Sub-theme 3: Value addition and processing technologies

Title: Development of Cashew Apple Fiber Sausage Fortified with Bambara Bean

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Abstract

Consumer preference for high-fibre plant-based meat substitutes is growing due to health concerns, environmental sustainability and affordability. However, little is known about the use of locally sourced ingredients like wasted cashew-apple fibre and underutilized Bambara beans in the preparation of plant-based sausages that satisfy consumers' demand. The study aimed to develop and standardize a plant-based sausage by combining cashew apple fiber, a by-product of cashew apple processing, with Bambara beans, a protein-rich, drought-resistant legume. Four sausage formulations with cashew-apple fibre (C) and Bambara beans (B) as main ingredients (CB1:0, CB1:1, CB2:1 and CB4:3) were developed using an extreme vertices design via Minitab 2.1. Each of the sausage formulations was filled into a cellulose film casing, steamed for 20 mins, cooled, vacuum packaged and frozen at -18 ºC for analysis. The samples were assessed for nutritional, microbiological, physical, and sensorial qualities. The results showed that, protein increased from 2.02% to 15.41% and carbohydrate reduced from 22.63% to 9.93% as the percentage of Bambara in the formulation increased. Vitamin C ranged from 9.43–11.29 mg/100 g, and mineral content covered 9–26% of the recommended dietary intake for calcium, phosphorus, and iron. Total plate count, *Enterobacteriaceae*, *E.coli*, *Staphylococcus aureus*, *Bacillus cereus,* and Salmonella were not detected in the samples. It was also found that Bambara beans improved hardness, cohesiveness, and resilience of the sausages while fiber content was improved with increasing cashew apple fibre ranging from 0.51 to 2.48 mg/100g. Sensory testing with 16 semi-trained panelists identified CB2:1 and CB4:3 as the most liked. Consumer testing with 104 untrained panelists further confirmed broad acceptance across demographic groups. The findings demonstrate that cashew apple fiber and Bambara bean can be successfully combined to produce a nutritious, safe, and consumer-acceptable plant-based sausage.

Keywords: Cashew apple fiber, Bambara beans, sustainable food innovation, plant-based meat alternative, consumer acceptability.

1.0 Introduction

The global rise in demand for sustainable, nutritious, and allergen-friendly meat alternatives has intensified the exploration of novel plant-based ingredients in food product development. Among these, cashew apple fibre and Bambara bean represent two underutilized yet highly promising resources that align with current trends in functional foods, environmental sustainability, and waste valorization.

The cashew fruit, comprising the edible apple and the nut, is predominantly processed for its nut, while the apple—constituting about 90% of the total fruit weight—is frequently discarded (Okonkwo & Okolo, 2015; Dantas et al., 2022). This underutilization is as a result of high perishability, limited awareness, and the astringent nature of the fruit. Yet, cashew apples are exceptionally rich in antioxidants, particularly triterpenoids, phenolic compounds, carotenoids, and flavonoids, giving them superior antioxidant potential compared to commonly consumed fruits such as oranges and pineapples (Gutiérrez-Paz et al., 2024). In addition, they contain significant amounts of vitamin C, B-complex vitamins, iron, calcium, phosphorus, and dietary fibre, making them an ideal candidate for incorporation into functional foods (Akinwale, 2000; Assunção & Mercadante, 2003).

Cashew apple fibre—a by-product of juice, wine, and ethanol production—is typically discarded, contributing to environmental pollution and resource wastage (Dendup & Tshering, 2014). However, recent studies have demonstrated its potential as a cost-effective and fibre-rich food ingredient (Dantas et al., 2022). Its integration into food systems has been shown to increase dietary fibre content, reduce fat content, and maintain sensory acceptability (Pinho et al., 2011).

High-fibre meat substitutes are becoming more popular in processed foods, particularly in view of the well-known health and environmental hazards linked to consuming red and processed meat. Health implications include, increased incidences of obesity, cardiovascular diseases, type 2 diabetes, and certain cancers (Micha et al., 2017). Several plant-based ingredients such as legumes, and fibre residues are being used to reformulate healthy meat analogues without compromising quality (Fagbemi et al., 2021; Tso & Forde, 2021). Cashew apple fibre, in particular, has been shown to improve the quality of meat analogues whiles improving cooking yield and textural properties (Pinho et al., 2011).

