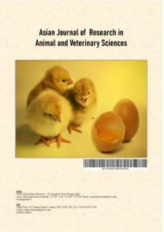

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Utilization of Solid State Fermented Cassava Peel Leaf Mix Meal as a Substitute for Maize in Broiler Chickens' Diets: Impact on Growth Performance, Carcass Indices and Lipid Peroxidation

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Authors' contributions

This work was carried out in collaboration among all authors. Authors RAA, SOA and GEO designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript. Authors JA and OOA managed the literature review, while authors APA and PO managed the analyses of the study. All authors read and approved the final manuscript.

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ABSTRACT

Aims: This research explored the potential of fermented cassava peel and leaf meal (FCPLM) as a maize substitute in broiler chickens' diets.

Study Design: Completely Dandomized Design.

Place and Duration of Study: The study took place at the Poultry Unit of the Teaching and Research Farm of Landmark University in Omu-Aran, Irepodun Local Government, Kwara State, Nigeria, located at coordinates 8°08′00″N 5°06′00″E for 7 weeks.

Methodology: The cassava peel and leaf were combined in a 19:1 ratio, milled, and then inoculated with *Aspergillus niger* (ATCC 16404) for solid-state fermentation (SSF), lasting 96 hours at room temperature with a substrate to water ratio of 1.0:1.0. Subsequently, FCPLM was integrated into diets for 480 seven-day-old Anak broiler chickens, divided into four groups of 60 chicks each, with each group further divided into 3 replicates. The diets included: Diet 1 (control, no FCPLM), Diet 2 (20% FCPLM), Diet 3 (40% FCPLM), and Diet 4 (60% FCPLM).

Results: Substituting maize with FCPLM significantly ($P < 0.05$) impacted broiler performance, carcass quality, lipid peroxidation, and production costs. Diet 3 exhibited the highest weight gain, optimal feed conversion ratio, and dressing percentage with respective values of 2286.80g, 1.95 and 75.95%, compare to 2252.60g, 2.00 and 75.81%.for the same parameters in Diet 1. Furthermore, as FCPLM inclusion levels increased, meat peroxidation decreased from 1.26 mmol/ml (Diet 1) to 0.16 mmol/ml (Diet 4). The feed cost and cost per kilogramme of meat decreased with higher FCPLM levels, with highest percentages of 26.35% and 13.50% for feed cost reduction per kilogram of feed, and 13.50% for feed cost per kilogram of chicken meat respectively in Diet 4.

Conclusion: The SSF with *Aspergillus niger* (ATCC 16404) enhances FCPLM, presenting a viable approach to enhance feed resources. This strategy improves feed efficiency, carcass yield, oxidative stability, and production costs,

Keywords: Alternative feed – resources; agro-industrial by-products; oxidative – stability; SDG – 1; SDG – 2; sustainability; value – addition.

1. INTRODUCTION

Monogastric animals are known for their high production rates and efficient conversion of nutrients into high-quality animal protein, despite the potentially high cost of this process [1]. These characteristics have positioned monogastric animals, particularly poultry, as a crucial pathway toward achieving United Nations Sustainable Development Goal 2 (UN SDG 2), which focuses on eradicating hunger and poverty.

In addition to these attributes, poultry boasts a short generational turnover, health-friendly meat (white flesh), and lower levels of unhealthy lipoproteins compared to red meat. Nearly every household in rural areas keeps backyard poultry, which can serve not only as a readily available food source but also as a means of generating income, thereby contributing to both hunger alleviation and poverty reduction. However, poultry production faces significant challenges, notably the high cost of production and the availability of sustainable feed resources. Feed constitutes approximately 75% of the production costs in poultry enterprises [2], which has deterred many from engaging in this business [3].

Nigeria is a major producer of cassava, yielding about 59.4 million metric tonnes annually as of 2019 [4]. One of the by-products of cassava processing is cassava peel, which makes up about 13% of the tuber [5]. Despite its potential, cassava peel is underutilized in the swine and poultry industries due to challenges such as low crude protein content (2 to 4% in dry matter, with true protein content less than 1%) and high levels of cyanogenic glycosides, which make it unsuitable for animal feed. Consequently, a significant amount of cassava peel goes to waste, contributing to environmental pollution [6].

Replacing corn with a cassava peel and leaf mixture in broiler diets is increasingly important due to several factors. Corn, as a primary energy source in poultry feed, is often subject to price volatility, supply shortages, and high import costs in many regions. By substituting corn with cassava by-products, which are more affordable and locally available, farmers can significantly reduce feed costs, making poultry production more economically sustainable. Additionally, cassava peels and leaves, often considered agricultural waste, are rich in fiber and nutrients that, when properly processed, can meet the dietary needs of broilers. This shift not only addresses the economic and logistical challenges of corn dependency but also promotes efficient waste management and environmental sustainability, making it a valuable focus for research in poultry nutrition.

