



## Nutritional Evaluation of *Spondias mombin* and *Theobroma cacao* as Potential Poultry Feed Supplements in Nigeria

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### ABSTRACT

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Poultry feed constitutes a significant portion of production costs in the poultry industry. Exploring underutilized plant species as alternative feed ingredients could help mitigate these costs while enhancing feed quality. However, limited research exists on such alternatives in Nigeria. This study evaluates the nutrient composition of byproducts from *Theobroma cacao* (cocoa bean shell) and *Spondias mombin* (hog plum) and their potential as poultry feed supplements in comparison with FAO standards. Kernel and husk samples of *S. mombin* and *T. cacao*, respectively, were collected from various locations, air dried and sun-dried for 80 hours respectively, ground, sieved (0.5 mm), and analyzed for proximate composition, metabolizable energy, minerals, and amino acids using AOAC methods. Results revealed significant variations in nutrient composition, with *T. cacao* husk exhibiting higher crude protein, moisture content, and in vitro organic matter digestibility ( $p < 0.001$ ) compared to *S. mombin* kernel. Additionally, *S. mombin* provided essential minerals such as calcium and phosphorus, along with lysine, which aligns with FAO requirements for poultry diets. While neither ingredient meets FAO standards individually, their complementary nutrient profiles suggest that a strategic blend could enhance overall feed quality. These findings highlight the potential of *T. cacao* and *S. mombin* byproducts as sustainable alternatives to conventional poultry feed ingredients, particularly in reducing reliance on soybean-based protein sources.

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### Introduction

As populations grow and incomes rise, the demand for livestock products continues to increase and is expected to surge significantly in the coming decades (FAO, 2018). This expansion drives a greater need for affordable, high-quality feed, which is essential for maintaining cost-effective and sustainable poultry production (Ravindran, 2013). Poultry farming involves the commercial rearing of various domestic birds primarily for the production of meat, eggs, and feathers. Among these, chickens are the most commonly raised and widely preferred poultry species (Mallick *et al.* 2020). Poultry feeding plays a crucial role in the poultry industry, as feed expenses typically make up 70–80% of the total production costs

(Gunasekar, 2007; Olugbenga, Abayomi, Oluseye, & Taiwo, 2015).

The poultry industry primarily depends on cereals, which are also essential for human consumption, driving up costs and creating shortages (Tekeli, 2014). To maintain nutritional quality, manufacturers use expensive additives like amino acids and vitamins. This increases the overall cost of modern poultry feeds (Mallick *et al.* 2020). To maximize returns on poultry investments, it is crucial to optimize feed formulations for poultry birds. Optimisation can be achieved by exploring the underutilised crops or forgotten crops in Africa as supplement for feed production.

Africa must ensure sustainable food and nutrition security for its growing population while minimizing environmental, social, and economic impacts. Forgotten food crops, known for their nutritional value and resilience, align well with local dietary practices (FAO, 2024).

*Spondias mombin* has been classified as a threatened tree species by the International Union for Conservation of Nature (IUCN) (BGCI, 2019). However, it thrives across diverse humid tropical climates, often found in secondary vegetation derived from evergreen lowland and semi-deciduous forests (<http://www.worldagroforestry.org/>). Commonly referred to as the Caja plant, *Spondias mombin* belongs to the Anacardiaceae family and is native to tropical America, with widespread naturalization in Africa and Southeast Asia (Duarte & Paull, 2015). It is abundant in Brazil and West Africa (Sofowora, 2013), particularly in Nigeria's southwestern and coastal regions (Fadimu et al., 2018). The mature fruit is characterized by a leathery skin, a thin pulp layer, and an oil content of 31.5%, with reported ethnobotanical applications, including diuretic, febrifuge, and astringent properties (Eromosele et al., 2003; Ayoka et al., 2008). The leaves serve as a vital forage source for livestock during dry seasons, while various plant parts are extensively utilized in traditional medicine (Tabuti et al., 2010). Phytochemical and nutrient evaluations by Njoku & Akumefula (2007) identified significant bioactive compounds, including tannins (3.82%), saponins (7.60%), flavonoids (3.00%), alkaloids (6.00%), and phenols (1.00%). Vitamin analysis revealed the presence of ascorbic acid (19.35 mg), niacin (3.75 mg), riboflavin (0.25 mg), and thiamine (0.05 mg). Additionally, mineral composition analysis showed potassium (2.55%), magnesium (0.3045%), sodium (0.100%), calcium (1.310%), and phosphorus (0.200%) (Njoku & Akumefula, 2007), indicating its potential as both a medicinal resource and a supplementary feed ingredient for ruminants in various African regions.