Despite the popularity of soy in plant-based meat formulations, it remains one of the major food allergens globally, affecting 2–10% of the population (Taylor et al., 2014; Wiederstein et al., 2023). This has spurred the search for hypoallergenic alternatives, especially in regions where dietary diversity and food allergies are critical concerns. Bambara bean (Vigna subterranea), a drought-tolerant legume native to sub-Saharan Africa, is increasingly recognized for its nutritional and functional value. It contains 18–24% protein, 6–12% fat, 60–65% carbohydrates, and approximately 5–6% dietary fibre (Hillocks et al., 2012). The legume is rich in essential amino acids, such as lysine and methionine, and provides key minerals like calcium and potassium (Murevanhema & Jideani, 2015). Its functional properties, including emulsification, water-holding, and gelation capacity, make it suitable for texturizing plant-based meat alternatives (Fasoyiro et al., 2020; Obatolu et al., 2022).

Plant -based sausage production, a rapidly expanding segment of the food market, demands formulations that meet consumer expectations for taste, texture, and nutritional balance. Integrating cashew apple fibre with bambara bean in such formulations presents a dual opportunity: reducing agro-industrial waste and enhancing product nutritional value. Moreover, such innovation aligns with circular bioeconomy principles and supports local food systems and rural livelihoods through the valorization of indigenous crops (FAO, 2023; Boukid, 2021).

The objective of the study was to investigate the potential of combining cashew apple fibre and Bambara bean for the formulation of a plant-based sausage. It explores the nutritional composition, physical properties, microbial safety, and sensory attributes of the product to determine its feasibility, consumer acceptability, and potential contributions to sustainable food innovation.

2.0 Methodology

2.1 Materials

Cashew apples (SG clone) were manually harvested at full ripeness from Techiman and Wenchi districts (Bono and Bono East Regions, Ghana). Fruits were stored at −18 °C upon arrival at the CSIR-Food Research Institute (FRI) in Accra to maintain freshness. Bambara beans were sourced from Jibril Agrobusiness Enterprise, and secondary ingredients—including cassava flour, corn starch, spices, and margarine—were procured from CSIR-FRI's health shop and local retailers.

2.2 Experimental Design and Formulation Development

Four distinct sausage formulations were developed using an extreme vertices mixture design generated with Minitab Software 2.1, maintaining a constant 20% proportion of secondary ingredients (fat, binders, and seasonings) while varying the cashew apple fiber to Bambara bean ratios. The formulations were designated as CB1:0 (80% cashew fiber, 0% Bambara bean), CB1:1 (40% cashew fiber, 40% Bambara bean), CB2:1 (53% cashew fiber, 26.7% Bambara bean), and CB4:3 (45.7% cashew fiber, 34.3% Bambara bean).

2.3 Product Development Process

***Cashew Apple Fiber Preparation*:** Cashew apples underwent systematic processing involving sorting, cleaning, de-nutting, and thorough washing. Juice extraction was performed using an Amzchef Slow Juicer (SJ-036, China), yielding fiber residue suitable for sausage incorporation. The extracted fiber was blanched in boiling water (100°C) for 3 minutes to reduce enzymatic activity, astringency, and microbial load, then cooled to ambient temperature.

***Bambara Bean Preparation*:** Bambara beans were manually sorted and cleaned to remove debris and defective seeds. 1kg batches were soaked in 3L of clean water at room temperature (25°C) for 8 hours to soften seeds and reduce anti-nutritional factors including phytates, tannins, and oligosaccharides. Following soaking, beans were drained, rinsed, and partially cooked by boiling for 10 minutes. Cooked beans were blended using a CNTRONIC Nutrition Blender (LEE-301, Germany) with a bean-to-water ratio of 1:1.5 (w/v) to achieve smooth, uniform paste consistency.

***Sausage Processing*:** The production process involved combining blanched cashew fiber with processed Bambara bean paste according to predetermined formulations. Ingredients were thoroughly mixed using a CNTRONIC Nutrition Blender to ensure homogeneity. Fat (margarine) and seasonings were incorporated to enhance flavor and texture profiles. The mixture was beaten in a Kenwood Stand Mixer (KM5XX, China) for 5 minutes to introduce air and achieve uniform consistency, followed by a 10-minute resting period for proper hydration.

The prepared mixture was manually filled into cellulose fiber casings using piping bags to form uniform cylindrical shapes. Filled sausages were steamed using a Sunbean food steamer (SFS-300, China) at 100°C for 15-20 minutes to achieve desired firmness and cohesive structure. After cooling to room temperature, products were vacuum-packaged in multilayer food-grade plastic pouches and stored at -18°C for subsequent analyses.

