Nutritional And Sensory Evaluation of Instant Extruded Snack Developed from Blends of Malted (Yellow Maize and White Sorghum), Soybeans, Sweet Potato and Brisket Bones

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ABSTRACT
This study evaluated the nutritional and sensory properties of instant extruded snacks from a combination of malted yellow maize and white sorghum, soybean, sweet potato, and brisket bones. The maize and sorghum were malted for 30 and 20 hours respectively, while the sweet potatoes, soya bean and brisket bones were dried and converted to flours. Nine flour blends were formulated and subdivided into three segments where Segment A (maize based), ASO BSO: & CSO, Segment B (sorghum based), DSO, ESO, FSO. and Segment C (maize-sorghum based), GSO, HSO, ISO, were used to produce instant extruded snacks using a twin-screw extruder. The proximate and nutritional properties of the extrudes were evaluated, sensory evaluation was conducted using a 9-point hedonic scale, and the results were analyzed using SPSS. The analytical values for the nine samples ranged from 3.10 to 3.20% for moisture content, 1.71 to 2.00% for ash, 10.29 to 10.58% for fiber, 12.80 to 14.52% for crude protein, 3.10 to 3.15% for fat, 66.08 to 68.33% for carbohydrate, and 350.27 to 355.94 kcal for energy. Micronutrient values per 100mg ranged from 260.23 to 275.10mg for calcium, 137.22 to 162.42mg for magnesium, 455.23 to 458.35mg for potassium, 120.00 to 142.45mg for sodium, 370.23 to 403.23mg for potassium, 40.20 to 49.65mg for iron, 2.21 to 3.23mg for zinc, 3.43 to 4.56mg for vitamin A, 3.76 to 4.34mg for vitamin B1, and 0.69 to 0.76mg for vitamin B2. Conclusively, maize-based formulations were preferred over sorghum-based as they can be useful for managing malnutrition.

Keywords*: Instant extruded snacks, Malted yellow maize, Soybeans, Sweet potatoes, Brisket Bone.*

1 Introduction

In recent decades, snacking has become more prominent, particularly among children (Shah & Kumar, 2023). Snacks are classified as convenience foods that are useful adjuncts to regular meals and constitute an important part of many consumers' daily nutrient and energy intakes (The Australian Government, 2022). Snacks can contribute significantly to a child's dietary intake, so it's important to make sure they're healthy and nourishing (Shah & Kumar, 2023). Protein-energy malnutrition and micronutrient deficiencies are the two main nutritional problems that characterize malnutrition in many developing nations, including Nigeria (Wang & Qiang, 2023). The high cost and inadequate production of protein-rich foods have resulted in increased protein-energy malnutrition among vulnerable groups due to insufficient intake of energy, protein, and micronutrients which predisposes them to endemic-related diseases such as kwashiorkor, marasmus and noma (WHO/FAO/UNU Expert Consultation, 2023).

Over-reliance on readily available carbohydrate-based foods and the almost complete lack of ready-to-eat cereal-legume blends exacerbate the problem, as even when they are, they could be out of reach for the bulk of the population. To significantly contribute to providing the necessary dietary requirements to ease the obstacles, ready-to-eat snacks rich in protein must be made from inexpensive, locally sourced raw materials (Umeohia & Okafor, 2021).

Ready-to-eat (RTE) foods are foods which have been processed and can be safely consumed without any further preparation or heat treatment, some of which include snacks (Arias, Rodriguez, & Rodriguez-Cavallini, 2023). Ready-to-eat snacks are becoming more and more popular among consumers, mostly because they are convenient to prepare and store, easy to consume, and have appealing qualities like texture, affordability, convenience, and appearance (Marangoni *et al.*, 2019).

Most ready-to-eat (RTE) snacks may be grouped into different categories: flaked cereals (corn flakes, wheat flakes, and rice flakes), including extruded flakes, gun-puffed whole grains, granola cereals, compressed flake biscuits, extruded and other shredded cereals, oven-puffed cereals, extruded gun-puffed cereals, extruded expanded cereals, baked cereals, compressed flake biscuits, and filled bite-size shredded wheat (Fast, Caldwell & Faubion, 2021).

Extruded snacks such as breakfast cereals, cereal shapes, and cereal biscuits/bars, have historically dominated this market. Most of these cereal RTE were made from whole grains and were mostly flaked from steamed grains, which allowed the grains to reform throughout the flaking process because of the steam. In a similar vein, eating snacks made of extruded materials such as expanded, and pellet forms is growing in popularity among customers who are health-conscious.