The use of agro-industrial residues in solid-state fermentation (SSF) processes presents an alternative approach to enhance the value of these otherwise overlooked residues [7]. SSF involves microbial growth on insoluble substrates in a low-moisture environment [8], creating favorable conditions for microbial flora such as bacteria, yeasts, and fungi. Filamentous fungi, particularly those like Aspergillus species, are well-studied for SSF due to their hyphal growth [9].

Research has shown that SSF can enhance the nutritional content of agricultural by-products characterized by high fiber, low protein, and poor digestibility [10,11]. Fungi like *Aspergillus niger* are capable of breaking down lignocellulosic biomass components such as hemicellulose, lignin, and cellulose into fermentable sugars and other metabolites, which have applications in biofuel production, bioremediation, and the synthesis of value-added chemicals [12,13]. Aspergillus and related fungi are known producers of various enzymes, including xylanases and mannanases, which efficiently hydrolyze hemicellulose [14].

Aspergillus niger is crucial in animal feed, especially when used directly or through solid-state fermentation, due to its ability to produce a wide range of enzymes, such as phytase, protease, and amylase. These enzymes enhance the nutritional profile and digestibility of feed components, particularly those that are less conventional, such as cassava or agricultural by-products. By breaking down complex carbohydrates, proteins, and phytates, *Aspergillus niger* improves nutrient absorption in animals, leading to better growth performance and feed efficiency. This approach not only optimizes the use of alternative feed ingredients, reducing reliance on traditional grains like corn but also lowers feed costs and promotes more sustainable animal farming practices.

Therefore, the objective of this study is to assess how substituting maize with solid-state fermented cassava peel and leaf mix affects the growth performance, carcass quality, and lipid peroxidation of broiler chickens.

2. MATERIALS AND METHODS

2.1 Location and Duration of the Study

The seven weeks study took place at the Poultry Unit of the Teaching and Research Farm of Landmark University in Omu-Aran, Irepodun Local Government, Kwara State, Nigeria. This location features a tropical wet and dry (savanna) climate and is situated at an elevation of 536.14 meters (1,758.99 feet) above sea level. The average annual temperature here is 29.72°C (85.5°F), which is 0.26% higher than the national average in Nigeria. The geographical coordinates are 8°08′00″N, 5°06′00″E.

2.2 Sources of Ingredients

Cassava by-products were sourced from a local cassava processing factory in Omu-Aran town, while other feed ingredients used in formulating the experimental diets were purchased from Ilorin, Kwara State.

2.3 Source of the Candidate Organism

The *Aspergillus niger* ATCC 16404 was obtained from the Microbiology Department stock at Landmark University, Omu-Aran. The organism was cultured using the agar plating technique on potato dextrose agar and incubated at 25 °C for 7 days. Spores were harvested by tapping the inverted plate, and spore counts were determined using a haemocytometer following the Fuchs-Rosenthal technique, yielding approximately 1.07×10^9 spore-forming units per milliliter (sfu/ml).

2.4 Preparation of Cassava by- products

Cassava peels and leaves were spread on black polythene sheets and air-dried in a well-ventilated area until the peels became brittle and the leaves crisp while retaining their color. The dried peels and leaves were then combined in a 19:1 ratio to create a cassava peel-leaf mix meal. This mixture was crushed using a manual mill to produce flour, which was then packed into 2 kg batches in cellophane bags, sealed, and stored in a refrigerator at 4°C until inoculation with the candidate microorganism.

2.5 Inoculation Process

The dried cassava peel-leaf mix flour was divided into 2 kg batches and placed in autoclavable nylon bags. Distilled water was then added at a 1:1 (w/v) ratio. The samples were steam-heated at 100°C for 30 minutes. After cooling, they were transferred to fermentation plates and wrapped in cellophane. Each batch was inoculated with 40 ml of Aspergillus niger ATCC 16404, containing 1.07 x 10^9 sfu per ml, inside a laminar flow chamber. The plates were then covered with cellophane and kept in a fermentation chamber at room temperature for 96 hours. After fermentation, the samples were air-dried for 5 days at 25°C and 60% relative humidity before being incorporated into the broiler chickens' feed.

2.6 Design and Management of Birds and Experimental Diets

A total of 480 mixed- sex Anak 2000 broiler chicks, aged 7 days, were utilized in this study. The chicks were randomly selected based on their average initial weights and allocated to four dietary treatments (1, 2, 3, and 4) in a complete randomized design (CRD). Each treatment group consisted of four replicates with 30 chicks per replicate. Throughout the seven-week study period, all chicks were housed in deep litter compartments. The housing, feeders, and drinkers were thoroughly cleaned and disinfected prior to the start of the experiment. For the first week, the chicks were acclimatized with a commercial broiler starter diet. Subsequently, they were provided ad libitum access to the experimental diets and clean water. Routine medication, vaccination, and other management practices were carried out in accordance with Ag Guide guidelines [15].