*Theobroma cacao* is widely cultivated in tropical lowland regions for its seeds, which are essential for food, medicine, fibre, and construction materials. Beyond its primary use, cocoa husk has shown potential as a supplementary feed ingredient in poultry nutrition due to its nutrient composition and bioactive compounds (Grechkina et al., 2021). Research suggests that incorporating up to 15% cocoa pod husk, along with exogenous enzymes, in layer diets does not adversely affect production performance or egg quality (Nortey et al., 2015). Moreover, its inclusion in broiler feed has demonstrated a protective effect by reducing the accumulation of toxic elements, lowering mercury, lead, tin, and strontium levels by 53.5%, 18.2%, 69.4%, and 26.3%, respectively (Grechkina et al., 2021). This study therefore aims to examine the nutrients value of these underutilized plant species and its potentials as supplements in poultry diet and compared with FAO standards.

## Materials and Method

### Study Area, Climate and Distribution

The study was conducted in southwestern Nigeria, a region where these species naturally thrive in both abandoned farmlands and wild rainforest ecosystems. This area spans longitudes 2°48'–6°0' E and latitudes 5°05'–9°12' N, sharing borders with the Republic of Benin to the west, Kogi and Edo States to the east, and Kwara State to

the north. Its southern boundary meets the Gulf of Guinea along the Atlantic coastline. The region experiences two primary seasons: a dry season from November to March and a rainy season from April to October. Temperature fluctuates between 21°C and 34°C, with annual rainfall varying from 1,500 mm to 3,000 mm (Borisade et al., 2021). The precise coordinates, including latitude, longitude, and elevation of collection sites, were recorded using a Global Positioning System (GPS; Garmin Model).

These species predominantly inhabit tropical evergreen rainforests and moist semi-deciduous forests at elevations ranging from sea level to 500 meters (CAB, 2000; WAC, 2004). Notably, they do not thrive in swampy areas (Ayuk et al., 1999). *Spondias mombin* and *Theobroma cacao* commonly exhibit gregarious growth patterns, often occurring in small clusters within lowland tropical rainforests of West Africa (WAC, 2004). The presence of these species in what appear to be natural forests is often attributed to historical human cultivation (WAC, 2004). Extensive farming practices, particularly for cacao, have led to significant deforestation, reducing habitat for both *Spondias mombin* and *Theobroma cacao* (Kouassi, 2023). Extensive farming practices, particularly for cacao, have led to significant deforestation, reducing habitat for both *Spondias mombin* and *Theobroma cacao* (Kouassi, 2023).

### Sample Collection and Preparation

Freshly harvested *Spondias mombin* fruits and *Theobroma cacao* pods were identified at the BOUESTI herbarium, Department of Biological Sciences, BOUESTI. The pericarp, mesocarp, and endocarp of the ripe *Spondias mombin* fruits were carefully removed using stainless steel knives to expose the kernels and seeds. These were chopped into smaller pieces, spread on a clean tarpaulin, and air-dried in the laboratory for 21 days. Similarly, fresh *Theobroma cacao* pods were split open to extract the beans along with their placenta. The husks were sliced into 2 cm pieces at the Product Development Unit of the Food Science and Technology Department at the same institution and sun-dried for approximately 80 hours to remove moisture. Both the dried *Spondias mombin* seed kernels and cocoa pod husks were milled using silver crest (C-1589) and Foss CT 293 cyclotec™. The resulting material was then passed through a 0.5 mm sieve to ensure uniform particle size.

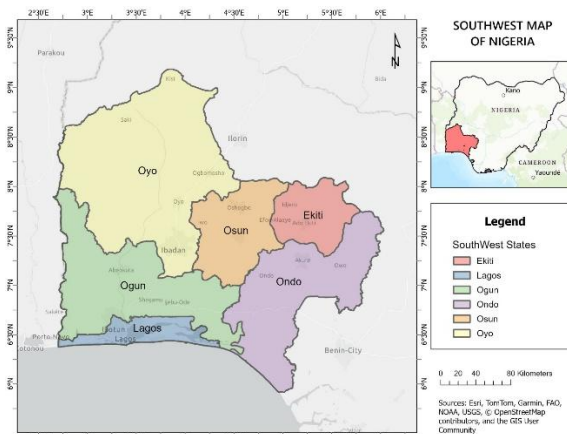


Figure 1. Map showing the geographical location of the sample collection.