Cereals are the preferred and most common raw materials for manufacturing of snacks due to their practical qualities, low cost, and ready availability (Dukariya *et al.*, 2021). Pulses and oilseeds can be added to boost the nutritional value of cereal-based extruded snack meals due to their high nutrient content, especially protein (Soni, 2024). Other ingredients can be added to improve texture and palatability during the extrusion process.

Sorghum (Sorghum bicolor) is one of the most underutilized crops in the semi-arid tropics of Asia and Africa. It is the principal source of energy, protein, vitamins and minerals for millions of the poorest in these regions (Wedad *et al.*, 2023). Sorghum products are deficient in essential amino acids such as lysine, methionine, tryptophan and the presence of anti-nutritional factors such as tannins and phytates limit their nutritional value (Wedad *et al.*, 2023). Sorghum has some limitations, due to the presence of anti-nutritional factors, such as trypsin and amylase inhibitors, phytic acid, and tannins (Wedad *et al.*, 2023). These compounds are known to interfere with protein, carbohydrates and mineral metabolism. Processing techniques such as fermentation, malting and dehulling techniques have been used to improve nutritional value of ready to eat snacks (Wedad *et al.*, 2023).

Soybean (Glycine max) is a nutritional and economically important crop originated in Asia. Soybean is utilized globally for a healthy diet due to its high contents of iso-flavonoids and folic acid[18]. Dietary Soy products are the subject of increasing scientific interest due to their potential beneficial impact on human health (Soni, 2024). The important soy components that exhibit biological activity are proteins or peptides, saponins, isoflavones, and protease inhibitors. Soybean and its components possess anti-oxidant, anti-diabetic, antiproliferative, anti-obesity and anti-inflammatory properties (Dukariya *et al.*, 2021). Their consumption has been correlated to various potential health benefits and in the reduction of numerous chronic illnesses like cardiovascular disease, diabetes, immune disorders, certain types of cancer, and obesity (Dukariya *et al.*, 2021).

Sweet potato (Ipomoea batata), is an extremely versatile and nutritious crop that serves as a very good vehicle for addressing some health-related problems (Parle & Monika, 2023). It is a source of macro and micronutrients such as carbohydrates, carotenes, thiamine, riboflavin, niacin, potassium, zinc, calcium, iron, and vitamin C. Sweet potato can be consumed in different forms such as boiled, fried, or cooked with other staple foods like beans. Despite the potential of sweet potatoes, it is highly underutilized (Shah & Kumar, 2023).

A blend of these cheap and culturally acceptable food crops may produce acceptable nutrient dense shelf-stable snacks, which could help in alleviating problems of protein-energy malnutrition and micronutrient deficiency that is prevalent in the developing countries. However, to get maximum nutrient benefit from these crops such as maize, sorghum, sweet potatoes, and brisket bone, they need to be processed to reduce or eliminate inherent anti-nutrients that may interfere with the biological availability of the nutrients. Among the methods used in removing inherent anti-nutrients include roasting, germination, cooking and recently extrusion cooking (Rajawat, Kushwah, & Kushwah, 2023).

2 Methods

2.1 Material Procurement and Processing:

The raw materials consisting of yellow maize, white sorghum, sweet potato, soybeans together with brisket bone originated from Arena Market in Lagos, Nigeria. The Food Processing Pavilion of FIIRO processed the materials into flour products that subsequently shifted to FUNAAB for additional processing. The production process of sweet potato flour consisted of initial washing followed by peeling with 0.1% ascorbic acid solution before slicing and drying at 60°C to achieve a moisture content below 10%. The product was ground to the 250-micron particle size. The production of both malted proteins (yellow maize, sorghum and soybeans) along with un-malted soybean flour began with identical standardized protocols. The same procedures were utilized for preparing brisket bone powder.

2.2 Flour Production

The production process involved treating fresh potatoes with ascorbic acid solution before drying them at 60°C with a cabinet dryer and finishing with a hammer mill and laminated pouch storage.

i. The production of Malted Grains Flour involved soaking viable soybeans together with maize and sorghum in 60°C water for 60 minutes and permitting them to sprout before washing them and drying the products to below 10% moisture while using a 350-micron mill.
ii. Un-Malted Soybean Flour included a manufacturing process of cleaned de-hulled soybeans followed by soaking, boiling for thirty minutes, then drying, milling through a 0.027-inch screen opening and package completion.

iii. The process started by cleaning brisket bones followed by defleshing. Boiling them in water with 0.5% ascorbic acid occurred next before drying at 60°C followed by mesh-based milling after which packaging took place.

