.

*Statistical analysis*

Results obtained on proximate composition, fibre fraction, phytochemical contents, and growth metrics were analysed with IBM SPSS[28] Version 27. For chemical composition, means were separated with Student's t-test via the equation: $Y_{ij} = \mu + Ti + E_{jj}$. Where Yij is proximate, fibre fraction, phytochemical characteristics; $\mu$ = population mean, Ti = impact of yeast-mediated SSF, and $E_{ij}$ = random error. Growth performance was assessed using the general linear models (GLM) procedure of the same software. Means were separated using Tukey's test using the model: $Y_{ijk} = \mu + Ti + E_{ijk}$, where Yijk is the growth performance, $\mu$ is the population mean, $T_i$ is the supplementation levels of FTB in the diets (i = 4; T0, T0.5, T1.0, and T1.5), and $E_{ijk}$ is the random error linked with observation. The dose-related responses to increasing supplementation levels of FTB for significant variables were modeled using the quadratic formula: $y = a + c_1x + c_2x_2$, where y is the FLW, ADG, and ADFI; a is the intercept; x = FTB supplementation levels; $c_1$ and $c_2$ = coefficients of the optimisation equation; and $-c_1/2c_2$ = FVB level for optimum starter broiler performance. These models were chosen as they gave the best fit, with significance at 5% level.

ISSN 2616-0684 (Print)
ISSN 2616-0692 (Electronic)

## Results and Discussion

FTB had higher ($p < 0.05$) CP, EE, and ash, but lower DM than unfermented tamarind bark (Table 2), which supports of previous results by Ahiwe et al.[15] The decreased DM value of FTB is likely because yeast enzymes broke down complex compounds in tamarind bark into simpler molecules (volatile fatty acids, gases, alcohols) during fermentation.[29-30] The results showed that FTB had lower CF, NDF, ADF, ADL, and hemicellulose compared to unfermented tamarind bark. Fibre limits feed digestion by preventing enzyme access to nutrients[30], making high-fibre feed resources undesirable for poultry. [31] The activities of yeast during SSF may have reduced the concentrations of CF, NDF, ADF, ADL, and hemicellulose in tamarind bark, which yeast may use as a carbon source, leading to increased CP level, enhanced by microbial mass. Results revealed fermentation didn't change cellulose levels in tamarind bark. This finding is at variance with the findings of Gbenle et al.[14], who found reduced cellulose levels in marama beans because of the actions of *Aspergillus oryzae* during fermentation. The EE results support the findings of Gbenle et al.[14] that fermentation with fungi enhances the EE value of fibre-rich feed ingredients. This variation in results may be linked to the type of substrate used.[20] These results imply that yeast fermentation of tamarind bark yields a low-fibre biomass suitable as a poultry feed additive.

Phytochemical values of unfermented and FTB are displayed in Table 3. FTB had significantly ($p < 0.05$) higher levels of phenol, flavonoids, and DPPH, but lower levels of tannins, oxalate, phytate, alkaloids, and saponins compared to unfermented tamarind bark. These findings support the earlier results that fungal-mediated SSF improved the feed/food value of marama beans.[14] The significantly low levels of tannins, alkaloids, and saponins in tamarind bark indicate the ability of yeast-mediated SSF to biodegrade tannins, alkaloids, and saponins into simpler, less harmful compounds. Yeast decreases the concentrations of tannin and saponin in feed during fermentation via enzymatic activity and changes in pH.[32] In similar research, Arjmand et al.[33] revealed that yeast strains with β-glucosidase activity can biodegrade saponins, whilst fermentation activity creates an acidic medium that aids in saponin breakdown. Oxalates, a naturally occurring compound in plants, can bind with calcium in feed or feedstuffs to form calcium oxalate, an insoluble compound, making minerals less available for absorption.[34] The reduction in oxalate content of tamarind bark during fermentation might be due to the yeast's ability to synthesize enzymes that break down oxalic acid or oxalate-mineral complexes, hence reducing the overall oxalate level.[35] The decreased phytate level upon fermentation is likely due to the yeast producing phytase, an enzyme that degrades phytate.[36] Phytate binds to proteins, carbohydrates, and minerals, making them less available to digestive enzymes.[37] Thus, a decline in the phytate level can improve the availability of important minerals in fibrous biomass such as tamarind bark. This is quite important given that poultry does not synthesize phytase in their digestive system.