## Chemical Analyses

### Moisture determination

A 2 g sample of the dried material was subjected to drying at 105°C for three hours under a pressure not exceeding 100 mm Hg until a constant weight was achieved. The procedure utilized a covered aluminum dish with a minimum diameter of 50 mm and a depth of 40 mm. The weight loss observed during drying was recorded as the moisture content.

### Calculations

$$M(\%) = 100 \times \frac{\text{wt loss on drying,g}}{\text{wt test portion,g}} \quad (1)$$

M(%): %(w/w)LOD=%(w/w)moisture

% Dry matter = 100 - %LOD

### Ash Determination

A 1 g sample was carefully weighed into a porcelain crucible and incinerated in a muffle furnace maintained at 550 °C for three hours. Upon completion, the crucible was promptly transferred to a desiccator for cooling before being weighed. The final ash content was expressed as a percentage, recorded to one decimal place.

$$A(\%) = \frac{(WTP-LA)}{WTP} \times 100 \quad (2)$$

A(%): % (w/w) Ash

WTP: weight of test portion,g weight

LA : Loss on ashing,g

### Crude Fat Determination

The system was powered on, ensuring the "MAINS" indicator was illuminated. The extraction temperature was adjusted to 230 °C to achieve an optimal solvent reflux rate of 3–5 drops per second. Before commencing the process, program settings for boiling, rinsing, evaporation, and pre-drying were confirmed on the control unit.

To maintain efficient solvent recovery, the cooling system was activated, setting the water flow rate to 2 L/min at approximately 15 °C. Extraction thimbles were prepared and attached to their respective adapters. A 1 g test sample was carefully weighed into each of six thimbles, followed by the addition of a thin layer of defatted cotton. These thimbles were securely positioned in the extraction unit using a thimble handler and magnetized supports.

For extraction, pre-dried cups containing 70 mL of petroleum ether were carefully placed into the system to prevent sudden boiling. The automated extraction and evaporation process was initiated using the RUN/STOP function. During the boiling phase, the thimbles remained immersed while the condenser valves stayed open. After the programmed boiling period, the thimbles were moved to the rinsing position, where solvent rinsing was conducted for 30 minutes. The condenser valves were subsequently closed, and the handle was adjusted to facilitate solvent recovery.

Following the extraction, the cups were removed and dried in an oven at 103°C for 30 minutes before being weighed. The fat content was then calculated based on the mass difference before and after extraction.

### Calculations

$$C(\%) = \frac{F-T}{S} \times 100 \quad (3)$$

C(%): % Crude fat, hexanes/Petroleum Ether extract

F : weight of cup + fat residue, g;

T : weight of empty cup, g;

S : test portion weight, g

### Crude Fiber Determination

Prior to analysis, fritted crucibles were pre-dried at 130°C for 30 minutes, cooled in a desiccator, and subsequently tared on an analytical balance. Each crucible was loaded with approximately 1.0 g of Celite 545 as a filtration aid, followed by 1.0 g of the prepared sample.

The Fibertec hot extraction unit was switched on, and a 1.25% H<sub>2</sub>SO<sub>4</sub> solution was prepared and heated on a hot plate. Using a crucible holder, the prepared crucibles were securely positioned in the Fibertec hot extraction system, locked in place, and aligned with the radiator. The safety latch was engaged, and the reflector was placed in front of the crucibles. Before initiating extraction, all system valves were closed.

Cold water was introduced at a steady flow rate of 1.2 L/min to facilitate the reflux system. Each column received 150 mL of preheated 1.25% H<sub>2</sub>SO<sub>4</sub> (reagent 1), along with two drops of n-Octanol to suppress foaming. The heating control was turned to its maximum setting until boiling commenced, after which the heat was adjusted to maintain a moderate boil for 30 minutes.

Upon completion of the acid digestion, the heater was switched off, valves were adjusted to the "VACUUM" setting, and the cold-water flow was maximized to enhance filtration via a water suction pump. The residue in each crucible was rinsed three times with 30 mL portions of hot deionized water, applying reverse pressure between washes to ensure thorough cleaning and drying.

The next stage involved alkaline digestion, where 150 mL of preheated 1.25% NaOH (reagent 2) was added to each column. The extraction and washing steps were repeated in the same manner as described for the acid treatment.