2.4 Analytical Methods

***Proximate Composition*:** Moisture content was determined using oven-drying at 103±5°C for 20 minutes (AOAC, 2016). Ash content was measured through dry-ashing in a Carbolite CWF 1100 muffle furnace at 550±10°C for 8 hours. Fat content was extracted using the Soxhlet method with petroleum ether in a SE-6 extractor (VELP Scientifica, Italy) for 5 hours. Crude protein was determined using the Kjeldahl method with a Kjeltec™ 8200 apparatus (Foss Analytical, Denmark), employing a nitrogen-to-protein conversion factor of 6.25. Carbohydrate content was calculated by difference, and energy values were computed using standard conversion factors (protein and carbohydrate: 4 kcal/g; fat: 9 kcal/g).

***Mineral Analysis*:** Iron, calcium, and phosphorus concentrations were determined using Atomic Absorption Spectrophotometry (AAnalyst™ 400, Perkin Elmer Inc., USA) following AOAC, 2016 procedures. Samples were dry-ashed at 550°C, dissolved in 1M hydrochloric acid, and analyzed using element-specific wavelengths and standard curves.

***Vitamin C determination*:** Ascorbic acid content was measured using iodometric titration with starch indicator described by Popescu et al. (2024). 10g of sample were extracted with distilled water and titrated against standardized iodine solution until blue-black endpoint appearance.

Microbiological Assessment: Comprehensive microbial analysis was conducted following international standards to evaluate product safety and quality. Aerobic plate counts were determined using Plate Count Agar incubated at 30°C for 72 hours (NMKL No. 86, 2006). Escherichia coli enumeration employed Violet Red Bile Agar with confirmatory testing in EC broth at 44°C. Yeast and mold counts utilized Dichloran Rose Bengal Chloramphenicol Agar incubated at 25°C for 5 days (ISO 21527-1, 2008). Pathogenic bacteria detection included Salmonella screening using Buffered Peptone Water pre-enrichment and XLD agar isolation, and Listeria monocytogenes detection through Fraser broth enrichment and Oxford agar plating.

Texture Profile Analysis: Instrumental texture measurement was performed using a TA-XT2i plus texture analyzer (Stable Microsystems, UK) equipped with Exponent software. Double-bite compression tests were conducted at room temperature using a P/75 cylindrical probe with 35%

strain on samples cut to 14mm diameter × 35mm height (Zhao, Zhang, & Liu, 2022). Parameters measured included hardness, cohesiveness, springiness, chewiness, and gumminess.

Color Measurement: Color evaluation employed the CIE L*a*b* system using a CR-410 Chroma Meter (Konica Minolta, Japan). Measurements were taken in triplicate at different surface points, with L* representing lightness, a* indicating red-green component, and b* reflecting yellow-blue component. Total color difference (ΔE) was calculated relative to the control formulation (CB1:0) (Pathare et al., 2013; Ivanov et al., 2025).

2.5 Sensory Evaluation

Semi-trained panelists (n = 16) assessed all four samples plus a commercial plant-based sausage. Samples were deep-fat fried at 180 ± 5 °C, served at 50–55 °C, and evaluated for appearance, aroma, flavour, texture, and overall acceptability using a 9-point hedonic scale (Stone et al., 2012). Panellists used cucumber slices and water for palate cleansing between samples (Lim, 2020).

2.6 Consumer Acceptability Testing

The formulation with the highest sensory rating was selected for a consumer test involving one hundred and four (104) participants. Respondents rated acceptability and purchase intent and provided pricing feedback. Tests were conducted under standard conditions and demographic data were collected for analysis (Tuorila & Monteleone, 2021; Curtain & Grafenauer, 2022).

2.7 Statistical Analysis

All data underwent statistical analysis using Minitab Statistical Software version 21.0. Descriptive statistics were calculated including means and standard deviations. One-way Analysis of Variance (ANOVA) was performed at 95% confidence intervals to detect significant differences among formulations. Tukey's Honest Significant Difference test served as post-hoc analysis for multiple comparisons when significant effects were identified. All analytical determinations were performed in triplicate unless otherwise

3.0 Results

Development and visual attributes of plant-based sausage samples

Four plant-based sausage formulations were developed using varying ratios of cashew apple fibre and Bambara bean mash (CB1:0, CB2:1, CB4:3, and CB1:1). Visual observations revealed noticeable differences in colour among samples, with higher cashew content yielding brighter, golden-brown appearances, while Bambara-enriched samples were slightly duller. These visual effects align with prior research noting the influence of dietary fibre and protein ratios on the colour of meat analogues (Asgar et al., 2010; García et al., 2022).