Four diets were formulated for both the starter and finisher phases, incorporating varying levels of fermented cassava peel-leaf mix meal (FCPLM) as a replacement for maize on a weight-for-weight basis. Treatment 1 (0% FCPLM) served as the control, while treatments 2 to 4 included FCPLM at inclusion rates of 20%, 40%, and 60%, respectively, replacing maize in their diets. Table 1 below presents the formulated broiler starter and finisher diets. The diets were formulated by substituting corn (weight-for-weight) with graded levels of fermented cassava by-products (FCBPs) ranging from 0% to 60%, while other feed ingredients remained constant across all diets. The chicks were fed an initial diet (broiler starter) from day 1 to day 21, followed by a final diet (broiler finisher) from day 22 to day 49. The crude protein content of the diets ranged from 23.19% (diet 4) to 23.90% (diet 1) in the starter diets and from 19.76% (diet 4) to 20.72% (diet 1) in the finisher diets. The metabolizable energy content ranged from 2935 kcal/kg (diet 4) to 3036 kcal/kg (diet 1) in the starter diets and from 2953 kcal/kg (diet 4) to 3073 kcal/kg (diet 1) in the finisher diets.

Table 1. Composition (%) of diets fed he experimental diets (on dry matter basis)

Feed ingredients	**Broiler starter feed (1 - 21 day)**				**Broiler finisher feed (22 – 49 day)**			
	Diet 1	**Diet 2**	**Diet 3**	**Diet 4**	**Diet 1**	**Diet 2**	**Diet 3**	**Diet 4**
Maize	56.00	44.80	33.60	22.40	65.00	52.00	39.00	26.00
FCPLM	0.00	11.20	22.40	33.60	0.00	13.00	26.00	39.00
SBM	38.01	38.01	38.01	38.01	30.00	30.00	30.00	30.00
Fish meal	2.00	2.00	2.00	2.00	1.20	1.20	1.20	1.20
Bone meal	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Salt	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Methionine	0.25	0.25	0.25	0.25	0.20	0.20	0.20	0.20
Lysine	0.15	0.15	0.15	0.15	0.10	0.10	0.10	0.10
Premix	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
TB	0.10	0.10	0.10	0.10	0.00	0.00	0.00	0.00
Calculated Analysis								
CP (%)	23.90	23.66	23.45	23.19	20.72	20.40	20.08	19.76
ME	3036	2948	2969	2935	3073	3031	2993	2953

**FCPLM = Fermented cassava peel- leaf mix meal, D1 = Control diet without FCPLM; D2 = Diet containing 20% FCPLM; D3 = Diet containing 40% FCPLM; D4 = Diet containing 60% FCPLM; SBM = Soya bean meal; TB = Toxin binder; CP = Crude protein; ME (kcal/kg) = Metabolizable energy*

2.7 Data Collection and Evaluations

2.7.1 Proximate Analyses of Unfermented and Fermented Cassava Peel – Leaf Mix Flour

The preliminary study of the proximate (dry matter, crude protein, ether extract, crude fiber, and ash) values of both the unfermented and fermented cassava peel – leaf mix flour was carried out using the method of AOAC [16].

2.7.2 Growth performance evaluation

Throughout the feeding trials, daily feed intake and weight changes were meticulously documented, with weight gain and feed conversion ratio calculated to assess the birds' performance. Daily feed intake was determined by measuring the amount of feed provided daily and subtracting any remaining feed at the end of each day.

Feed intake = Feed given - Remnant

The weekly weight gain was determined by the difference between the weight at the beginning of the week and the weight at the end of the week. The feed conversion ratio is the ratio of the feed intake to that of the weight gain.

$$\text{Feed conversion ratio (FCR)} = \frac{Feed\ intake\ (g)}{Weight\ gain\ (g)}$$

2.7.3 Carcass quality assessment

At the conclusion of the feeding trial, the birds underwent an overnight fasting period. From each treatment group, 12 chickens were selected for carcass evaluation. These chickens were weighed, slaughtered, bled, plucked, and eviscerated. The weights of the plucked, eviscerated, and dressed chickens were recorded. Subsequently, the dressed chickens were segmented into parts, and their individual weights were measured relative to their live weights. The weights of internal organs and abdominal fat were also measured individually relative to live weights. Using an electronic balance. Dressing percentage was calculated using the formula:

$$\text{Dressing percentage} = \frac{dressed\ weight}{live\ weight} \times 100\ \%$$