The significant increase in phenolics upon fermentation of tamarind bark could be related to the ability of yeast to produce lignocellulolytic enzymes such as cellulases, hemicellulases, and ligninases[38] that release bound forms of phenols and flavonoids during cell wall breakdown.[34] Phenolic compounds act as antioxidants and can enhance the antioxidant activity of functional feed ingredients, as confirmed by the DPPH results in this study. This observation confirms that fermentation increased the DPPH level in lignocellulosic biomass.[5] The higher contents of phenolics in FVB could provide a plausible explanation for the increased DPPH activity in FTB.

Table 4 shows the initial live weight (ILW), FLW, ADG, ADFI, FCR. and percentage mortality of birds fed FTB supplemented diets are shown in Table 4. Birds on T0.5, T1.0, and T1.5 performed better in terms of FLW, ADG, and ADFI than birds on T0.5. The enhanced ADG may be due to yeast breaking down complex fibre in tamarind bark into simpler, more readily absorbable nutrients, lignocellulosic complex reduced antinutritional factors in tamarind bark, as confirmed by our fibre fraction and phytochemical results. However, this finding was at variance with Ogbuewu and Mbajiorgu[5], who observed that inclusion of unfermented tamarind bark to broiler rations at the rate of 1.0 - 1.5 g/kg decreased ADG. This discrepancy suggests that fermentation improves physicochemical values of fibrous biomass, leading to improved nutrient utilization and uptake in poultry.[15] The FCR of broilers on T0.5, T1.0, and T1.5 was numerically lower ($p > 0.05$) than that on T0, indicating a high ability of broilers to utilize FTB-supplemented diets, leading to high FLW and ADG. There were no differences ($P>0.05$) in ILW and percentage mortality between broilers offered FTB and control diets.

**Table 2:** Proximate composition and fibre fractions of unfermented and fermented tamarind bark

| Parameters (%) | Unfermented | Fermented | Mean | SD | SEM | *p*-value |
|---|---|---|---|---|---|---|
| Dry matter | 93.47[a] | 91.51[b] | 92.49 | 1.14 | 0.57 | < 0.001 |
| Crude protein | 6.16[b] | 8.16[a] | 7.16 | 1.16 | 0.58 | 0.001 |
| Ether extract | 0.61[b] | 0.68[a] | 0.65 | 0.04 | 0.02 | 0.038 |
| Crude ash | 9.91[b] | 10.60[a] | 10.25 | 0.40 | 0.20 | < 0.001 |
| Crude fibre | 30.80[a] | 20.20[b] | 25.50 | 6.12 | 3.06 | 0.011 |
| Neutral detergent fibre | 61.36[a] | 48.39[b] | 54.87 | 7.53 | 3.77 | 0.006 |
| Acid detergent fibre | 50.29[a] | 46.34[b] | 48.27 | 2.41 | 1.20 | 0.028 |
| Acid detergent lignin | 24.04[a] | 20.47[b] | 22.25 | 2.06 | 1.03 | 0.001 |
| Cellulose | 26.26 | 25.77 | 26.01 | 0.57 | 0.29 | 0.512 |
| Hemicellulose | 11.07[a] | 2.16[b] | 6.61 | 5.30 | 2.65 | 0.029 |