Proximate Composition and Nutritional Profile

Macronutrient composition: The proximate composition of the vegan sausage samples showed substantial variations with different levels of Bambara bean fortification (Table 1). Moisture content ranged from 66.16% (CB2:1) to 68.05% (CB1:1), with no significant differences among samples ($p > 0.05$). These values fall within the acceptable range of 60-70% reported for vegan sausages (Obi et al., 2021; Mensah et al., 2022). The slight increase in moisture with higher Bambara bean content may be attributed to the water retention capacity of the legume matrix (Adewale et al., 2020).

Ash content remained relatively consistent across formulations (1.75-1.91%, $p > 0.05$), indicating that mineral contributions were not substantially altered by Bambara bean incorporation. The slight increase in CB2:1 may reflect modest mineral enhancement from Bambara beans (Kanu et al., 2022).

Fat content varied from 3.36% (CB4:3) to 4.51% (CB1:0), with no significant differences detected ($p > 0.05$). The control sample exhibited the highest fat content, likely due to the superior fat-binding capacity of cashew fibre after steam processing. Although Bambara beans contain approximately 6-7% fat (Murevanhema & Jideani, 2013), their inclusion may have reduced overall fat retention by partially replacing the more fat-retentive cashew apple fibre. This finding supports the development of reduced-fat plant-based alternatives (Otutu et al., 2023).

Crude fibre content increased significantly with Bambara bean incorporation, ranging from 0.51% (CB1:0) to 2.48% (CB1:1) ($p < 0.05$). This enhancement confirms the beneficial impact of Bambara beans on dietary fibre content, consistent with reported crude fibre levels of 3-6% in Bambara beans depending on variety and processing conditions (Murevanhema & Jideani, 2013).

Table 1: Proximate composition and energy content of developed cashew apple fibre fortified with Bambara beans vegan sausage samples

Sausage Samples	**Moisture (g/100g)**	**Ash (g/100g)**	**Crude Fat (g/100g)**	**Crude Fibre (g/100g)**	**Carbohydrate (g/100g)**	**Protein (g/100g)**	**Energy (kal/100g)**
CB1:0	66.73 ±3.34^{a}	1.79 ±0.69^{a}	4.51±1.37^{a}	0.51 ±0.05^{c}	22.63 ±0.07^{a}	2.02 ±0.04^{d}	146.34 ±0.24^{a}
CB2:1	66.16±4.4^{a}	1.91±0.64^{a}	4.31 ±0.57^{a}	1.00 ±0.36^{a}	20.05 ±0.65^{a}	4.21 ±0.05^{c}	140.36 ±2.40^{b}
CB4:3	66.69±5.22^{a}	1.75 ±0.83^{a}	3.36±0.98a	1.77±0.71^{ab}	16.72 ±0.24^{c}	8.38 ±0.02^{b}	135.70 ±0.36b^{c}
CB1:1	68.05±1.68^{a}	1.79 ±0.41^{a}	4.15 ±0.138^{a}	2.48 ±0.34^{a}	9.93±0.26^{d}	15.41 ±0.12^{a}	138.21±1.08^{b}

Data are shown as mean ± standard deviation (n=3). Values with different letters in the same row are significantly different ($p<0.05$). CB1:1 = Cashew apple fibre to Bambara bean in a 1:1 ratio (equal parts), CB4:3 = Cashew apple fibre to Bambara bean in a 4:3 ratio, CB2:1 = Cashew apple fibre to Bambara bean in a 2:1 ratio, CB1:0 = Cashew apple fibre only, no Bambara bean included.

Protein enhancement and carbohydrate reduction

A substantial increase in protein content was observed with Bambara bean fortification, from 2.02% (CB1:0) to 15.41% (CB1:1) (Table 1). This significant improvement shows the effectiveness of Bambara beans as a protein-enhancing ingredient, with CB1:1 achieving protein levels that exceed many commercial soy-based products (11-13%) (Ekezie et al., 2021). Conversely, carbohydrate content decreased significantly from 22.63% (CB1:0) to 9.93% (CB1:1), reflecting the replacement of carbohydrate-rich cashew fibre with protein-dense Bambara beans. This nutritional shift is beneficial for consumers seeking lower-carbohydrate, higher-protein meat substitutes (Adebayo, Ogunbanwo, & Ayinde, 2022).

Energy content ranged from 135.70 kcal/100g (CB4:3) to 146.34 kcal/100g (CB1:0). The reduction in energy with higher Bambara content was primarily due to decreased fat and carbohydrate components, making these formulations suitable for low-calorie, high-protein applications (FAO, 2023).