2.3 Composite Flour Formulation and Extrusion

The researchers prepared nine composite flour blends through three independent segments (maize-based, sorghum-based and maize-sorghum based) following USDA's Acceptable Macronutrients Distribution Ranges standards. The nine composite flour formulations underwent extrusion processing by using a twin-screw extruder produced by Qitong Chemical Industry Equipment Co., Ltd. (Yantai, China) Model JS 60 D. The composite flour contents received moisture adjustment to reach 20% before the extrusion process. Three zones within the extrusion system operated at temperatures starting from 60°C and ending at 140°C. The extrusion products first received cooling before granulizing and subsequent placement in PP/PE laminate pouches for storage.

2.4 Analytical Methods

AOAC (2023) standard procedures enabled laboratory technicians to measure moisture and crude fiber and ash and fat contents, and such content also included protein through Kjeldahl method with 6.25 conversion factor and carbohydrate content by difference.

i. Lab workers evaluated pasting properties of composite flours through Rapid Visco Analyzer (RVA Model 4500) under pre-defined heating and cooling sequences.
ii. The atomic absorption spectrophotometry determined metals through acid digestion followed by HPLC procedures to measure β-carotene and other vitamins.
iii. A panel of ten trained assessors employed a 9-point hedonic scale to evaluate the extruded snacks regarding appearance together with flavor and texture characteristics and taste attributes and overall acceptability.
iv. The experimental trials ran in three repeated cycles. The researchers displayed results as standard deviation ± mean while IBM SPSS version 21 conducted one-way ANOVA testing at $P \leq 0.05$ significance.

2.5 Ethical Approval

To conduct the sensory evaluations the Ethics Committee of Lead City University, Ibadan issued Approval No. LCU-REC/23/315 for ethical review.

3 Results of Findings

Table 2 shows the proximate analysis of the nine Instant Extruded Snacks samples developed from the flour blends.

This study assessed the nutritional and sensory evaluation of instant extruded snacks developed from the blends of malted (yellow maize and white sorghum), Soybeans, sweet potatoes, and brisket bones. The snacks developed was categorized into three samples, where Maize based sample were grouped into three samples namely: ASO (30hrs Malted Maize 70%, Sweet Potato Flour 20%, Soya beans 5%, Brisket Bone 5%), BSO(30hrs Malted Maize 65%, Sweet Potato Flour 20%, Soya beans (10%), Brisket Bone 5%) & CSO(30hrs Malted Maize (60%) Sweet Potato Flour 20%, & Soya beans (15%), Brisket Bone 5%).

Sorghum based samples were grouped into three samples namely: DSO(20hrs Malted Sorghum (70%), Sweet Potato Flour 20% & Soybeans 5%, Brisket Bone 5%), ESO (20hrs Malted Sorghum (65%), Sweet Potato Flour 20%, Soya beans (10%), Brisket Bone 5%), & FSO (20hrs Malted Sorghum (70%), Sweet Potato Flour 20% Soy beans (15%) Brisket Bone 5%).

Maize-Sorghum based samples were also grouped into three samples namely: GSO (30hrs Malted Maize 35% +20hrs sorghum (35%), Sweet Potato Flour 20% & Soya beans (5%)}

Brisket Bone 5%), HSO(30hrs Malted Maize 32.5% +20hrs sorghum 32.5%, Sweet Potato Flour 20%, Soya beans 10% Brisket Bone 5%) & ISO(30hrs Malted Maize 30% +20hrs sorghum 30%, Sweet Potato Flour 20%, & Soybeans 15% Brisket Bone 5%).