2.7.4 Peroxidation test (meat oxidative stability)

Meat samples (2 g) from the thigh of one carcass per replicate from each of the four treatments were packed individually in cellophane bags, sealed, and stored in a freezer for 5 days. Lipid oxidation was then assessed using a thiobarbituric acid reactive substances (TBARS) assay following the method described by [17]. The meat samples were homogenized in a buffer solution to extract lipids. Subsequently, the homogenate was incubated at 95 °C for 1 hour to promote the formation of malondialdehyde (MDA). A solution containing 0.05 % thiobarbituric acid (TBA) and 30 % trichloroacetic acid (TCA) was added to the homogenate, which reacted with MDA, resulting in the formation of a pink-colored complex. After centrifugation to remove any precipitates, the absorbance of the pink-colored complex was measured using a spectrophotometer at a wavelength between 532-535 nm. The concentration of MDA was calculated as:

$$\text{MDA (nmol/mL)} = \frac{A532\ X\ M.Wt\ of\ MDA\ X\ Tv}{T\ X\ E\ X\ 1000\ X\ SV}$$

Where:

A = Absorbance of test at 532 nm
M.Wt = molecular weight of malondialdehyde = 72 gmol-1
Tv = Total volume of reaction mixture = 2.5mL
T = Time for colour development
E = Molar extinction coefficient of MDA-TBA 2 complex
Sv = Volume of sample used = 1.0 ml

2.7.5 Economic analysis of production costs

The economic evaluation involved estimating the costs of producing the experimental diets based on prevailing market prices of the ingredients, and assessing the percentage cost reduction achieved. Additionally, the cost of producing 1 kg of meat under each treatment condition was calculated, while disregarding other shared experiment costs.

The cost of feed consumed = cost of 1kg of feed x total feed consumed

$$\%\ \text{cost reduction in feed} = \frac{Cost\ of\ control\ diet - Cost\ of\ test\ diet}{Cost\ of\ control\ diet}\ x\ 100$$

$$\text{Cost of feed/kg meat} = \frac{Cost\ of\ feed\ Intake}{Weight\ of\ the\ bird}$$

% Cost reduction in production of 1kg meat=(Cost of producing 1kg meat in control diet-Cost of producing1kg meat in test diet/ Cost of producing 1kg meat in control diet) x 100

2.8 Data Analyses

All data collected on growth performance, carcass parameters, lipid peroxidation and cost evaluation were subjected to Analysis of Variance (ANOVA) using SAS 2000 package Where significant difference existed, Duncan Multiple Range Test (DMRT) of the same package was used to separate the means.

3. RESULTS AND DISCUSSION

3.1 Proximate Analysis of Unfermented and Fermented Cassava Peel-Leaf Mix Meal

Solid-state fermentation (SSF) using *A. niger* ATCC 16404 significantly (*P = 0.05*) influenced the proximate composition of cassava peel-leaf mix meal (Table 2). The crude protein (CP), ether extract (EE), ash, and crude fiber (CF) values were enhanced through SSF, while the nitrogen-free extract (NFE) content was reduced. This finding supports previous reports, such as that of [11], indicating that SSF can improve the nutritional profile of agro-industrial by-products.

The CP, EE, and ash content increased from 4.32%, 3.75%, and 7.13%, respectively, in the unfermented cassava peel-leaf mix meal (UCPLM) to 8.54%, 12.01%, and 9.45% in the fermented cassava peel-leaf mix meal (FCPLM). This represents enhancements of 98.14%, 220.27%, and 32.54% in CP, EE, and ash, respectively. CF decreased from 13.32% in UCPLM to 10.33% in FCPLM, indicating a 22.47% improvement. NFE decreased from 62.01% to 49.56%. These results align with findings by [18], and [19], who reported similar trends in CP, EE, ash, NFE, and CF when employing SSF techniques on cassava peels and leaf mixes using various microorganisms.

The neutral detergent fiber and acid detergent fiber were significantly reduced (*P* = .01 and *P* = .04 respectively), further indicating an improvement in the nutritional quality of the cassava peel-leaf mix meal. This reduction in fiber content was also noted in studies by [20] and [21], where SSF using different fungal species led to decreased CF in animal feed ingredients.

The microorganisms utilize the carbohydrates in CPLM as an energy source, growing and reproducing. This growth translates into an increase in microbial biomass, which is rich in protein. The final product (FCPLM), after fermentation and drying, has a higher protein content compared to the unfermented cassava peels and leaves. This enriched feed ingredient when used as a replacement for maize in the diet of broiler chickens, provided them with more protein, which is essential for their growth and development. In other word, biomass contributes to protein increase through microbial growth, nutrient enrichment, efficient bioconversion, and enhanced digestibility, ultimately leading to a protein-rich end product that is highly beneficial in animal nutrition.

The increase in CP content observed in the fermented cassava peel-leaf mix meal is particularly beneficial for normal growth, repair, and maintenance in livestock. This enhancement is likely due to the secretion of extracellular enzymes by fermenting microorganisms, facilitating the utilization of starch as a carbon source [22,23]. Additionally, the proliferation of microbial biomass may contribute to the observed increase in protein content [24,25,26].