**Table 3:** Phytochemical composition of unfermented and fermented tamarind bark

| Parameters | Unfermented | Fermented | Mean | SD | SEM | *p*-value |
|---|---|---|---|---|---|---|
| Tannins (mg/ g) | 8.73[a] | 1.73[b] | 5.23 | 4.04 | 2.02 | < 0.001 |
| Phenols (mg/g) | 8.22[b] | 15.99[a] | 12.11 | 4.51 | 2.25 | 0.004 |
| Flavonoids (mg/g) | 1.60[b] | 3.91[a] | 2.75 | 1.34 | 0.67 | < 0.001 |
| Oxalate (mg/g) | 0.48[a] | 0.28[b] | 0.38 | 0.12 | 0.06 | < 0.001 |
| Phytate (mg/g) | 0.11[a] | 0.09[b] | 0.10 | 0.01 | 0.01 | < 0.001 |
| Alkaloids (%) | 24.48[a] | 4.10[b] | 14.29 | 11.76 | 5.88 | < 0.001 |
| Saponins (%) | 13.56[a] | 8.04[b] | 10.80 | 3.19 | 1.60 | 0.001 |

**ISSN 2616-0684 (Print)**
**ISSN 2616-0692 (Electronic)**

| | | | | | | |
|---|---|---|---|---|---|---|
| DPPH (µg/ml) | 35.71[b] | 46.52[a] | 41.11 | 6.26 | 3.13 | 0.003 |

[a,b] Means with common superscripts do not statistically differ (P > 0.05). DPPH -2,2-Diphenyl-1-picrylhydrazyl; SD- standard deviation; SEM – standard error of the mean; p - probability.

**Table 4:** Performance of starter broilers fed diets supplemented with fermented tamarind bark

| Parameters | Dietary fermented tamarind bark Levels | | | | SEM | *p* val |
|---|---|---|---|---|---|---|
| | **T0** | **T0.5** | **T1.0** | **T1.5** | | |
| ILW (g/bird) | 44.15 ± 0.06 | 44.12 ± 0.01 | 44.15 ± 0.06 | 44.15 ± 0.05 | 0.01 | 0.846 |
| FLW (g/bird) | 511.15 ± 38.72[b] | 616.08 ± 35.49[a] | 614.51 ± 3.25[a] | 610.98 ± 11.61[a] | 14.97 | 0.003 |
| ADG (g/bird) | 24.34 ± 1.84[b] | 29.34 ± 1.69[a] | 29.26 ± 0.15[a] | 29.09 ± 0.55[a] | 0.71 | 0.003 |
| ADFI (g/bird) | 38.04 ± 2.17[b] | 44.86 ± 1.65[a] | 44.77 ± 0.46[a] | 44.41 ± 0.73[a] | 0.94 | 0.001 |
| FCR | 1.56 ± 0.04 | 1.53 ± 0.05 | 1.53 ± 0.01 | 1.53 ± 0.02 | 0.01 | 0.501 |
| Mortality (%) | 1.00 | 0.00 | 0.00 | 1.00 | - | - |

[a,b] Means ± SD in the same row with the same superscript are significant at $p < 0.05$. *FTB* fermented tamarind bark; T0 = 0 g FTB/kg feed; T0.5 = 0.5 g FTB/kg feed; T1.0 = 1.0 g FTB/kg feed; T1.5 = 1.5 g FTB/kg feed; *ILW* initial live weight; *FLW* final live weight; *ADG* average daily gain; *ADFI* average daily feed intake; *FCR* feed conversion ratio; *SD* standard deviation; *SEM* standard error of the mean

Results of the impact of FTB supplementation level on optimal FLW, ADG, and ADFI of starter broilers are presented in Figures 1 to 3 and Table 5. The results indicated that growth performance had high (74.8–80.2%) coefficients of determination ($r^2$). Not many studies have used quadratic regression to find the best tamarind bark levels that support broiler performance and health[5,7] Presently, there's a gap in research on using regression analysis to determine the optimal FTB levels for starter broiler growth. FLW and ADG were optimised at 3.05 g FTB/kg feed (Figures 1 and 2). This is expected since live weight and ADG are indirectly related. In addition, result indicates that ADFI was optimized at a level of 3.03 g/kg feed (Figure 3), indicating that the response of broilers to dietary FTB supplementation may depend on the production variable in question. The high $r^2$ levels for growth parameters suggest a strong relationship between FTB and improved growth variables. These results have implications for formulating broiler feed with FTB to improve growth parameters, thereby reducing additive wastage. The high $r^2$ values of FLW, ADFI, and ADG on FTB diets indicate that these results could be predicted at a given amount of FTB supplemented to the diets of starter broilers.