Following the digestion steps, the crucibles were carefully detached using a safety hook and transferred to the Fibertec cold extraction unit for solvent removal. Each crucible was treated with 25 mL of acetone, and vacuum filtration was applied. This process was repeated three times to ensure complete removal of any residual reagents. The crucibles were then left to air-dry on a stand at room temperature, preventing direct heating to avoid fiber degradation.

For final analysis, the crucibles were dried at 130°C for a minimum of 2 hours, cooled in a desiccator, and weighed to the nearest 0.1 mg.

### Calculation

$$\% \text{ Crude Fibre} = \frac{W_2 - (W_3 + C)}{W_1} \times 100 \quad (4)$$

W<sub>1</sub> = Sample weight

W<sub>2</sub> = Crucible + Residue

W<sub>3</sub> = Crucible + ash residue

C = Blank

### Crude Protein Determination

A digestion block was preheated to 420°C before analysis. One gram of the finely ground and homogenized sample was accurately weighed into designated digestion tubes. A reagent blank, consisting solely of 12 mL of concentrated sulfuric acid and two Kjeltabs Cu catalyst tablets, was included in each batch to ensure analytical accuracy.

Each digestion tube received two Kjeltabs Cu catalyst tablets, followed by the addition of 12 mL of concentrated H<sub>2</sub>SO<sub>4</sub> using a pipetting dispenser. To ensure safe operation, heat side shields were attached to the tube rack, and a fume manifold was securely positioned over the tubes. The H<sub>2</sub>O aspirator was initially set to full capacity before placing the rack of tubes into the preheated digestion block.

After 10 minutes, the aspirator flow was reduced to allow acid fumes to be efficiently contained within the exhaust hood, maintaining a visible condensation zone within the tubes. As the initial phase of digestion progressed and sulfur oxide fumes diminished, the vacuum strength was further adjusted to minimize sulfuric acid loss. The digestion process was maintained for an additional 50 minutes, culminating in a total digestion time of approximately 60 minutes.

Following digestion, the block was switched off, and the rack of tubes was carefully removed while keeping the exhaust system operational. The tubes were placed in a stand and allowed to cool for 20 minutes. To accelerate cooling, an air blower or fume hood with the sash lowered was used to increase airflow. Once visible fuming had ceased, the fume manifold was detached, the aspirator was turned off, and the side shields were removed. The tubes were then left to cool further at ambient conditions before proceeding with subsequent analysis.

### Distillation

For the distillation process, a 40% NaOH solution was loaded into the alkali tank of the distillation unit. If the system included an automatic dilution function, it was activated accordingly. A 250 mL graduated Erlenmeyer flask containing 30 mL of boric acid (H<sub>3</sub>BO<sub>3</sub>) solution with an indicator was positioned on the receiving platform. The condenser outlet tube was carefully submerged below the surface of the boric acid solution to ensure efficient absorption of the released ammonia.

The distillation was carried out under controlled conditions, and the collected distillate was titrated against 0.1851 N hydrochloric acid (HCl) until a stable pink endpoint was achieved, indicating the completion of the reaction.

### Calculations

Calculate the % Nitrogen according to the formula below:

$$\% \text{ Kjeldahl Nitrogen} = \frac{(V_s - V_b) \times N \times 14.007}{W \times 10} \quad (5)$$

Where:

V<sub>s</sub> : ml of standardized acid used to titrate a sample

V<sub>b</sub> : ml of standardized acid used to titrate a reagent blank

N : normality of standard HCl

W : weight, in grams, of sample or standard

10 : factor to convert mg/gram to percent

0.2000: normality of standard HCl; 14.007: atomic weight of nitrogen

Calculate the % crude protein according to the formula below:

$$\% \text{ Crude Protein} = \% \text{ Kjeldahl Nitrogen} \times F \quad (6)$$

F : factor to convert nitrogen to protein

F-factors are: 6.25 = Feeds, Meats, Other samples not specified below

5.70 = Wheat

### Carbohydrate Determination

Carbohydrate was calculated by difference. Energy values were estimated as the sum of carbohydrate, protein and lipid kilocalories according to Atwater factor.

$$E = [(4 \times \text{carbohydrate}) + (4 \times \text{protein}) + (9 \times \text{fat})] \quad (7)$$

E : Energy (kcal)

### Near-Infrared Reflectance Spectroscopy (NIRS) Instrument Analysis

Near-Infrared Reflectance Spectroscopy (NIRS) was employed to enhance the reliability and precision of the analysis. The FOSS Forage Analyzer (DS 2500), integrated with the WinISI II software package, was used for the assessment. This instrument applied globally calibrated equations developed by the International Livestock Research Institute (ILRI), which were based on conventional analytical methods (AOAC, 1990; Van Soest et al., 1994), ensuring consistency and reproducibility in the results.