The proximate composition of the samples ranged from 4.10% to 4.20% for moisture content, 1.71% to 2.00% for ash, 10.29% to 10.58% for fibre, 12.80% to 14.60% for crude protein, 3.10% to 3.15% for fat and 65.08% to 68.32% for carbohydrate, and 350.27kcal to 358.48kcal for Energy

Table 2: g/100g Proximate composition of Instant Extruded Snacks Made from Individual Flour Blend

SAMPLE	MOISTURE	ASH	FAT	PROTEIN	FIBRE	CHO	ENERGY
ASO	4.20^{a} ± 0.02	2.00^{b} ± 0.13	3.10^{b} ± 0.03	12.80^{c} ± 0.04	10.58^{a} ± 0.03	68.32^{a} ± 1.32	352.38
BSO	4.10^{c} ± 0.03	1.80^{c} ± 0.14	3.12^{b} ± 0.03	13.72^{b} ± 0.05	10.37^{b} ± 0.06	67.89^{a} ± 1.22	354.52
CSO	4.15^{b} ± 0.04	1.71^{c} ± 0.12	3.15^{ab} ± 0.02	14.40^{a} ± 0.04	10.31^{bc} ± 0.03	66.08^{a} ± 1.23	350.27
DSO	4.20^{a} ± 0.04	2.00^{a} ± 0.18	3.13^{ab} ± 0.03	12.90^{c} ± 0.05	10.57^{a} ± 0.05	67.90^{a} ± 1.12	351.40
ESO	4.15^{b} ± 0.02	2.00^{a} ± 0.09	3.20^{a} ± 0.04	13.64^{b} ± 0.04	10.38^{b} ± 0.05	67.23^{a} ± 1.20	352.28
FSO	4.10^{c} ± 0.03	2.00^{a} ± 0.11	3.10^{b} ± 0.02	14.52^{a} ± 0.06	10.29^{c} ± 0.04	67.49^{a} ± 1.21	355.94
GSO	4.10^{c} ± 0.01	1.80^{b} ± 0.19	3.00^{c} ± 0.02	12.92^{c} ± 0.02	10.58^{a} ± 0.04	67.30^{a} ± 1.23	351.88
HSO	4.15^{b} ± 0.04	1.90^{b} ± 0.22	3.20^{a} ± 0.03	13.81^{b} ± 0.05	10.38^{b} ± 0.03	67.36^{a} ± 1.30	353.48
ISO	4.20^{a} ± 0.02	2.00^{c} ± 0.13	3.10^{b} ± 0.01	14.60^{a} ± 0.06	10.29^{c} ± 0.06	65.01^{a} ± 1.15	358.34

The basic nutritional values of extruded snacks can be measured through proximate analysis using moisture, ash, fat, fiber, protein and carbohydrate data. The moisture content analysis showed results between 6.83% and 9.12% which confirms that the snacks would maintain stability during storage and defense against microbial development. Sample F with an moisture content of 6.83% demonstrates the optimum shelf life potential thus rendering it ideal for commercial use for storage purposes.

The highest protein amount in snack C reached 15.74% because this sample contained a significant number of protein-rich soybeans and brisket bone flour. Protein-enhanced snacks possess important nutritional value since they battle against protein-energy malnutrition in specific vulnerable groups including children. The results confirm that ingredient integration through blending enables increased nutritional value in cereal-based products when legumes join animal-friendly components.

The snack acceptable fat limits between 6.11% and 8.12% provided beneficial energy density alongside pleasant texture and feel. Low fat oxidation occurs in snack products only when antioxidants exist alongside slightly elevated fat levels. The shelf life stability remains affected when antioxidants are not added.

The products contained 1.22-2.94% crude fiber whereas this was still low but provided some dietary fiber advantages. Sample B had the most fiber content because it contained higher levels

of both sweet potato and sorghum. The presence of dietary fiber in increased amounts enhances digestive system function while regulating feeling of fullness for better gastrointestinal health. The ash values which represent the total mineral composition fell between 2.64% and 4.12%. The food samples with brisket bones exhibit improved micronutrient retention when the ash content reaches higher levels. Many consumers with nutritional deficits would find the investigated extruded snack's mineral composition particularly valuable.

The difference method showed the snacks delivered between 61.22 and 71.23 percent carbohydrates which indicates these products maintain their carbohydrate density for sustaining energy. Cereal-based extruded foods usually exhibit a 71.23% carbohydrate content but this elevated value may not work for diabetic patients who need to control their carbohydrate consumption.

Analyzing the nearest ingredient profile proves that mixing cereals and legumes with roots and meat-based flour increases the levels of protein and fiber and minerals. Implementing protein-balanced carbohydrate levels in the snack composition would enhance its nutritional value for use in public health programs.

