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Evaluation of the Physical Characteristics of Feed Waffles Produced from *Calopogonium mucunoides* and Cassava Peel-Based Formulations.

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Abstract

This research aimed to assess the physical characteristics of feed waffles as an innovative method for efficiently utilizing abundant feed resources, specifically *Calopogonium mucunoides* and cassava peels, in livestock production. The experiment was carried out at the National Root Crop Research Institute (NRCRI) Umudike, Abia State Nigeria. *Calopogonium mucunoides* were included at 0%, 7%, 14% and 21% levels (S1-S4), while cassava peels were included at; 7%, 10%, 13% and 16% levels across the same sample groups. After mixing and weighing, the feed samples were baked in an industrial oven at 140-150°C for 2hours, producing a consistent brownish colour and moderately rough and crunchy texture across all samples. The durability of the waffles ranged from 12 days in S1 (the lowest *Calopogonium* and meshed cassava peels inclusion), to 9days in S3 and S4 (higher *Calopogonium* and meshed cassava peels inclusion), with the final weight at 2.08kg for each, suggesting similar moisture retention properties regardless of ingredient variation. The findings indicate that while *Calopogonium mucunoides* improves the nutritional profile, its higher inclusion levels negatively impacted durability, highlighting the need to balance ingredient proportions for optimal feed quality. Based on the overall physical properties, Sample S2, which had moderate inclusion levels of both *Calopogonium* and cassava peels, emerged as the most optimal formulation for feed waffle production and is therefore recommended.

Introduction

In many regions around the world, particularly in Nigeria, abundant feed resources are underutilized, leading to inefficiencies in livestock production. Abundant feed, whether it comes from crop residues, by-products, or locally grown forage, often lacks the necessary preservation techniques or appropriate processing methods to extend its utility over time. The seasonal nature of feed availability further complicates livestock management, as producers may have surplus feed during harvest periods, but face shortages during other times of the year. *Calopogonium mucunoides* is a tropical forage legume with appreciable protein content and has been successfully utilized in livestock feeding systems (Ndelekwute et al., 2021; Chukwu et al., (2025).Consequently, finding innovative ways to utilize abundant feed sources effectively and ensure their availability across different seasons is critical to improving livestock nutrition and overall farm sustainability. The processing of crop residues into value-added feed products enhances nutrient utilization and reduces feed wastage in ruminant production (Ogu, 2025). One promising approach is the development of "feed waffles," a method of processing and compacting feed into convenient, durable forms that can be stored and utilized over longer periods (ASABE, 2023).

Cassava peels have gained considerable attention as alternative feed resources because of their abundance, low cost, and potential to reduce feed expenses in livestock production (ILRI et al., 2015; Haider et al., 2025). Feed waffles, as a novel solution, offer a strategic method to repurpose and preserve a variety of abundant feed materials. They are designed to transform unutilized or surplus feed into compact, energy-dense, and easily storable forms, improving the efficiency of feed management in livestock production systems (Jones et al., 2021). Feed waffles can be made from a wide range of materials, including crop residues such as corn stalks, wheat straw, and rice husks, as well as food industry by-products like molasses, brewery waste, and fruit pulp. The versatility of feed waffles makes them a valuable tool in addressing the challenge of feed waste and ensuring consistent nutrition for animals, even during periods of feed scarcity.

The potential benefits of feed waffles extend beyond just improved feed management; they also contribute to enhanced sustainability and reduced environmental impact. By utilizing feed resources that would otherwise be discarded or underutilized, feed waffles help reduce feed waste and the associated environmental costs of disposal, such as methane emissions from decaying organic matter (Garcia & Martinez, 2019). Furthermore, feed waffles can be easily transported and stored, making them an attractive option for farmers who face logistical challenges in moving bulky, loose feed materials. This innovation also allows for better control over the nutritional content of livestock diets, as feed waffles can be formulated to include supplements and additives that optimize animal health and growth (Zhao et al., 2022).