The analysis covered multiple parameters, including proximate composition, fiber fractions, digestibility, amino acid profile, mineral content, and fatty acid profile. Samples were dried to achieve a moisture content of 12% and milled to a uniform particle size of 0.5 mm. Proximate composition included crude protein, calculated as nitrogen multiplied by 6.25, crude fiber, ether extract, and ash content. The fiber analysis encompassed neutral detergent fiber (NDF), acid detergent fiber (ADF), and acid detergent lignin (ADL). Digestibility was evaluated using in vitro organic matter digestibility (IVOMD), while metabolizable energy (ME) was reported in megajoules per kilogram of dry matter (MJ/kg DM).

Mineral composition was assessed for both macro- and micro-minerals, expressed in parts per million (ppm). The minerals analyzed included sodium, potassium, magnesium, calcium, manganese, iron, copper, zinc, and phosphorus. The amino acid profile was determined and reported as grams per 100 grams (g/100 g) on a dry matter basis, with quantification of amino acids such as aspartic acid, serine, glutamic acid, glycine, histidine, arginine, threonine, alanine, proline, cystine, tyrosine, valine, methionine, lysine, isoleucine, leucine, phenylalanine, and tryptophan. Fatty acid content was measured and expressed in milligrams per 100 grams (mg/100 g) on a dry matter basis. The fatty acids assessed included omega-3 and omega-6 fatty acids, as well as saturated, monounsaturated, and polyunsaturated fatty acids.

### Statistical Analysis

The data obtained were analyzed using descriptive statistics. A Student's t-test was performed to compare the mean nutritive values between the two species and to assess deviations from the standard values recommended by the FAO.

## Results and Discussions

### Comparison with FAO Requirements

#### Broilers (0–8 weeks)

There is a dearth of information on the nutrient contents of the plants studied as additives in poultry diets in Nigeria and comparison with the FAO standard. Therefore, our results were evaluated against the standard requirements

established by the FAO and compared with findings from previous studies that have investigated the nutrient composition of the plant species examined in this study. Studies have indicated that soybean meal continues to be the predominant protein source in poultry feed, largely due to its high crude protein content and well-balanced amino acid composition (Osthus et al., 2022). However, the increasing demand and cost of soybean meal necessitated the exploration of alternative protein sources to reduce dependency on synthetic feed formulations. The crude protein content of Cocoa Bean Shell (CBS) and *Spondias mombin* were below the FAO-recommended levels for poultry nutrition, yet their inclusion in feed formulations could help mitigate the overdependence on soybean as a primary protein source.

Table 1. Nutritional and phytochemical properties of cocoa bean shell and *Spondias mombin* (mean  $\pm$  SD, n=3).