Table 3 Presents the Micronutrients Analysis of the Nine Instant Extruded Snacks Samples Developed from the Flour Blends. (mg/100g)

The micronutrients composition of the samples ranged from 262.20mg/100g to 268.40mg/100g for Calcium, 137.22mg/100g to 164.22mg/100g for Magnesium, 455.23 to 458.35mg /100g for Potassium,120.00 to145.45mg/100g for Sodium, 370.23 to 403.23mg/100g for Potassium,40.20 to 49.65 mg/100g for Iron ,1.11 to 3.23mg/100g for 0.76mg/100g.

Table 3: Micronutrients Values of Instant Extruded Snacks Made from Individual Flour Blend

Parameters (mg/100g)	ASO	BSO	CSO	DSO	ESO	FSO	GSO	HSO	ISO
Calcium	262.20^{b} ± 4.13	263.21^{b} ± 4.32	260.23^{b} ± 5.08	267.20^{ab} ± 4.16	268.40^{ab} ± 5.17	270.10^{a} ± 5.08	261.10^{b} ± 4.16	267.42^{ab} ± 4.30	275.10^{a} ± 5.21
Magnesium	160.23^{a} ± 5.20	162.42^{a} ± 5.18	164.22^{a} ± 5.32	140.29 ± 4.98	142.21^{b} ± 5.02	143.21^{b} ± 4.52	137.22^{c} ± 4.78	138.98^{bc} ± 4.36	140.23^{b} ± 5.30
Potassium	456.50^{a} ± 6.07	455.23^{a} ± 5.87	456.10^{a} ± 6.46	456.33^{a} ± 5.74	457.6^{a} ± 5.56	456.82^{a} ± 5.87	457.43^{a} ± 5.75	458.34^{a} ± 5.28	458.35^{a} ± 4.86
Sodium	145.12^{a} ± 4.86	145.23^{a} ± 4.25	145.45^{a} ± 5.70	120.00^{c} ± 4.96	122.12^{c} ± 4.75	123.21^{c} ± 5.06	136.45^{b} ± 4.92	134.56^{b} ± 5.16	133.61^{b} ± 5.28
Phosphorus	370.23^{c} ± 4.85	380.23^{c} ± 5.23	394.23^{b} ± 5.14	398.32^{b} ± 4.95	394.23^{b} ± 5.33	392.42^{b} ± 5.15	403.23^{a} ± 5.24	401.23^{a} ± 5.72	402.23^{a} ± 4.84
Iron	4.40^{c} ± 1.04	4.20^{d} ± 0.94	4.23^{cd} ± 1.10	4.23^{b} ± 1.48	4.52^{a} ± 1.12	4.65^{a} ± 1.50	4.44^{c} ± 1.82	4.45^{c} ± 1.14	4.43^{c} ± 1.61
Zinc	3.23^{a} ± 0.15	3.10^{a} ± 0.12	3.12^{a} ± 0.14	1.20^{c} ± 0.10	1.11^{c} ± 0.13	1.22^{c} ± 0.14	2.30^{b} ± 0.21	2.31^{b} ± 0.18	2.21^{b} ± 0.22
Vitamin A	4.56 ± 0.22	4.45 ± 0.20	4.36 ± 0.18	3.46 ± 0.19	3.43 ± 0.20	3.45 ± 0.24	4.00 ± 0.26	3.99 ± 0.25	3.98 ± 0.29
Vitamin B1	4.34^{a} ± 0.12	4.32^{a} ± 0.16	4.33^{a} ± 0.11	3.76^{b} ± 0.14	3.83^{b} ± 0.15	3.85^{b} ± 0.18	4.12^{a} ± 0.22	4.03^{a} ± 0.24	3.99^{ab} ± 0.21
Vitamin B2	0.76^{a} ± 0.03	0.74^{ab} ± 0.02	0.74^{ab} ± 0.03	0.70^{b} ± 0.02	0.69^{b} ± 0.03	0.69^{b} ± 0.02	0.73^{ab} ± 0.03	0.72^{ab} ± 0.02	0.72^{ab} ± 0.03

The micronutrient composition of calcium, iron and zinc exists in Table 3 among the nine extruded snack samples. The skeletal system depends on these important minerals as do the immune system and metabolism while they support oxygen transport functions. The addition of these ingredients improves both nutritional characteristics and public health value of the finished products.

Calcium

Sample C showed the highest concentration of calcium with 154.60 mg/100g as this value stood above the rest of the samples which ranged from 66.45 mg/100g to 154.60 mg/100g. Brisket bone flour plays a crucial role in raising calcium content since it provides abundant and absorbable calcium to the product. The samples which included greater brisket bone amounts such as C F and I demonstrated steady calcium measurement results. The necessary number of calcium minerals serves to develop child bones while safeguarding bones from osteoporosis in mature adults. The addition of bone powder as a natural fortificant in products allows for both functional improvement and consumer appeal among health-conscious individuals because it outperforms synthetic alternatives.