**Table 5:** Fermented tamarind bark levels for optimal performance characteristics of starter broilers

| Parameters | Equation | X | Y | $r^2$ | *p*val |
|---|---|---|---|---|---|
| FLW (g/bird) | Y=378.118 +165.370x - 27.115$x^2$ | 3.05 | 630.26 | 0.748 | 0.003 |
| ADG (g/bird) | Y = 18.006 +7.875x -1.291$x^2$ | 3.05 | 30.02 | 0.748 | 0.003 |
| ADFI (g/bird) | Y=29.287+10.884 x -1.797$x^2$ | 3.03 | 45.77 | 0.802 | 0.001 |

*X* level optimal FTB level; *Y* value optimal growth metric; $r^2$ coefficient of determination; *pval* probability.

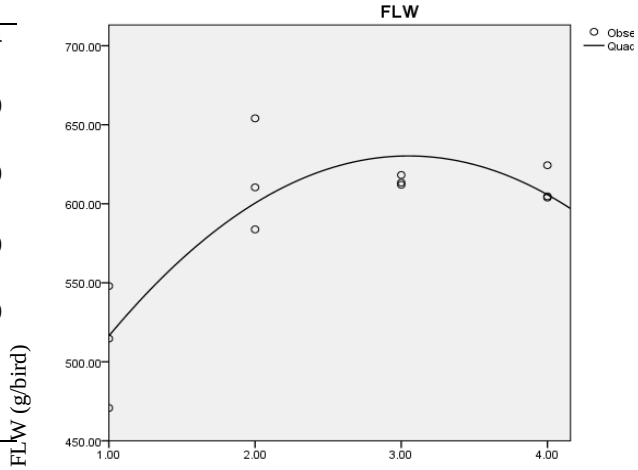


**Figure 1:** Relationship between dietary fermented tamarind bark supplementation level and FLW in starter broilers

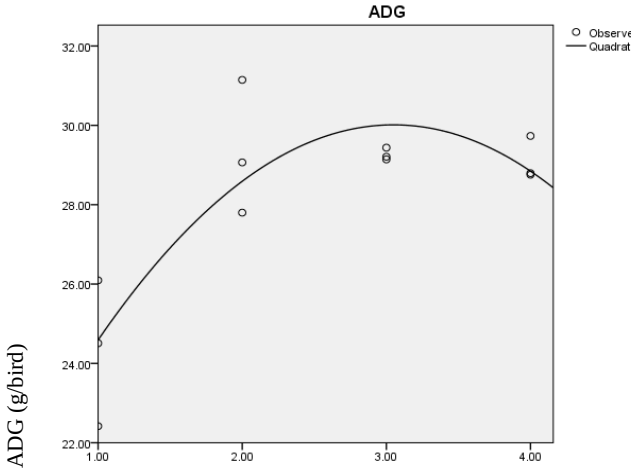


**Figure 2:** Relationship between dietary fermented tamarind bark supplementation level and ADG in starter broilers

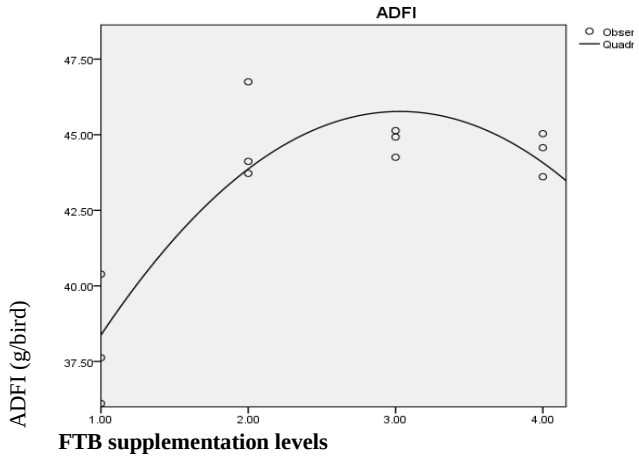


**Figure 3:** Relationship between dietary fermented tamarind bark supplementation level and ADFI in starter broilers

## Conclusion

In conclusion, yeast-mediated SSF improved proximate composition, fibre fractions, beneficial phytochemicals (flavonoids and phenols), DPPH activity, and decreased antinutrient content in tamarind. Results also indicated that FTB supplementation at 0.5, 1.0, and 1.5 g/kg feed enhanced FLW, ADG, and ADFI in broilers without negatively impacting FCR and percentage mortality. The quadratic optimization results suggested that FTB should be supplemented in the starter broiler diet at 3.05 and 3.03 g kg feed for the best FLW, ADG, and ADFI. Blood characteristics, plasma antioxidative status, gut histology, and microbiota composition of starter broilers fed FTB-supplemented diets are recommended, as such published data is lacking in the literature.

## Conflict of Interest

The authors declare no conflict of interest.

## Authors' Declaration

The authors hereby declare that the work presented in this article is original and that any liability for claims relating to the content of this article will be borne by them.

## Acknowledgements

This project was fully funded by the 2023 Tertiary Education Trust Fund (TETFUND) Institution-Based Research (IBR) Grants of the Federal University of Technology Owerri (FUTO), Nigeria with grant number: FUT/OVC/TETF/GEN.8/VOL 4.