Parameter	Cocoa Bean Shell (Mean $\pm$ SD)	Spondias Mombin (Mean $\pm$ SD)
Moisture (%)	15.83 $\pm$ 0.06	5.83 $\pm$ 0.06
Crude Protein (%)	7.73 $\pm$ 0.12	5.68 $\pm$ 0.39
Crude Fat (%)	1.36 $\pm$ 0.05	4.59 $\pm$ 0.08
Fibre (%)	11.28 $\pm$ 0.34	13.04 $\pm$ 0.92
Ash (%)	9.11 $\pm$ 0.15	50.39 $\pm$ 0.13
CHO (%)	54.70 $\pm$ 0.34	20.47 $\pm$ 1.15
Metabolisable Energy (kcal/kg)	2616.5 $\pm$ 0.94	1458.8 $\pm$ 3.74
Starch (%)	6.60 $\pm$ 0.04	20.63 $\pm$ 0.19
Acid Detergent Fibre (%)	42.20 $\pm$ 1.01	61.91 $\pm$ 0.70
Acid Detergent Lignin (%)	9.22 $\pm$ 0.57	15.51 $\pm$ 1.03
Neutral Detergent Fiber (%)	55.28 $\pm$ 0.57	18.37 $\pm$ 2.17
Sodium (mg/kg)	0.69 $\pm$ 0.00	6.08 $\pm$ 0.28
Potassium (mg/kg)	7.20 $\pm$ 0.02	N.D
Magnesium (mg/kg)	4.81 $\pm$ 0.29	10.89 $\pm$ 0.65
Calcium (mg/kg)	5.40 $\pm$ 0.65	13.17 $\pm$ 0.15
Manganese (mg/kg)	0.16 $\pm$ 0.01	1.10 $\pm$ 0.02
Iron (mg/kg)	0.23 $\pm$ 0.05	11.18 $\pm$ 0.35
Copper (mg/kg)	0.00 $\pm$ 0.00	0.03 $\pm$ 0.00
Zinc (mg/kg)	0.02 $\pm$ 0.00	0.11 $\pm$ 0.00
Phosphorus (mg/kg)	2.40 $\pm$ 0.11	6.60 $\pm$ 0.17
In Vitro Organic Matter Digestibility (%)	52.26 $\pm$ 1.03	46.19 $\pm$ 0.38
Omega 3 (mg/100g)	N.D	1,295.82 $\pm$ 70.43
Omega 6 (mg/100g)	1,189.01 $\pm$ 21.33	N.D
Trans Fat (mg/100g)	24.16 $\pm$ 0.05	41.51 $\pm$ 0.47
Monounsaturated Fatty Acid (mg/100g)	10,706.12 $\pm$ 456.54	12,005.80 $\pm$ 393.89
Saturated Fatty Acid (mg/100g)	976.93 $\pm$ 68.05	4,800.27 $\pm$ 417.94
Polyunsaturated Fatty Acid (mg/100g)	N.D	8,786.06 $\pm$ 183.92
Aspartic Acid (%)	1.22 $\pm$ 0.09	0.78 $\pm$ 0.11
Serine (%)	0.46 $\pm$ 0.02	0.04 $\pm$ 0.03
Glutamic Acid (%)	1.35 $\pm$ 0.04	N.D
Glycine (%)	0.72 $\pm$ 0.03	2.62 $\pm$ 0.02
Histidine (%)	0.30 $\pm$ 0.02	0.06 $\pm$ 0.01
Arginine (%)	0.79 $\pm$ 0.01	N.D
Threonine (%)	0.41 $\pm$ 0.03	0.06 $\pm$ 0.00
Alanine (%)	0.51 $\pm$ 0.01	1.16 $\pm$ 0.04
Proline (%)	0.73 $\pm$ 0.02	2.14 $\pm$ 0.03
Cystine (%)	0.21 $\pm$ 0.02	0.09 $\pm$ 0.04
Tyrosine (%)	0.26 $\pm$ 0.04	1.20 $\pm$ 0.01
Valine (%)	0.73 $\pm$ 0.00	1.04 $\pm$ 0.00
Methionine (%)	0.05 $\pm$ 0.01	0.31 $\pm$ 0.01
Lysine (%)	0.46 $\pm$ 0.06	1.85 $\pm$ 0.02
Isoleucine (%)	0.51 $\pm$ 0.02	0.97 $\pm$ 0.01
Leucine (%)	1.22 $\pm$ 0.00	0.69 $\pm$ 0.01
Phenylalanine (%)	0.57 $\pm$ 0.01	N.D
Tryptophan (%)	0.19 $\pm$ 0.02	N.D

N.D = Not detected

Table 2. Mean comparison of the cocoa bean shell and *Spondias mombin* using t-test