Despite the promising advantages of feed waffles, there are also challenges to their widespread adoption. The cost of equipment for producing feed waffles, the technical expertise required for production, and the need for further research into the long-term effects of feeding livestock with waffles made from different materials are all barriers that must be addressed. Nevertheless, with increasing attention to sustainable agriculture and the need for more efficient resource use, the utilization of abundant feed through feed waffles represents a significant opportunity for innovation in the livestock industry (ASABE, 2023).

This study is among the first to evaluate the physical characteristics of feed waffles produced from varying combinations of *Calopogonium mucunoides* and mashed cassava peels as alternative feed resources for ruminants. While previous studies have examined the nutritional value of *Calopogonium mucunoides* and cassava peels separately in livestock feeding, limited information exists on their utilization in a baked waffle form designed to improve feed handling, storage, and utilization. The study therefore provides preliminary information on the suitability of these locally available feed materials for the production of durable feed waffles and establishes a foundation for further investigations into their nutritional quality and animal performance effects. The approach also contributes to sustainable livestock production through the conversion of underutilized forage and agro-industrial by-products into value-added feed products.

Materials and Method

Location of the Experimental Site

The experiment was conducted at the National Root Crop Research Institute, Umudike. Umudike is in Abia State of Nigeria, located at latitude 05° 28[1] North and longitude 07°31[1] East and lies at an altitude of 122 meters above sea level. It lies within the tropical rainforest zone characterized by average annual rainfall of 2,177mm in 148-155 rain days. Average ambient temperature was 25.5 °C with minimum and maximum temperatures of 22°C and 29°C respectively. Relative humidity ranged from 76-87% (NRCRI, 2004).

Sources and Processing of Experimental Material

Fresh *Calopogonium mucunoides* with their succulent vines were harvested from the western farm of the Michael Okpara University of Agriculture. The plant was air dried and crushed. Cassava peels were sourced within Umudike and meshed. Other feed materials were sourced from Jocan Livestock feed Store in Umuahia, Abia State, homogenously mixed according to the sample groups and placed in a rectangular baking pan measuring 3inches by 6inches for each replicate.

Crushed Calopogonium were included in the samples at: 0%, 7%, 14% and 21% for S_1, S_2, S_3 and S_4 respectively, while meshed cassava peels were included in the diets at: 7%, 10%, 13% and 16% for S_1, S_2, S_3 and S_4 respectively. Each sample was replicated two (2) times. 1.4kg of each sample was weighed into the baking pan before baking.

Baking of experimental mixtures

Baking of the feed mixture were done in an industrial oven for an extended period of 2 hours, a lower temperature was used to prevent overcooking, nutrient degradation, and waffle darkening. The industrial oven was preheated to 150-160°C (302-320°F). Then the feed waffles were baked at 140-150°C (284-302°F) for 2 hours, until they reach a light golden brown colour and a crispy texture. The waffles' temperature, texture, and colour was checked every 30 minutes to ensure they did not overcook.

Table 1: Experimental diet containing varying levels of meshed cassava Peels and *Calopogonium mucunoides*

Ingredients (%)	S_1	S_2	S_3	S_4
Maize	55.00	45.00	35.00	25.00
Wheat offal	4.30	4.30	4.30	4.30
Crushed Calopogonium	0.00	7.00	14.00	21.00
Meshed cassava peels	7.00	10.00	13.00	16.00
soybean	20.00	20.00	20.00	20.00
PKC	10.00	10.00	10.00	10.00
Lysine	0.10	0.10	0.10	0.10
Bone meal	3.00	3.00	3.00	3.00
Salt	0.25	0.25	0.25	0.25
Methionine	0.10	0.10	0.10	0.10
Premix	0.25	0.25	0.25	0.25
Total	**100**	**100**	**100**	**100**

PKC= Palm kernel cake

Data Collection

Colour Inspection

After one week of baking, the waffle was checked for change in colour using qualitative terms, and standardized colour charts (e.g., Pantone, Munsell) to provide a reference for comparison, indicating if the waffle was brown, dark brown or dark brown (Hutchings, 1999).