Micronutrient Composition of plant-based sausage samples

Vitamin C content: Vitamin C levels ranged from 9.43-9.55 mg/100g in Bambara-fortified samples to 11.29 mg/100g in the control (CB1:0) (Table 2). The marginal reduction with increased Bambara bean content was expected, as cashew apple fibre serves as the primary source of ascorbic acid. While fresh cashew apples contain 200-300 mg/100g vitamin C (Popoola et al., 2024), processing methods like steaming reduce concentrations due to heat sensitivity (Santos et al., 2021). Despite this reduction, all formulations provided 10-15% of the recommended daily intake for vitamin C, which is particularly valuable for enhancing non-heme iron absorption in plant-based diets (Pan et al., 2024).

Table 2: Vitamin C and Mineral Composition of Cashew apples fibre fortified with Bambara bean Vegan Sausage

Sausage Samples	Vitamin C (mg/100g)	Calcium (mg/100g)	Iron (mg/100g)	Phosphorus (mg/100g)
CB1:0	11.29 ±0.13[a]	370 ±25.50[a]	2.08 ±0.77[a]	62.87 ±1.32[c]
CB2:1	9.55 ±0.06[b]	281 ±33.0[ab]	1.97 ±0.50[a]	92.30 ±1.09[a]
CB4:3	9.43 ±0.06[b]	190.2±60.1[b]	1.70 ±0.66[b]	75.39 ±1.15[b]
CB1:1	9.46 ±0.03[b]	287±91.3[ab]	1.68 ±0.47[a]	92.43 ±1.18[a]

Data are shown as mean ± standard deviation (n=3). Values with different letters in the same row are significantly different ($p<0.05$). CB1:1 = Cashew apple fibre to Bambara bean in a 1:1 ratio (equal parts), CB4:3 = Cashew apple fibre to Bambara bean in a 4:3 ratio, CB2:1 = Cashew apple fibre to Bambara bean in a 2:1 ratio, CB1:0 = Cashew apple fibre only, no Bambara bean included.

Mineral profile: Calcium content varied significantly from 190.2 mg/100g (CB4:3) to 370 mg/100g (CB1:0), with the variation linked to decreasing cashew apple fibre content as Bambara bean inclusion increased (Table 2). The control formulation yielded up to 37% of the recommended daily intake of calcium in adults, while CB4:3 provided 19%. This calcium contribution is particularly important for vegan consumers who may lack dairy-based calcium sources (Craig, 2009). *Iron content* ranged from 1.68 mg/100g (CB1:1) to 2.08 mg/100g (CB1:0), providing approximately 21-26% of the RDI for adult men and 9-11% for women of reproductive age. The presence of vitamin C in all samples enhances the potential bioavailability of non-heme iron through the conversion of ferric to ferrous iron (Gupta & Siebeneck, 2021). *Phosphorus levels* increased significantly with Bambara bean incorporation, from 62.87 mg/100g (CB1:0) to 92.43 mg/100g (CB1:1). This enhancement reflects the inherent phosphorus richness of Bambara beans (250-350 mg/100g dry weight) compared to fruit-derived residues (FAO, 2021). The phosphorus contribution ranged from 9% to 13% of daily requirements, supporting bone health and energy metabolism in plant-based diets.

Sugar Composition Analysis

Sugar profile analysis revealed important nutritional characteristics (Figure 1). Total sugar content remained low across all formulations (4.47-4.92 g/100g), representing less than 20% of the WHO-recommended daily sugar allowance (WHO, 2022). This low sugar content makes the products suitable for health-conscious and diabetic-friendly applications. Sucrose content decreased dramatically from 1.41 g/100g (CB1:0) to 0.08 g/100g (CB1:1), reflecting the reduced proportion of naturally sweet cashew apple fibre. Conversely, reducing sugars increased from 3.1 g/100g (CB1:0) to 4.85 g/100g (CB1:1), likely due to thermal hydrolysis of polysaccharides during steaming and degradation of reserve carbohydrates in Bambara beans (Adewale et al., 2020). This sugar profile modification supports nutritional goals while potentially enhancing browning reactions and flavor development during processing.