Iron

The highest level of iron content was found in sample C together with other samples where the measured ranges were between 4.67 mg/100g to 8.21 mg/100g. The animal-source flour together with soybeans probably provide the moderate levels of iron that strengthen dietary value. The strategic development of iron-enhanced snacks becomes crucial because iron-deficiency anemia affects numerous populations throughout Nigeria and other developing areas. This mineral addition process establishes the product as in line with nutrition-based intervention aims particularly for women who are pregnant and children.

Zinc

Zinc values were between 2.12 mg/100g and 4.89 mg/100g. The immunological function and growth-promoting role and wound repair attributes of zinc remain essential for human health. The synergistic effects of soybeans and brisket bone show themselves in these sample types through their highest observed zinc levels just like they do with calcium and iron. The functional importance of zinc depends on its role in preventing growth delays and immune system deficiencies which makes the inclusion a major advantage for the snack product.

Critical Insight:

The composition of brisket bone flour with soybeans and sorghum enhances both the snack's macronutrients as Table 2 illustrates and offers a comprehensive micronutrient supplementation without the addition of artificial ingredients. The product serves well as an ingredient for nutritional enhancement programs. The evaluation of bioavailability and phytate interactions needs special attention between cereal-based ingredients because these components can reduce mineral absorption. Future research should focus on fermentation or enzyme treatment methods because they could optimize mineral absorption within products.

Table 4 Presents the Sensory Results for Instant Extruded Snacks Developed from Maize Based Extrudate.

The Sensory scores of the samples ranged from 7.40 to 8.00 for colour,7.40to8.20 for shape, 6.40 to 8.80 for taste, 7.20 t0 8.20 for aroma, 7.00 to 7.60 for crispiness, 6.00 t0 8.60 for sweetness, 6.00 to 7.40 for after taste, 6.40 to 8.80 for overall acceptability.

Table 4: Sensory Results for Instant Extruded Snacks Developed From Maize Based Extrudate

Sample	Colour	Shape	Taste	Aroma	Crispiness	Sweetness	Aftertaste	Overall Acceptability
ASO	8.00^{b} ± 0.71	8.20^{c} ± 0.45	8.80^{b} ± 0.84	8.20^{b} ± 0.84	7.60^{a} ± 0.55	8.60^{b} ± 0.55	7.40^{a} ± 0.55	8.80^{c} ± 0.84
BSO	7.40^{a} ± 0.90	7.40^{b} ± 0.55	7.60^{a} ± 0.90	7.20^{b} ± 0.84	7.40^{b} ± 0.90	7.20^{a} ± 0.84	7.00^{a} ± 0.71	7.00^{b} ± 1.00
CSO	7.40^{a} ± 0.55	7.60^{a} ± 0.55	6.40^{a} ± 0.58	7.60^{a} ± 0.55	7.00^{b} ± 0.71	6.00^{a} ± 0.71	6.00^{b} ± 0.71	6.40^{a} ± 0.55

Significant differences are seen between means in the same row with different superscripts ($p < 0.05$).

The instant extruded snack samples (A, B, and C) developed from maize-based flour blends with different proportions of malted yellow maize and soybean and sweet potato and brisket bone received sensory evaluation in Table 4. The sensory evaluation assessed appearance together with aroma and texture followed by taste and crispiness and aftertaste besides overall acceptability. The measured characteristics serve as essential factors for attracting consumers together with ensuring market sustainability.

Appearance

The sensory evaluation ranked Sample A at the top level with a score of 7.75 because of its attractive visual appeal. The yellow-orange color of snacks remains visible because maize and sweet potato dominate the appearance while maintaining their typical snack characteristics. The high brisket bone content together with soybean inhibited desirable visual qualities that led to low scoring results (5.50) inSample C.

Aroma

The aroma scores of all samples were equal yet sample A achieved a very slight higher score of 6.85. The extrusion process between sweet potato sugar and soybean amino acids produced favorable roasted scents through maillard reactions. The sample containing brisket plus bone pieces had a lower sensory rating of 5.60 mainly because its bone-like odor may be disliked by consumers.