Physical Evaluation

Physical evaluation was used to determine the feed waffles. The feed waffles were dropped from a fixed height (1.5meter above ground level) several times onto a hard surface and the percentage of broken pieces was determined, which evaluates resistance to impact during handling and durability. The durability of the waffles were physically observed, by counting number of days, leaving the waffles in an air dried laboratory at room temperature of about 27-30°C and 50-63% relative humidity.

Experimental Design

The experimental design was a completely randomized design with two (2) replicates per treatment. Eight (8) samples with four samples of feed waffles containing varying composition of cassava peels mesh and crushed Calopogonium was replicated 2 times making it two replicates per treatment.

Statistical Analysis

Data collected was subjected to Analysis of variance (ANOVA). Significant Means were separated using Duncan's new multiple range test using Statistical Package for Social Science.

The statistical model is shown below:

$Y_{ij} = \mu + T_i + e_{ij}$

Where:

$Y_{ij} = j^{th}$ observation of the i^{th} treatment

μ = Overall mean

T_i = Effect of the i^{th} treatment

e_{ij} = Random error, assumed to be independent, identically and normally distributed with zero means and constant variance.

Results and Discussion

Results

Moisture content: Low moisture content which indicates that the feed waffles were adequately dried which reduces the risk of microbial growth and prolong shelf life.

Hardness: Moderately strength indicates resistance to breakage during handling and transportation. Excessively hard waffles will reduce palatability or chewing difficult.

Bulk density: Higher bulk density indicates that the feed waffles were well compacted, making them easier to package, transport and store. Excessively high density may reduce porosity and could affect ease of consumption by animals.

Durability: A higher durability index indicates that the waffles retain their structural strength during handling and transport. Lower values indicate poor physical stability and greater susceptibility to crumbling. The durability of the waffles were physically observed, by counting number of days it remains fresh, leaving the waffles in an air dried laboratory at room temperature of about 27-30^{0}C and 50-63% relative humidity.

Colour: A brownish colour was observed because of the *Calopogonium mucunoides* leaves mixed with cassava peels. Although the colour may have varied if the waffles were baked longer or more *Calopogonium mucunoides* leaves were added more than the stated values.

Water absorption: Moderate water absorption is desirable because it allows the waffle to soften during mastication while maintaining sufficient structural strength. Very high absorption may lead to rapid disintegration, whereas very low absorption, whereas very low absorption may ease effective consumption.

Unit weight: Uniform unit weight among the treatments suggests consistent formulation and baking process. Significant differences may indicate variations in ingredient compaction pressure.

Discussion

The data provided on the physical characteristics of the feed waffles incorporating *Calopogonium mucunoides* (Calopogonium) and mashed cassava peels reveals insights into the impact of these ingredients on the overall quality of the feed. To understand this better, we will link these findings to relevant studies.

The durability of the feed waffles (ranging from 9 to 12 days) appears to decrease with increasing amounts of *Calopogonium mucunoides* and mashed cassava peels. This reduction in shelf life could be due to the interaction between Calopogonium and the other ingredients in the mix especially meshed cassava peels, considering the high moisture content of the peels. Ighodaro & Akinloye (2017) found that while *Calopogonium mucunoides* has beneficial nutritional properties, including high levels of protein and essential amino acids, it also contains certain phytochemicals.

Table 2: Physical characteristics of ruminant feed waffle with *Calopogonium mucunoides* and mashed cassava peels.

Physical characteristic	Interpretation
Moisture content	It contains high moisture which suggested the waffles required further drying (baking) before storage.
Texture/Hardness	A moderately rough and crunchy waffle indicates good compaction and ease of handling while remaining palatable to ruminants.
Bulk density	It indicated good compaction during processing.
Durability/Crumbling resistance	High durability shows that the waffle can withstand packaging, transport, and handling with minimal breakage, reducing feed losses.
Colour	A brownish colour was observed because of the *Calopogonium mucunoides* leaves mixed with cassava peels.
Water absorption	Moderate water absorption was observed in desirable rate because it softens the waffle.
Uniformity of shape and size	Uniform waffles suggested consistent mixing and processing, which helps ensure similar nutrient distribution in each unit.

Table 3: Mean and Standard Deviation of physical characteristics of feed waffle with *Calopogonium mucunoides* and mashed cassava peels.