## References

1. Amponsah SK, Otoo D, Peprah AK, Ampofo SD. Modelling the feed mix for poultry production, the case of Adama Musa farms, in Ghana. Int J. Appld Math Res. 2015; 4 (2): 404-410.
2. El-Fateh M, Bilal M, Zhao X. Effect of antibiotic growth promoters (AGPs) on feed conversion ratio (FCR) of broiler chickens: A meta-analysis. Poult Sci. 2024; 103:104472.
3. Ahiwe EU, Dos Santos TTT, Graham H, Iji PA. Can probiotic or prebiotic yeast (Saccharomyces cerevisiae) serve as alternatives to in-feed antibiotics for healthy or disease-challenged broiler chickens? A review. J. Appld Poult Res. 2021; 30:100164.
4. Egenuka FC, Obikaonu HO, Ogbuewu IP, Aladi NO. Changes in the bioactive compounds of sun-dried ginger rhizome and their effects on growth performance, blood profile, carcass and meat quality of broiler chickens. Nig J. Anim Prod. 2023; 50(2): 120-140.
5. Ogbuewu IP, Mbajiorgu CA. Dietary *Dialium guineense* stem-bark supplementation improves growth performance and haemato-biochemical characteristics of broiler chickens. Heliyon 2023; 9: e17341.
6. Savage GP, Morrison SC. Trypsin inhibitor. In: Caballero, B. (Ed.), Encyclopedia of Food Sciences and Nutrition. Elsevier Science Ltd, Canterbury, 2003; pp. 5878–5884.
7. Ogbuewu IP, Mbajiorgu CA. Dose related responses of broiler chickens to black velvet tamarind (*Dialium guineense*) stem bark supplementation: carcass characteristics, organ weight and intestinal biometry. Agroforest Syst. 2024; 98:245–254
8. Onah GT, Ajaegbu EE, Enweani IB. Proximate, phytochemical and micronutrient compositions of *Dialium guineense* and *Napoleona imperialis* plant parts. GSC Biol and Pharmaceut Sci. 2022; 18(03): 193–205.
9. Kumar A, Chandra R. Ligninolytic enzymes and its mechanisms for degradation of lignocellulosic waste in environment. Heliyon, 2020; 6: e03170.
10. Abduh MY, Yulianto R, Avima D, Widianto AK, Alfianny R. Solid-state fermentation of cinnamon bark using *Aspergillus awamori* to increase cinnamon oil yield extracted using hydrodistillation, maceration, and Soxhlet extraction. Nat Volatiles & Essent Oils 2021; 8(6): 1575-1588.
11. Arzinnahar M, Islam N, Shuvo AAS, Kabir AKMA, Islam KMS. Effect of feeding fermented (*Saccharomyces cerevisiae*) de-oiled rice bran in broiler growth and bone mineralization. J. the Saudi Soc Agric Sci. 2021; 20: 476-481.
12. Yang Q, Zhang H, Li X, Wang Z, Xu Y, Ren S, Chen X, Xu Y, Hao H, Wang H. Extracellular enzyme production and phylogenetic distribution of yeasts in wastewater treatment systems, Biores Tech. 2013; 129: 264-273.
13. Onyekuru SO, Nwankwor GI, Okeke OC, Okoye C, Opara KD. An assessment of the pollution potential of hand pump wells from septic tank units in the hostel areas of the Federal University of Technology, Owerri, Nigeria. Futo J. Ser (FUTOJNLS). 2017; 3: 138 – 160.
14. Gbenle J, Mert M, Phasha NN, Madibana MJ, Manyeula F, Bamidele OP, Toefy R, Dibakoane SR, Mlambo V. Fungal-mediated solid-state fermentation ameliorates antinutritional factors but does not improve in vitro digestibility of marama (*Tylosema esculentum*) beans. Future Foods, 2025;11: 100664,
15. Ahiwe EU, Iwuji TC, Egenuka FC, Okehie UN, Ejifor I, Chidinma A. Peter-Onoh CA, Ogbuewu IP, Emenalom OO. Performance and blood indices of broilers fed diets containing fermented *Citrus sinensis* (orange) pulp supplemented with or without multi-enzyme. Trop J. Nat Prod Res. 2025; 9(10): 5237 – 5244.
16. AOAC. Official Methods of Analysis of AOAC International. AOAC International, Rockville, MD, USA 2016.
17. Van Soest PJ, Robertson JB, Lewis BA. Methods for dietary fibre, neutral detergent fibre, and non-starch polysaccharides in relation to animal nutrition. J. Dairy Sci. 1991; 74(10):3583-3597.
18. Harborne JB. Textbook of Phytochemical Methods: A Guide to Modern Techniques of Plant Analysis, fifth ed., Chapman and Hall Ltd, London, 1998; pp. 21–72.
19. Trease GE, Evans WC. Phytochemicals, in: Pharmacognosy, Saunders Publishers, London 2002.
20. Olukomaiya OO, Fernando WC, Mereddy R, Li X, Sultanbawa Y. Solid state fermentation of canola meal with *Aspergillus sojae*, *Aspergillus ficuum* and their co-