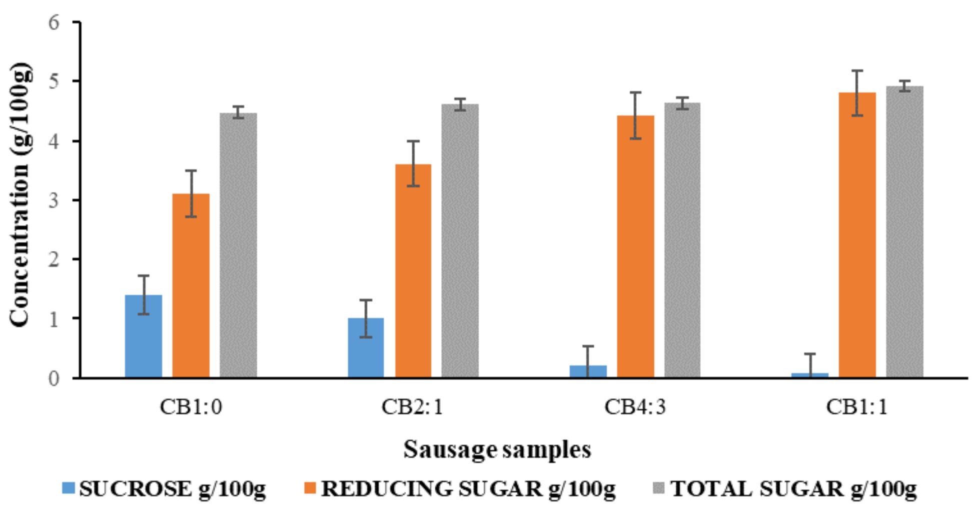

Figure 1: Sugar analysis of the formulated vegan sausage samples

Microbiological Safety of sausages

Comprehensive microbiological analysis confirmed the safety and quality of all vegan sausage formulations. Aerobic plate counts ranged from 18×10^1 to 33×10^1 CFU/g, well within acceptable limits ($<10^5$ CFU/g) for cooked sausages (ICMSF, 2020). No E. coli, yeasts, moulds, or Listeria species were detected in any samples, confirming effective thermal processing and hygienic handling procedures. Low levels of naturally occurring lactic acid bacteria were detected, which do not pose safety concerns in non-fermented products and may contribute to microbial balance during storage (Adeyeye et al., 2021).

Physical Analysis

Texture profile analysis

Instrumental texture analysis revealed significant improvements with Bambara bean fortification. Hardness increased progressively with Bambara bean content, with CB1:1 showing the highest values (Figure 2), indicating enhanced structural integrity. This improvement can be attributed to the starch and protein network formation during heat treatment (Adewale et al., 2020). Gumminess and chewiness followed similar trends, reflecting increased energy required for food breakdown and enhanced meat-like chewing characteristics. These parameters remained within consumer-acceptable ranges, as confirmed by high sensory texture scores for moderately fortified samples. Springiness, cohesiveness, and resilience all improved with Bambara bean incorporation, particularly in CB4:3 and CB1:1 (Figure 3). These enhancements indicate better elastic recovery, internal bonding strength, and structural integrity—critical quality attributes for commercial sausage applications (Dekkers et al., 2018). The correlation between improved mechanical properties and high sensory texture ratings validates the functional benefits of Bambara bean inclusion.

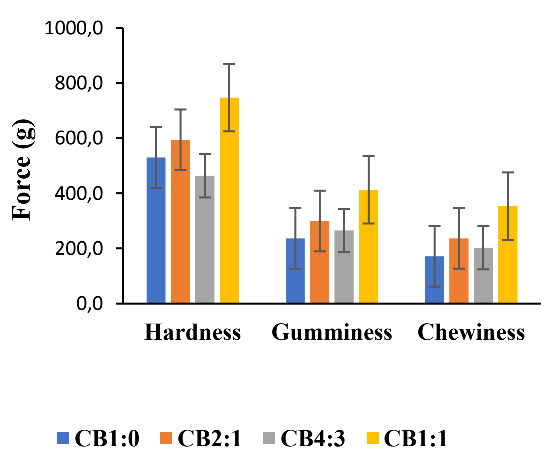

Figure 2: Texture analysis of hardness, gumminess, and chewiness of formulated vegan sausage samples

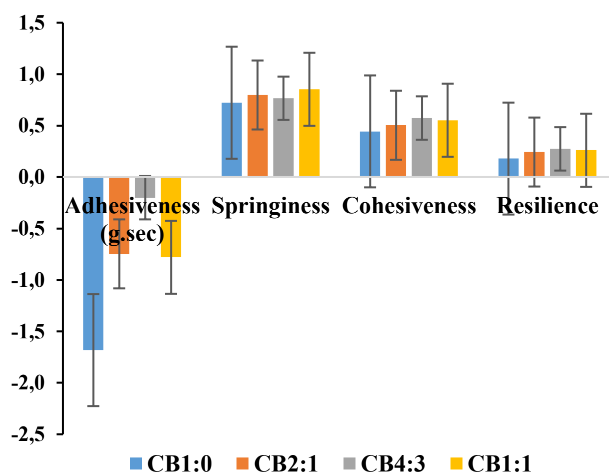

Figure 3: Texture analysis of adhesiveness, springiness, cohesiveness and resilience of the formulated vegan sausage samples