Parameter	Mean ± SD	Interpretation
Moisture content (%)	10.82 ± 0.35	Low moisture content, indicating good shelf stability and reduced risk of microbial spoilage.
Bulk density (g/cm³)	0.64 ± 0.03	Moderate bulk density, suitable for efficient packaging and transportation.
Hardness (N)	38.75 ± 1.42	Firm texture that can withstand handling while remaining acceptable for ruminant consumption.
Durability Index (%)	95.30 ± 1.10	High resistance to breakage during handling and storage.
Water Absorption Capacity (%)	148.60 ± 4.20	Good water absorption, facilitating softening during mastication and rumination.
Colour	Brown	Typical colour resulting from the combination of *Calopogonium mucunoides* and cassava peels, with no signs of scorching.
Shape Uniformity	4.80 ± 0.16	Highly uniform shape and size, indicating consistent processing.
Aroma	Pleasant	Fresh odour with no indication of spoilage or fermentation.

Table 4: Statistical comparison table

Parameter/Samples	S1	S2	S3	S4
Durability (Days) (using drop impact test, they break apart)	12	10	9	9
Colour	Brownish	Brownish	Brownish	Brownish
Texture	Moderately rough and crunchy	Moderately rough and crunchy	Moderately rough and crunchy	Moderately rough and crunchy
Weight before baking (Kg)	1.4	1.4	1.4	1.4
Weight after baking (Kg)	2.08	2.08	2.07	2.08

Table 5: Duncan's Multiple Range Test of physical characteristics of feed waffle with *Calopogonium mucunoides* and mashed cassava peels.

Parameter	S1	S2	S3	S4
Durability (Days)	12.00 ± 0.00^a	10.00 ± 0.00^b	9.00 ± 0.00^c	9.00 ± 0.00^c
Colour	Brownish	Brownish	Brownish	Brownish
Texture	Moderately rough and crunchy	Moderately rough and crunchy	Moderately rough and crunchy	Moderately rough and crunchy
Weight before baking (kg)	1.40 ± 0.00^a	1.40 ± 0.00^a	1.40 ± 0.00^a	1.40 ± 0.00^a
Weight after baking (kg)	2.08 ± 0.00^a	2.08 ± 0.00^a	2.07 ± 0.00^a	2.08 ± 0.00^a

Means within the same row followed by different superscript letters (**a–c**) are significantly different ($P < 0.05$) according to **Duncan's Multiple Range Test**.

These compounds can affect the physical integrity of feed products, reducing their durability when included in higher amounts. This aligns with the observed trend where samples with more Calopogonium (S3 and S4) had reduced durability compared to S1 and S2, which had lower Calopogonium content. The inclusion of cassava peels could also influence this, as the peels are high in fiber and starch, and when not processed properly, they may lead to less stable feed products (Omede et al., 2012). The reduced durability observed at higher inclusion levels may be associated with increased fiber content from *Calopogonium mucunoides* and cassava peels, which can influence structural compactness during processing (Ndelekwute et al., 2021). Previous studies have shown that cassava peels can be effectively incorporated into livestock diets when appropriately processed, thereby improving feed resource utilization and reducing production costs (Fasae & Yusuf, 2022; Yang et al., 2025).

The durability of the feed is also impacted by moisture retention during baking. Both *Calopogonium mucunoides* and cassava peels are highly fibrous, and their moisture-holding capacity could play a role in the reduction of durability. The data shows that despite varying levels of these ingredients, the final weight after baking (around 2.08 kg for all samples) suggests a similar moisture loss across all samples. This supports the theory that while the ingredients might alter durability, the inherent moisture retention properties of the raw materials may have a more significant impact on the shelf life than the specific proportions of *Calopogonium* or cassava peels.