Ether extract plays a crucial role in livestock nutrition by providing essential fatty acids, fat-soluble vitamins, and concentrated energy. While SSF can lead to lipid degradation and a decrease in EE content, it can also result in the formation of bioactive lipid-derived compounds and the utilization of lipid substrates for microbial metabolic activities. Study by [27] has demonstrated increases in EE content following SSF of various agricultural by-products. The increase in ash content in the fermented cassava peel-leaf mix meal highlights the potential mineral enrichment achieved through microbial fermentation, which is valuable for animal feed formulations.

The decrease in NFE content in the fermented cassava peel-leaf mix meal suggests that microorganisms likely hydrolyzed starch into glucose for their own growth. Alternatively, increased protein levels in inoculated cassava peels may have contributed to the reduction in carbohydrates [28,29].

The practice of enhancing the nutritional quality of agro-industrial by-products through microbial fermentation is gaining popularity, as noted by [30] and [31], particularly in improving poultry feeding practices.

Table 2. Proximate values of unfermented and fermented cassava peel – leaf mix meal

Parameters (%)	UCPLM	FCPLM	SEM (±)	*P* value
Moisture	9.58	10.11	1.85	.06
Crude protein	4.21^{b}	8.54^{a}	2.01	.04
Ether extract	3.75^{b}	12.01^{a}	2.03	.01
Crude fiber	13.32^{a}	10.33^{b}	3.01	.02
Ash	7.13^{b}	9.45^{a}	2.94	.05
Nitrogen free extract	62.01^{a}	49.56^{b}	5.02	.03
Neutral detergent fiber	48.01^{a}	19.64^{b}	3.35	.01
Acid detergent fiber	27.92^{a}	13.94^{b}	4.57	.04

$^{a, b}$ = Means on the same row but with different superscripts are statistically significant (P < 0.05); UCPLM = unfermented cassava peel - leaf mix meal; FCPLM = Fermented; unfermented cassava peel - leaf mix meal; SEM = Standard error of mean

Table 3. Performance of broiler chickens fed diets containing the fermented cassava peel-leaf mix meal

Parameters (%)	Level of fermented cassava peel- leaf mix meal					
	Diet 1	Diet 2	Diet 3	Diet 4	SEM (±)	*P* value
Initial body weight	45.40	45.45	44.98	45.00	3.32	.07
Final body weight	2298.00^{b}	2332.25^{a}	2347.33^{a}	2184.50^{c}	5.02	.01
Total weight gain	2252.60^{ab}	2286.80^{b}	2303.35^{a}	2139.50^{c}	3.05	.01
Total feed intake	4512.56^{a}	4465.04^{b}	4456.56^{b}	4433.04^{c}	4.18	.02
FCR	2.00^{ab}	1.95^{b}	1.93^{b}	2.07^{a}	2.02	.04

$^{a, b, c}$ = Means on the same row but with different superscripts are statistically significant (P < 0.05);); Diet 1 contain 0% FCPLM, Diet 2 contain 20% PCPLM; Diet 3 contain 40% FCPLM; Diet 4 contain 60% FCPLM SEM = Standard error of mean, SEM = Standard error of mean, EW = Eviscirated weight mean

Table 4. Carcass parameters and relative organs' weights of broiler chickens fed diets fermented cassava peel- leaf mix meal

Parameters (%)	Level of fermented cassava peel- leaf mix meal					
	Diet 1	Diet 2	Diet 3	Diet 4	SEM (±)	*P* value
Live weight (g)	2290.78^{b}	2330.53^{a}	2345.23^{a}	2185.75^{c}	5.55	.04
EW %	84.20^{a}	85.87^{a}	85.99^{a}	79.49^{b}	1.58	.04
Dressing (%)	75.81^{a}	75.95^{a}	76.98^{a}	70.84^{b}	2.50	.02
Heart (%)	0.53	0.53	0.51	0.55	0.50	.07
Lung (%)	0.59	0.60	0.62	0.62	0.50	.14
Liver (%)	2.50	2.53	2.55	2.55	0.10	.11
Gizzard (%)	1.61	1.60	1.65	1.68	1.25	.42
Proventriculus (%)	0.40	0.43	0.47	0.45	0.10	.66
Spleen (%)	0.001	0.001	0.001	0.001	1.01	.83
Belly fat (%)	0.01	0.01	0.01	0.01	0.01	.55

$^{a, b, c}$ = Means on the same row but with different superscripts are statistically significant (P < 0.05); Diet 1 contain 0% FCPLM, Diet 2 contain 20% FCPLM; Diet 3 contain 40% FCPLM; Diet 4 contain 60% FCPLM SEM = Standard error of mean, EW = Eviscirated weight

3.2 Growth Performance Study of Broiler Chickens Fed the Experimental Diets

The study on growth performance of broiler chickens fed experimental diets revealed significant (*P=0.05*) improvements when including fermented cassava peel – leaf mix (CPLM). The total weight gain increased (*P* = .01) with CPLM levels in the diets up to 40%, after which it sharply decreased. The highest weight gain (2303.35 g) was achieved with the 40% CPLM diet. Conversely, feed intake decreased (*P* = .02) as CPLM levels increased. Similarly, the feed conversion ratio (FCR) decreased with increasing CPLM levels up to 40%, but then began to rise. The highest (P = .04) FCR with value of 2.02) occurred with Diet 4 (60% CPLM), while Diet 3 (40% CPLM) had the lowest FCR at 1.93. Diets containing up to 40% CPLM replacement exhibited superior weight gain and FCR.