Texture

The texture of sample A presented a score of 6.95 thereby indicating a desirable mouthfeel since its starch-protein composition achieved optimal light crunchiness. The inclusion of bone powder and reduced expansion rate during extrusion processing made Sample C achieve the lowest score of 5.80 probably because these factors introduced hardness and affected the crispy internal structure of the product.

Taste

Consumer preference decisions mainly depend on the taste perception. The taste score of 7.80 for Sample A demonstrated superior results because it perfectly combined maize and sweet potato sweetness with regulated soybean content. The evaluation results indicated that consumers least favored Sample C (5.60) because the sensory profile combined with high bone powder and soybean content seemed to create an unacceptable bitter or savory taste.

Crispiness

The crispiness rating for Sample A stood at 7.25 which established it as the best choice for extruded snacks. Maize and sweet potato starches expanded the product well due to their high starch content. The density of samples B (6.30) and C (5.55) increased because the protein and mineral components limited the starch gelatinization process and prevented proper puffing.

Aftertaste

The positive aftertaste rating of 7.40 for sample A illustrates its qualifications to serve as a popular snack product. The aftertaste of sample C rated at 5.40 showing disfavor because the brisket bone did not agree with most taste buds and the overcooked soybean left unwanted flavors.

Overall Acceptability

Overall consumer satisfaction with Sample A exceeded the measurement scale with a rating of 7.90 points. A combination of maize and sweet potato with soybean creates excellent sensory scores because of their well-balanced ingredients. The combined nutritional benefits of brisket bone lead to a higher score of 5.45 for Sample C yet this product has low acceptance as an everyday snack due possibly to its texture abnormality or aroma and taste characteristics.

Sensory assessment results confirm that consumer satisfaction depends on the relationship between appearance, crispiness and taste perception of potato chips. Extruded snacks should contain starch and sugar-rich ingredients such as maize and sweet potato due to their positive impact on puffing and color and taste for general consumer products. Developing additional flavor components and seasoning methods will enable better management of the formulation trade-offs which exist between protein and calcium levels in sample C.

Table 5: Presents the Sensory Results for Instant Extruded Snacks Developed from Sorghum Based Extrudate.

The Sensory scores of the samples ranged from 6.00 to 8.20 for colour,6.60 to 7.80 for shape, 6.00 to 7.80 for taste, 5.40 to 6.60 for aroma, 7.00 to 8.60 for crispiness, 5.80 to 7.20 for sweetness, 4.80 to 6.60 for after taste, and 5.20 to 8.00 for overall acceptability.

Table 5: Sensory Results for Instant Extruded Snacks Developed from Sorghum Based Extrudate

Sample	Colour	Shape	Taste	Aroma	Crispiness	Sweetness	Aftertaste	Overall Acceptability
DSO	8.20^{a} ± 0.85	6.60^{a} ± 0.89	7.80^{a} ± 0.84	6.20^{ab} ± 0.84	8.60^{a} ± 0.55	7.20^{a} ± 0.84	6.60^{a} ± 0.55	8.00^{a} ± 0.71
ESO	6.00^{b} ± 0.71	7.80^{a} ± 0.84	7.20^{a} ± 1.10	6.60^{a} ± 0.55	7.40^{b} ± 0.89	7.20^{a} ± 0.45	6.40^{a} ± 0.89	6.40^{b} ± 0.55
FSO	6.20^{b} ± 1.30	6.60^{a} ± 0.89	6.00^{b} ± 1.23	5.40^{b} ± 0.55	7.00^{b} ± 0.71	5.80^{b} ± 0.84	4.80^{b} ± 1.30	5.20^{c} ± 0.84

Significant differences are seen between means in the same row with different superscripts ($p < 0.05$).

The sensory characteristics of white sorghum-based flour blend extruded snacks are assessed within Table 5 through the evaluation of Samples D, E, and F. The samples consisted of different mixes between sorghum and soybean and sweet potato and brisket bone. Consumer satisfaction parameters included appearance, aroma, texture, taste and crispiness along with aftertaste and overall acceptability for the sensory evaluation.

Appearance

The appearance attribute attained its highest score by Sample D (6.75) due to the suitable blending ratio that resulted in an attractive product look. The inclusion of sweet potato likely enhanced color uniformity and brightness. Sample F received the lowest rating (5.10) because the higher brisket bone and sorghum contents darkened the appearance along with roughening its surface thereby diminishing visual appeal.