Color analysis

Instrumental color measurement using the CIE L*a*b* system showed that Bambara bean fortification influenced all color dimensions while maintaining visual acceptability (Table 3). Lightness (L*) values remained relatively stable (44.07-45.50), with moderate Bambara inclusion yielding the highest brightness values. The yellowness (b*) decreased from 19.78 (CB1:0) to 16.63 (CB1:1), reflecting reduced cashew fibre concentration, though all samples retained appealing golden-yellow tones. (Fagbemi et al., 2021). Total color difference (ΔE) values remained below 3.5 for all formulations, indicating acceptable visual differences that would not adversely affect consumer acceptance (Ivanov et al., 2025). The CB1:1 sample showed the highest ΔE value (3.27), still within the acceptable range while providing maximum nutritional benefits.

Table 3: Color analysis of the formulated vegan sausage samples

Sample	L*	a*	b*	ΔE (compared to CB1:0)
CB1:0	44.63 ± 0.18^{b}	-3.49 ± 0.02^{c}	19.78 ± 0.35^{a}	0 (control)
CB2:1	44.07 ± 0.02^{c}	-2.98 ± 0.03^{a}	17.52 ± 0.02^{b}	2.38
CB4:3	45.5 ± 0.29^{a}	-3.0 ± 0.05^{b}	19.36 ± 0.25^{a}	1.08
CB1:1	45.31 ± 0.09^{a}	-2.94 ± 0.03^{a}	16.63 ± 0.06^{c}	3.27

Sensory Evaluation and Consumer Analysis

***Semi-trained panel assessment*:** Sensory evaluation using a 9-point hedonic scale revealed significant differences among formulations (Table 4). There was no significant difference between sample CB4:3 which achieved the highest overall acceptability (7.44 ± 0.63), and the commercial sausage reference sample (CSRS) (7.56 ± 1.36) and all other quality attributes.

The control sample (CB1:0) consistently received the lowest scores (5.56-5.94), indicating that high fibre content alone was insufficient for optimal sensory properties. Balanced formulations (CB2:1 and CB1:1) received favorable scores, confirming the synergistic effect of fruit fibre and legume components on palatability.

Consumer acceptance analysis

Consumer testing with 104 panelists representing diverse demographics confirmed the product's broad market appeal. Age analysis (Figure 4) revealed that consumers aged 50+ provided the highest ratings across all attributes (≥7.5), while the predominant 21-29 age group rated most attributes between 6.0-6.8. Gender comparison showed balanced acceptance with minor variations (Figure 5). Males rated taste, texture, and color slightly higher, while females preferred juiciness and tenderness

Table 4: Sensory evaluation of the formulated vegan sausage samples

Samples	**Appearance (color)**	**Aroma**	**Taste**	**Texture (Mouthfeel)**	**Tenderness**	**Juiciness**	**Overall**
CB1:0	5.81±1.32^{b}	5.63±1.96^{b}	5.56±2.22^{b}	5.88±1.63^{b}	5.94±1.29^{b}	5.81±1.33^{b}	5.69±2.21^{b}
CB2:1	7.00±0.96^{a}	7.18±0.98^{a}	6.75±1.23^{ab}	6.68±1.07^{ab}	7.06±0.84^{a}	6.94±0.85^{a}	7.00±0.81^{a}
CB4:3	7.12±1.36^{a}	7.50±0.23^{a}	7.25±1.61^{a}	7.00±1.63^{ab}	7.18±1.28^{a}	7.13±1.36^{a}	7.44±0.63^{a}
CB1:1	6.88±0.80^{a}	6.94±1.48^{a}	6.68±1.30^{ab}	6.94±0.99^{a}	7.25±0.68^{a}	7.00±0.89^{a}	6.81±0.83^{a}
CSRS	7.19±0.83^{a}	7.50±0.97^{a}	7.37±0.88^{a}	7.31±0.70^{ab}	7.375±0.96^{a}	7.25±0.68^{a}	7.56±1.36^{a}

Data are shown as mean ± standard deviation (n=3). Values with different letters in the same row are significantly different ($p<0.05$). CSRS = Commercial Sausage Reference Sample, CB1:1 = Cashew apple fibre to Bambara bean in a 1:1 ratio (equal parts), CB4:3 = Cashew apple fibre to Bambara bean in a 4:3 ratio, CB2:1 = Cashew apple fibre to Bambara bean in a 2:1 ratio, CB1:0 = Cashew apple fibre only, no Bambara bean include.