Emmanuel et al [32] also observed higher weight gain with graded levels of fermented cassava peel. In contrast, [33] found no significant effect when using solid state fermented cassava root – PKC mixture with *Rhizopus oligosporus*. Valdez et al. [34] previously reported improved broiler growth and carcass yield with cassava leaf meal supplementation, possibly due to bioactive substances like antioxidants and flavonoids.

Notably, [35] observed inferior growth performance in broiler chickens fed diets containing cassava peel – leaf mix compared to those on a control diet without it. This suggests that the enhanced growth performance in the present study might be attributed to solid state fermentation of cassava peel – leaf meal using *A. niger* ATCC 16404. Sugiharto and Ranjitkar [36] also advocated for solid state fermentation as a method to improve broiler chicken growth performance.

3.3 Impact of the Fermented Cassava Peel – Leaf Mix Meal on the Carcass and Relative Organ Weights of Broiler Chickens

The live weight, eviscerated weight, and dressing percentages were significantly influenced by the FCPLM levels (*P = 0.05*), while there was no significant impact on the relative weights of evaluated visceral organs (Table 4). Live weight, eviscerated weight, and dressing percentages exhibited a similar pattern, gradually increasing and then decreasing at the 60 % FCPLM level. The highest values for these parameters were observed at the 40 % FCPLM level. However, the increases observed from the control diet (0 % FCPLM) up to the 40 % FCPLM diet were not statistically significant *(P* > 0.05).

Khempaka et al. [37] reported improved carcass yield in growing pigs fed diets containing microbially enhanced cassava peel, with the highest dressing percentage noted in swine fed a 40 % microbially fermented cassava peel diet. Conversely, [38] found that *A. oryzae* fermented cassava peel had no significant effect on carcass yield or growth performance in broiler chickens. Similarly, [39] reported no significant effect (*P > 0.05*) on the dressing percentage of pigs fed *Aspergillus tamarii* fermented cassava peel – leaf mix.

Contrary to [40], who reported reduced carcass yield in broiler chickens fed *A. niger* fermented cassava meal, the present study found no significant effect on relative organ weights, consistent with these results. Leaf meals in broiler diets are known to positively influence carcass yield due to their rich content of vitamins, minerals, and bioactive substances that promote carcass and organ development. The inclusion of fermented cassava leaves in the experimental diets likely contributed to the observed enhanced carcass yield compared to the control.

The findings regarding carcass indices and relative visceral organ sizes suggest that solid state fermentation of cassava peel – leaf mix using *A. niger* ATCC 16404 supported muscle and organ development in broiler chickens. This aligns with the findings of [30], who noted that fermented cassava root meal did not affect abdominal fat size in broiler chickens. The lack of significant impact on abdominal fat content suggests that the tested diets could potentially produce lean broiler chicken meat.

3.4 Lipid Peroxidation in Meat from Broiler Chickens Fed the Experimental Diets

The degree of peroxidation/oxidative stability as indicated by the level of malondialdehyde (mmol/ml) in the broiler chicken meat represented in Fig. 1. The assessment of blood parameters, enzyme activity, and oxidative status of various organs provides a precise estimation of bird health and nutritional status, thereby elucidating the effects of additives on the organism [41]. Malondialdehyde (MDA), a three-carbon compound, is a prominent aldehyde resulting from lipid peroxidation in foods. The thiobarbituric acid reactive substances (TBARS) method is commonly used to quantify lipid oxidation products by measuring MDA levels [42].

In our current investigation, we found that the levels of MDA, a key marker of lipid peroxidation, were notably influenced by the inclusion of fermented cassava peel – leaf mix (FCPLM) in broiler chicken diets (P = .05). Specifically, as the proportion of FCPLM increased in the diets, the concentration of MDA in the meat showed a consistent decrease.

This observation aligns with earlier study by [42], where higher MDA concentrations were reported in control diets compared to those enriched with fermented cassava derivatives. The higher MDA levels in the control diet imply greater lipid peroxidation, potentially indicating increased fat accumulation and reduced oxidative stability in the meat. Conversely, the solid-state fermentation of cassava peel – leaf mix using *A. niger* ATCC 16404, as observed in our study and supported by [43], likely contributed to decreased lipid peroxidation and enhanced meat stability. This improvement suggests that the FCPLM effectively prolong meat shelf-life by mitigating oxidative damage.