cultures: effects on physicochemical, microbiological and functional properties. LWT. 2020; 127: 109362.
21. Chang C, Yang M, Wen H, Chern J. Estimation of total flavonoid content in propolis by two complementary colorimetric methods. J. Food Drug Anal. 2002; 10: 178–182.
22. Stankovic MS. Total phenolic content, flavonoid concentration and antioxidant activity of *Marrubium peregrinum* L. extracts. Kragujevac J. Sci. 2011; 33: 63–72.
from wheat bran. J. Food Comp and Analy. 2013; 32: 6-11.
25. Aviagen. Aviagen Ross 308 Nutrient Specifications. Available online at https://eu.aviag en.com/assets/Tech_Center/Ross_Broiler/RossBroiler NutritionSpecs2019-EN.pdf.2019. Accessed on 16 May 2025.
26. Khan S, Mobashar M, Mahsood FK, Javaid S, Abdel-Wareth AA, Ammanullah H, Mahmood A. Spirulina inclusion levels in a broiler ration: Evaluation of growth performance, gut integrity, and immunity. Trop Anim Hlth and Prod. 2020: 52: 3233–3240.
27. Pauzenga U. Feeding parent stock. Zootech Int. 1985; 22–25
28. IBM SPSS. IBM SPSS Statistics for Windows (Version 27.0) [Computer software]. IBM Corp, 2020.
29. Koni TNI, Soi R, Foenay TAYF. Content of dry matter, crude fibre, and ash in fermented rice bran with palmyra sap at different length of fermentation. BIO Web of Conf. 2023; 81: 00035. https://doi.org/10.1051/bioconf/20238100035.
30. Ng YV, Ismail TAT, Ishak WRW. Effect of overripe banana in developing high dietary fibre and low glycaemic index cookie. British Food J. 2020; 122 (10): 3165–3177.
31. Jha R, Mishra P. Dietary fibre in poultry nutrition and their effects on nutrient utilization, performance, gut health, and the environment: a review. J. Anim Sci Biotech. 2021; 12: 1–16.
32. Sharma R, Garg P, Kumar P, Bhatia SK, Kulshrestha S. Microbial fermentation and its role in quality improvement of fermented foods. Fermentation 2020; 6(4):106.
33. Arjmand S, Mollakhalili-Meybodi N, Akrami Mohajeri F, Madadizadeh F, Khalili Sadrabad E. Quinoa dough fermentation by *Saccharomyces cerevisiae* and lactic acid bacteria: Changes in saponin, phytic acid content, and antioxidant capacity. Food Sci Nutr.
23. Amaza IB. Determination of proximate composition, amino acids, minerals and phytochemical profile of Cassava (*Manihot esculenta*) peel from sweet cassava variety grown in Yobe State of Northeast Nigeria. Nig J. Anim Prod. 2021: 48(1): 124 - 134.
24. Ruan QY, Zheng XQ, Chen BL, Xiao Y, Peng XX, Leung DWM, Liu EE. Determination of total oxalate contents of a great variety of foods commonly available in Southern China using an oxalate oxidase prepared

2023;11(12):7594-7604. https://doi: 10.1002/fsn3.3679.
34. Zayed A, Adly GM, Farag MA. Management strategies for the anti-nutrient oxalic acid in foods: A comprehensive overview of its dietary sources, roles, metabolism, and processing. Food Bioprocess Tech. 2025; 18: 4280–4300.
35. Sulaiman I, Noviasari S, Lubis YM, Rozali ZF, Eriani K, Asrizal CW. Analysis types and functions of microbes and duration of fermentation in the process of reducing levels of concentration oxalate levels in taro kimpul. Syst Reviews in Pharm 2020; 11(11):1450-1456.
36. Samtiya M, Aluko RE, Dhewa T. Plant food anti-nutritional factors and their reduction strategies: an overview. Food Prod Process and Nutr. 2020; 2(6):1-14. https://doi.org/10.1186/s43014-020-0020-5.
37. Shi H, Wang J, Kim WK. Interactive effects of calcium, phosphorus, and exogenous phytase on growth performance and bone ash in broilers under Eimeria or necrotic enteritis infections: a systemic review and meta-analysis. J. Appld Poult Res. 2024; 33:100422.
38. Claes A, Deparis Q, Foulquié-Moreno MR, Thevelein JM. Simultaneous secretion of seven lignocellulolytic enzymes by an industrial second-generation yeast strain enables efficient ethanol production from multiple polymeric substrates, Metabol Eng. 59: 131-141.
39. Zhao YS, Eweys AS, Zhang JY, Zhu Y, Bai J, Darwesh OM, Zhang HB, Xiao X. Fermentation affects the antioxidant activity of plant-based food material through the release and production of bioactive components. Antioxidants (Basel) 2021;10(12):2004.
40. Ogbuewu IP, Modisaojang-Mojanaga MMC, Mokolopi BG, Mbajiorgu CA. Nutritional and chemical composition of black velvet tamarind (*Dialium guineense* Willd) and its influence on animal production: A review. Open Agric. 2023; 8: 20220174.