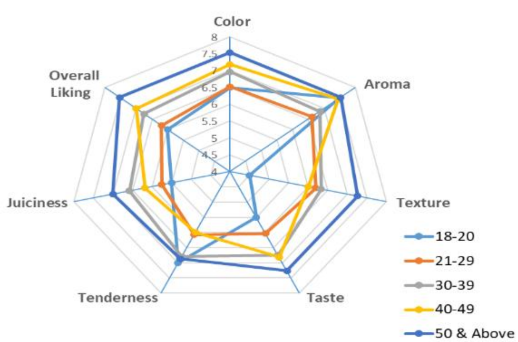

Figure 4: Consumer acceptance analyses by Age

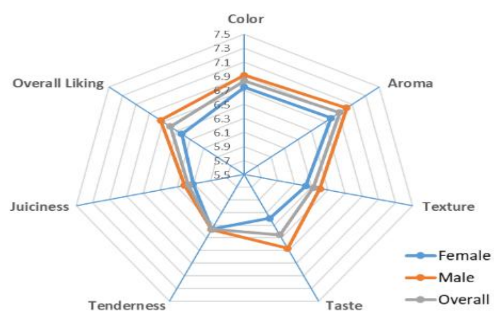

Figure 5: Consumer acceptance analysis by Gender

Dietary preference analysis demonstrated that vegan consumers consistently rated the product higher than non-vegans across all attributes, with vegans rating juiciness and overall liking above 7.0 versus approximately 6.0 for non-vegans (Figure 5). Interestingly, non-vegan scores exceeded average levels across all criteria, indicating significant cross-market appeal beyond traditional plant-based consumers.

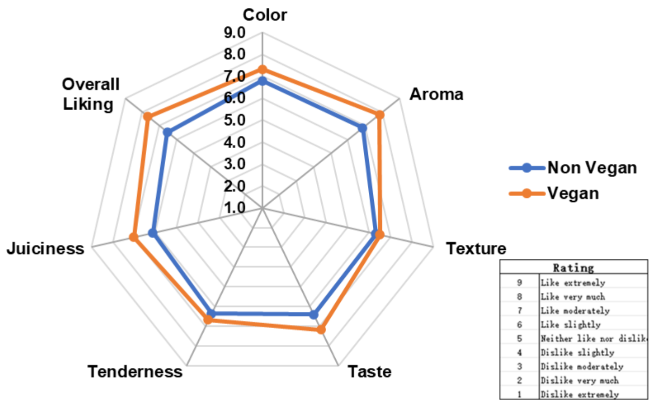

Figure 5: Consumer acceptability of vegan and non-vegans

4.0 Conclusion

This study demonstrates the successful development of a novel vegan sausage using cashew apple fibre fortified with Bambara beans. The findings affirm that the incorporation of Bambara beans significantly enhances the nutritional, functional, and sensory qualities of plant-based sausages, addressing key limitations found in current meat alternatives. Nutritionally, bambara bean fortification resulted in a substantial increase in protein and phosphorus content while maintaining desirable levels of moisture, fat, and energy. Although slight reductions in dietary fibre and vitamin C were observed with higher Bambara inclusion, the formulations remained nutritionally dense and suitable for health-conscious and plant-based consumers. Instrumental texture analysis revealed improvements in key mechanical properties—hardness, springiness, cohesiveness, and resilience—especially in moderately fortified samples. These attributes mimic the structure and bite of traditional meat, enhancing the product's appeal. Adhesiveness remained low, indicating ease of handling and pleasant mouthfeel. Sensory evaluation confirmed that sausages with moderate Bambara bean inclusion (CB2:1 and CB4:3) were most preferred for taste, texture, and overall acceptability. Although high Bambara content led to minor reductions in colour vibrancy and aroma, these did not detract significantly from consumer satisfaction. Importantly, both vegan and non-vegan participants rated the sausages favorably, indicating broad market potential, especially among flexitarian and mainstream health-focused consumers. Microbiological analysis confirmed the safety of all formulations, with no detectable pathogens and acceptable microbial loads, reinforcing their readiness for commercial distribution under appropriate handling conditions.

The integration of cashew apple fibre and Bambara bean presents a promising strategy for formulating nutritious, safe, and sensory-acceptable vegan meat analogues, while promoting the valorisation of underutilized local crops and food processing by-products.

5.0 Ethical Considerations

This study was conducted in accordance with ethical standards approved by the Institutional Review Board (IRB) and the Institutional Animal Care and Use Committee (IACUC) of the Council for Scientific and Industrial Research (CSIR-IRB/IACUC_CSIR-IRB/RPN025/2024). Informed consent was obtained from all sensory and consumer test participants. Participants were introduced to the study objectives, procedures, potential allergen risks, confidentiality and their rights prior to participation.

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