Moreover, our findings suggest a beneficial effect of higher maize replacement levels in the diet on the oxidative stability of broiler chicken meat, as previously indicated by [44]. This underscores the potential for dietary modifications to positively influence meat quality parameters, including lipid oxidation and overall oxidative stability.

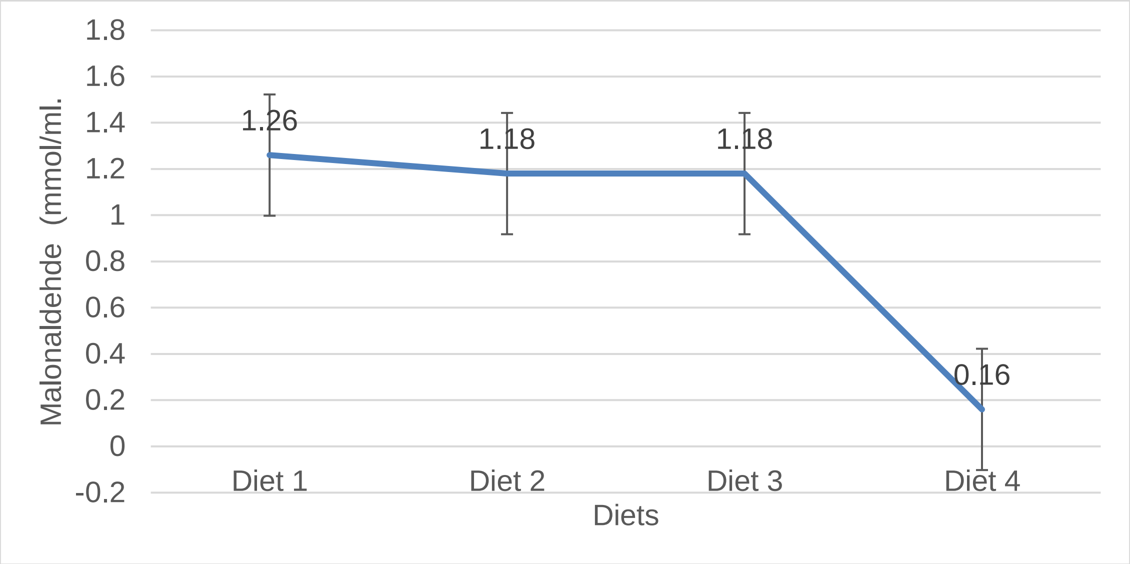

Fig. 1. The degree of Lipid peroxidation in broiler chickens fed dietary fermented cassava peel – leaf mix meal

Diet 1 contain 0% FCPLM, Diet 2 contain 20% FCPLM; Diet 3 contain 40% FCPLM; Diet 4 contain 60% FCPLM

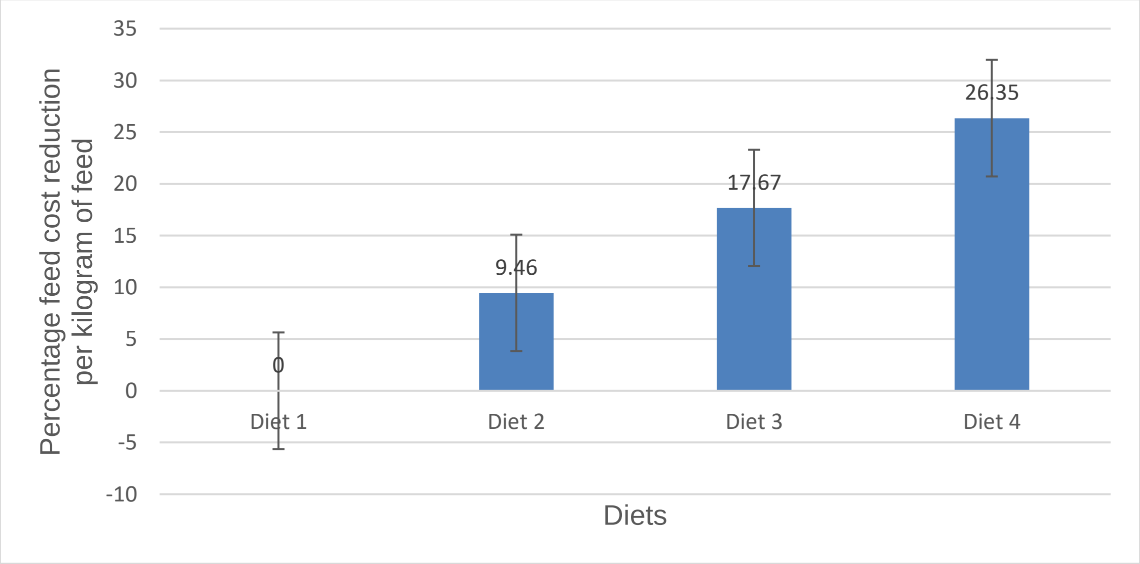

Fig. 2. The Feed cost reduction per kilogram of feed in Broiler chickens fed dietary fermented cassava peel – leaf mix meal