Parameter	t-value	p-value	Significance
Moisture (%)	312.00	< 0.001	*
Crude Protein (%)	9.87	< 0.001	*
Crude Fat (%)	-85.71	< 0.001	*
Fiber (%)	-4.67	<0.001	*
Ash (%)	-632.50	< 0.001	*
CHO (%)	58.42	< 0.001	*
Metabolisable Energy (kcal/kg)	623.4	< 0.001	*
Starch (%)	-183.33	< 0.001	*
Acid Detergent Fiber (%)	-36.00	< 0.001	*
Acid Detergent Lignin (%)	-10.50	< 0.001	*
Neutral Detergent Fiber (%)	37.50	< 0.001	*
Sodium (mg/kg)	-39.00	< 0.001	*
Potassium (mg/kg)	N/A	N/A	-
Magnesium (mg/kg)	-16.50	< 0.001	*
Calcium (mg/kg)	-19.00	< 0.001	*
Manganese (mg/kg)	-94.00	< 0.001	*
Iron (mg/kg)	-52.00	< 0.001	*
Copper (mg/kg)	N/A	N/A	-
Zinc (mg/kg)	-90.00	< 0.001	*
Phosphorus (mg/kg)	-48.00	< 0.001	*
In Vitro Organic Matter Digestibility %	10.50	< 0.001	*
Omega 3 (mg/100g)	N/A	N/A	-
Omega 6 (mg/100g)	N/A	N/A	-
Trans Fat (mg/100g)	-73.00	< 0.001	*
Monounsaturated Fatty Acid (mg/100g)	-4.50	<0.001	*
Saturated Fatty Acid (mg/100g)	-18.00	< 0.001	*
Polyunsaturated Fatty Acid (mg/100g)	N/A	N/A	-
Aspartic Acid (%)	6.50	< 0.001	*
Serine (%)	22.00	< 0.001	*
Glutamic Acid (%)	N/A	N/A	-
Glycine (%)	-120.00	< 0.001	*
Histidine (%)	24.00	< 0.001	*
Arginine (%)	N/A	N/A	*
Threonine (%)	20.00	< 0.001	*
Alanine (%)	-32.00	< 0.001	*
Proline (%)	-70.00	< 0.001	*
Cystine (%)	6.00	<0.001	*
Tyrosine (%)	-50.00	< 0.001	*
Valine (%)	-90.00	< 0.001	*
Methionine (%)	-40.00	< 0.001	*
Lysine (%)	-46.00	< 0.001	*
Isoleucine (%)	-48.00	< 0.001	*
Leucine (%)	90.00	< 0.001	*
Phenylalanine (%)	N/A	N/A	-
Tryptophan (%)	N/A	N/A	-

N/A= Not available; \*There is high significant difference at  $p < 0.01$ ; -Inconclusive

Studies have suggested that *Spondias mombin* is a rich source of nutrients, including proteins, vitamins, and minerals, with bioactive compounds that contribute significantly to animal nutrition (e.g., Ogunro et al., 2023; Almeida et al., 2023). Despite CBS and *Spondias mombin* not meeting the FAO protein requirements individually, their strategic combination could enhance overall feed value. Table 5 indicates that for broilers, CBS (7.73% crude protein) and *Spondias mombin* (5.68% crude protein) are significantly lower than the FAO requirement of 23% for the starter phase, 20% for the finisher phase, and 18% for the late finisher phase, in table 3. This deficiency poses a limitation, as protein is essential for muscle development and overall growth (Ewuola et al., 2024). However, combination of the CBS with *Spondias mombin* protein

contents could serve to augment total dependency on soybean. Some studies have suggested that 10% inclusion of fermented CBS in broiler diets did not negatively impact on the weight gain, feed intake, or feed conversion ratio (FCR) (Olumide et al., 2021; Suleiman et al., 2024). However, at levels beyond 15% could lead to reduced growth performance due to amino acid limitations (Olumide et al., 2024).

The amino acid profile of CBS revealed deficiencies in lysine (0.46%), methionine + cystine (0.26%), and threonine (0.41%) compared to FAO standards. However, *Spondias mombin* pericarp offered 1.85% lysine, which exceeded the FAO recommendations and indicated its potential as supplements in poultry diets.

Table 3. Comparative analysis of the essential nutritional components of *Spondias mombin* and cocoa bean shell against FAO standards for broiler poultry feed.

Nutrient	Cocoa Bean Shell (CBS)	Spondias mombin (SM)	FAO Requirement (Starter/Finisher/Late)	Gap Analysis
Crude Protein (%)	7.73	5.68	23 / 20 / 18	Both severely deficient (66–74% below requirement)
Metabolisable Energy (kcal/kg)	261.65	145.88	3200	Extremely deficient (92–95% below requirement)
Calcium (%)	0.54	13.17	1.0 / 0.9 / 0.8	CBS: 46% deficit; SM: ~13× excess
Phosphorus (%)	0.24	6.60	0.45 / 0.35 / 0.35	CBS: 47% deficit; SM: ~14× excess
Lysine (%)	0.46	1.85	1.10 / 1.00 / 0.85	CBS: 58% deficit; SM: 68% surplus
Methionine (%)	0.05	0.31	0.50 / 0.38 / 0.32	CBS: 90% deficit; SM: 38% deficit
Methionine + Cystine (%)	0.26	0.40	0.90 / 0.72 / 0.60	Both deficient (71–80% below requirement)

Source: Ravindran, (2013)

Table 4. Comparative analysis of the essential nutritional components of *Spondias mombin* and cocoa bean shell against FAO standards for layer poultry feed.