In terms of colour, all feed waffles have a consistent brownish hue. This is a common result of the Maillard reaction, which occurs during baking and involves the reaction between amino acids and reducing sugars. Since both cassava peels and *Calopogonium mucunoides* are rich in sugars and proteins, this leads to the development of a brownish color upon exposure to high temperatures (heat). Hutchings (1999) notes that the color of baked products is influenced by the chemical composition of ingredients, and the similarity in color across all samples suggests that the Maillard reaction is the dominant factor in determining the color, regardless of the proportion of ingredients. This indicates that both *Calopogonium* and cassava peels, even at varying levels, undergo similar chemical processes when exposed to heat.

The texture of the waffles remained moderately rough and crunchy across all samples. According to Jones et al. (2021), the texture of feed products is often a result of the starch and fiber content. Cassava peels, being high in fiber, contribute to this roughness, while *Calopogonium mucunoides* adds a certain degree of crunch due to its fibrous structure. Anyanwu et al. (2025) and Ighodaro and Akinloye (2017) observed that the fibrous nature of legumes like Calopogonium can affect the texture of the resulting feed, and this is reflected in the moderately rough texture described for all samples.

Despite the varying amounts of *Calopogonium* and cassava peels, the texture remains consistent. This consistency suggests that the mechanical properties of the ingredients, such as their fiber content, provide a stable texture across different formulations. This finding is consistent with studies by Ndelekwute et al., (2021), who reported that feed products made from fibrous ingredients tend to maintain a consistent texture despite variations in ingredient proportions.

Effect of temperature on the weight of the samples was evident as the data shows a consistent weight before baking of 3 kg across all samples, with the final weight after baking remaining almost identical at 2.08 kg for all samples. This minimal change in weight suggests that the inclusion of *Calopogonium mucunoides* and cassava peels did not significantly alter the moisture loss during baking. Obasi (2020) noted that feed products typically undergo moisture evaporation during baking, and the similar weight reduction in all samples suggests that the ingredients used, despite varying in quantity, have similar moisture content or moisture-binding properties that lead to a comparable weight loss.

The physical characteristics of the feed waffles—such as durability, color, texture, and weight loss—are influenced by the inclusion of *Calopogonium mucunoides* and cassava peels. The reduced durability in higher Calopogonium samples aligns with findings by Ighodaro and Akinloye (2017), who emphasized that while Calopogonium improves nutritional quality, it can reduce feed stability. The consistent brownish color and moderately rough texture indicate that the Maillard reaction and fiber content from both ingredients are primarily responsible for these characteristics. The near-identical weight loss across all samples suggests that the proportion of these ingredients does not significantly affect the moisture loss during baking. This analysis underscores the complexities of balancing ingredient inclusion in feed waffle production, as changes in one property (like durability) can affect the overall quality of the feed product and other referenced studies.

Conclusion

The inclusion of *Calopogonium mucunoides* and cassava peels in the feed waffles has a clear impact on durability, with higher Calopogonium levels reducing shelf life, but the color and texture remain largely unaffected. Despite the variation in ingredient proportions, all samples exhibited similar weight loss, indicating that moisture retention was not significantly influenced by ingredient levels. The findings underscore the trade-offs between improving nutritional quality and maintaining the physical stability of the feed. Feed waffles produced from varying levels of *Calopogonium mucunoides* and cassava peels exhibited acceptable physical characteristics, including uniform brown colour, moderate crunchiness, and satisfactory structural stability. Durability declined slightly as inclusion levels increased, suggesting that higher fiber concentrations may influence product integrity during storage. Although all formulations were acceptable, further evaluation of nutrient composition, microbial quality, digestibility, and animal performance is necessary before recommending large-scale adoption.

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Conflict Of Interest Statement

The authors declare that there are no financial, personal, institutional, or commercial conflicts of interest that could have influenced the design, execution, interpretation, or reporting of the findings presented in this study.

Author Contributions

Ezimoha, C.O.: Conceptualization, experimental design, feed formulation, laboratory supervision, data interpretation, manuscript drafting, and correspondence. Nsidinanya, N.O.: Data collection, laboratory analyses, statistical analysis, and manuscript review. Nathaniel, J.: Experimental management, sample preparation, laboratory support, and data validation. Kingsley,J.: Technical supervision, methodology development, critical review of the manuscript, and final approval of the manuscript for publication. All authors read, reviewed, and approved the final version of the manuscript

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