Diet 1 contain 0% FCPLM, Diet 2 contain 20% FCPLM; Diet 3 contain 40% FCPLM; Diet 4 contain 60% FCPLM

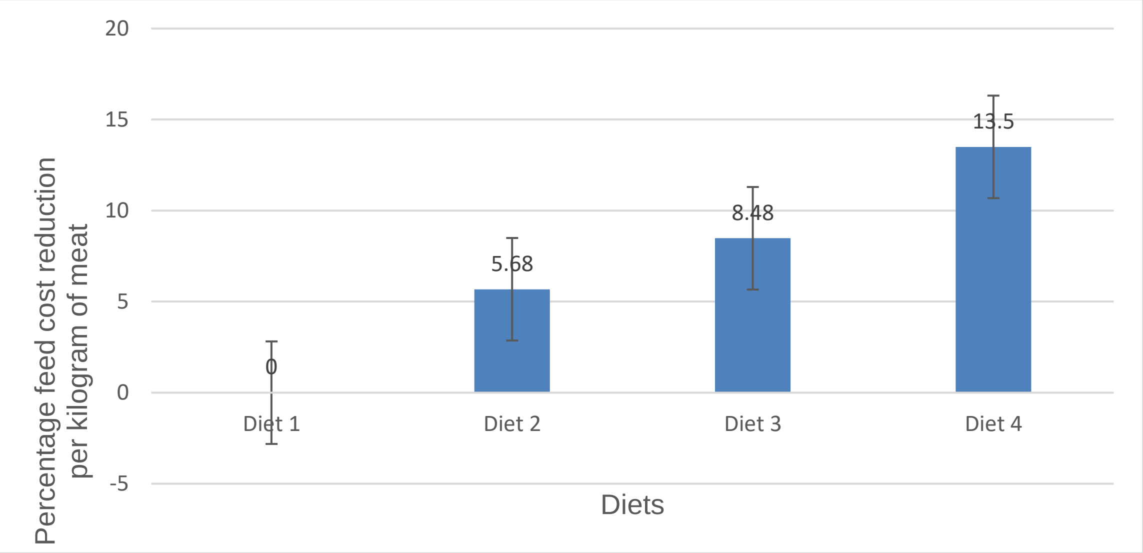

Fig. 3. The Feed cost reduction per kilogram of meat in Broiler chickens fed dietary fermented cassava peel – leaf mix meal

Diet 1 contain 0% FCPLM, Diet 2 contain 20% FCPLM; Diet 3 contain 40% FCPLM; Diet 4 contain 60% FCPLM

3.5 Economy Utilization of Dietary Fermented Cassava Peel – Leaf Mix Meal inf Broiler Production

The economic parameters assessed in this study such as the cost of starter and finisher feeds per kilogram, total feed cost, and feed cost per kilogram of broiler meat decreased as the level of FCPLM used as maize replacement increased, consistent with findings by [45]. The feed cost reduction per kilogram of feed, increased from 9.46% in Diet 2 to 26.35% in Diet 4, when compared to cost of feed in Diet 1 (the control diet with no FCPLM). Likewise, the feed cost reduction per kilogram of broiler meat produced increased from 5.68% in Diet 2 to 13,50% in Diet 4 when compared to the cost in the control diet.

This study provides evidence that sustainable cost reduction in feed can be achieved by utilizing fermented cassava by-products, which are readily available year-round, cost-effective, and safe for poultry [46]. The findings also align with [47] who reported lower feed costs per kilogram due to the incorporation of locally available alternative feedstuffs. This substantial cost reduction has prompted discussions by [48,49] advocating for increased research focus on utilizing unconventional feed sources to revolutionize the livestock industry in developing economies.

As the inclusion level of FCPLM increased in the diets, there was a corresponding increase in percentage reductions in total feed costs, feed costs per kilogram of broiler meat, return on investment, and economic efficiency. This suggests that using FCPLM can potentially increase meat yield at reduced costs.

4. CONCLUSION

The study findings indicate that employing solid-state fermentation with *A. niger* ATCC 16404 is a cost-effective method to enhance the nutritional profile of cassava peel – leaf mix meal, suitable for adoption by local farmers with minimal support. Substituting maize with FCPLM up to 40% improved broiler chickens' growth performance, carcass yield, and the oxidative stability of their meat.

This research enhances our understanding of how dietary modifications, such as replacing maize with fermented cassava peel – leaf mix (FCPLM), can influence meat quality by affecting lipid peroxidation and oxidative stability. These findings are pivotal for optimizing poultry diets to enhance meat quality and extend shelf-life, aligning with consumer demands for nutritious and sustainable food products.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

ETHICAL APPROVAL

All authors hereby declare that "Principles of laboratory animal care" (NIH publication No. 85-23, revised 1985) were followed, as well as specific national laws where applicable. All experiments have been examined and approved by the appropriate ethics committee.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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