Nutrient	Cocoa Bean Shell (CBS)	Spondias mombin (SM)	FAO Requirement for layer birds	Gap Analysis
Crude Protein (%)	7.73	5.68	15	Both severely deficient (48–62% below requirement)
Calcium (%)	0.54	13.17	3.25	CBS: 83% deficit; SM: ~4× excess
Phosphorus (%)	0.24	6.60	0.25	CBS: 4% deficit; SM: ~26× excess
Lysine (%)	0.46	1.85	0.69	CBS: 33% deficit; SM: 168% surplus

Source: Ravindran, (2013)

CBS met the FAO requirements for leucine (1.22%) and tryptophan (0.19%), yet the overall amino acid imbalance necessitated further supplementation or dietary adjustments. Studies have shown that amino acid supplementation, particularly with glycine and cysteine, could mitigate the effects of low-protein diets (e.g., Elahi et al., 2020; Aguihe et al., 2022).

#### Laying Birds

For laying birds, CBS and *Spondias mombin* were below the FAO-required crude protein level of 15% in table 5. However, their incorporation in feed could help diversify protein sources and reduce reliance on soybean. The calcium content of CBS (0.54%) was below the FAO requirement of 3.25%, whereas *Spondias mombin* provided 13.17% calcium, making it a viable supplement for skeletal health and eggshell formation (Ogunro et al., 2023). Likewise, CBS's phosphorus content (0.24%) was inadequate, but *Spondias mombin* offered 6.60% phosphorus, surpassing FAO recommendations and improving overall mineral balance in the feed. Although, CBS did not meet FAO requirements for methionine + cystine (0.26% vs. 0.58%), blending with *Spondias mombin*, which have lysine requirements, may improve amino acid availability. The calculated use of these alternative ingredients derived from wastes of these plants could help to reduce cost of purchasing feeds, while maintaining acceptable performance in poultry birds' production.

#### Conclusion

Cocoa Bean Shell (CBS) and *Spondias mombin* offer a promising alternative to conventional poultry feed ingredients, particularly in reducing dependency on soybean-based protein sources. While neither ingredient met the FAO nutrient requirements individually, their complementary profiles suggested a strategic blend could enhance the feed quality. The high calcium and phosphorus content of *Spondias mombin* addressed critical mineral deficiencies in CBS, particularly for laying birds, where calcium is essential for egg shell formation. Additionally, *Spondias mombin*'s lysine content exceeded that of FAO standards, and this partially compensated for CBS's amino acid limitations. However, the low crude protein content in both ingredients remain a challenge, demanding supplementation or formulation adjustments to meet poultry growth and production in lieu of soya beans protein. For broilers, balanced inclusion levels of CBS and *Spondias mombin* could contribute significantly to sustainable feed alternatives without compromising their performance. For laying birds, *Spondias mombin*'s mineral profile makes it a viable supplement, but essential amino acid deficiencies must be addressed through targeted supplementation.

To fully harness the potential of these alternative feed sources, more importantly nutritive values derived from some other underutilized plant species is needed to

optimize inclusion ratios, evaluate digestibility, and conduct controlled feeding trials. Understanding their impact on poultry health, growth performance, and economic feasibility will be crucial for their successful adoption in commercial feed formulations.

## Declarations

### Author Contribution Statement

**Conceptualization:** Conceptualization of the study was carried out by F.A., A.O., and T.B., with support from S.I. and O.I..

**Data Curation:** Conducted by all five authors.

**Laboratory and Data Analysis:** Performed by S.I. and validated by the remaining four authors.

**Resources:** Provided by all five authors.

**Writing – Original Draft:** Prepared by all five authors.

**Draft Review and Editing:** The final draft was reviewed by F.A., A.O., T.B., and S.I..

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### Conflict of Interest

The authors declare that there are no conflicts of interest related to this research. The funding agency, Tertiary Education Trust Fund (TETFund), had no role in the study's design, data collection, analysis, interpretation, manuscript preparation, or decision to publish. The authors affirm that there are no financial, personal, or professional relationships that could have influenced the outcomes of this research.

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