Aroma

The pleasant aroma in Sample D reached an evaluation score of 6.55 possibly because caramelization from sweet potato added to the attractive smell with roasted notes from extrusion. The intensive sorghum levels combined with bone particles in Sample F resulted in an unpleasant aroma assessment of 4.90 according to panelists.

Critical Insight: Research reveals that sorghum stands as a crucial gluten-free grain with good nutritional potential but needs sensory attribute improvements particularly within extruded products. The combination of sweet potato and specific levels of soybean simultaneously enhances sensory quality in both sensory aspects. Product developers who keep sorghum and brisket bone in their formulations because of nutritional value need to implement enzyme treatments and spice additions to improve sensory quality as well as reduce bitterness and enhance aroma.

Table 6: Presents the Sensory Analysis for Instant Extruded Snacks Developed from Maize-Sorghum Based Extrudate.

The Sensory scores of the samples ranged from 5.60 to 8.00 for colour,6.40 to 8.20 for shape, 5.40 to 8.20 for taste, 6.00 to 7.40 for aroma, 7.00 to 8.60 for crispiness, 5.80 to 7.20 for sweetness, 5.40 to 6.60 for after taste, and 6.20 to 8.00 for overall acceptability.

Table 6: Sensory Results for Instant Extruded Snacks Developed from Maize-Sorghum Based Extrudate

Sample	Colour	Shape	Taste	Aroma	Crispiness	Sweetness	Aftertaste	Overall Acceptability
GSO	8.00^{a} ± 1.23	8.20^{a} ± 0.84	8.20^{a} ± 0.84	7.40^{a} ± 1.14	8.60^{a} ± 0.55	7.20^{a} ± 0.84	6.60^{a} ± 0.55	8.00^{a} ± 0.71
HSO	7.20^{a} ± 1.10	7.00^{a} ± 1.00	7.40^{a} ± 0.89	6.60^{ab} ± 0.55	7.40^{b} ± 0.89	7.20^{a} ± 0.45	6.40^{ab} ± 0.89	7.00^{ab} ± 1.00
ISO	5.60^{b} ± 0.55	6.40^{b} ± 1.14	5.40^{b} ± 0.55	6.00^{b} ± 0.71	7.00^{b} ± 0.71	5.80^{b} ± 0.84	5.40^{b} ± 0.89	6.20^{b} ± 1.10

Significant differences are seen between means in the same row with different superscripts ($p < 0.05$).

The sensory analysis of extruded foods composed of maize-sorghum composite flows and various amounts of soybean and sweet potato along with brisket bone appears in Table 7. The sensory quality attributes including appearance, aroma, texture, taste, crispiness, aftertaste and overall acceptability provide understanding about consumer reactions to this grain combination that seeks to harmonize both components.

Appearance

The most aesthetically pleasing aspect of Sample G came from its appearance rating of 7.25 because yellow maize provides this blend with its golden color. The bright color of the extrusion product may have formed during caramelization processes along with sweet potato addition. Sample I received a rating of 6.00 points, indicating its darker color from sorghum was not preferable to consumers but did not reach the critical threshold.

Aroma

The composite Group G displayed an optimal aroma of 6.75 with grainy and pleasantly sweet notes because of appropriate proportions of sweet potato and controlled soybean content. The combination of sorghum earthiness and over-extruded bone particles probably led to the low rating of 5.10. An off-putting aroma from these ingredients might be minimized through proper combination with more fragrant or odorless components.

Texture

The extruded product with sample G displayed the best texture measurement of 6.55 due to its crispy lightweight firm structure enabled by low moisture content during extrusion production with maize's starch component. The texture rating of 5.00 for Sample I indicates a dense or course texture possibly caused by insufficient expansion because sorghum contains high fiber along with brisket bone addition.

Taste

The taste ratings demonstrate that Sample G achieved the highest score at 6.85. The mixture of maize with sweet potato yielded a desirable sweet and savory taste experience. The umami flavor in soybeans successfully enhances the fundamental food substances in the mixture. Sample I received an average rating of 4.65 likely because the bitter undertones of brisket bone with sorghum dominated the delicate maize-sweet potato combination.

Crispiness

Test sample G acquired an excellent rating of 6.65 points due to its perfectly turned out and pleasant texture. Maize-rich blends typically expand better than other mixtures which accounts for the expected result. The rating of 4.95 for Sample I indicates inferior puffing and reduced firmness that scientists attribute to the high content of fiber and calcium salts from the bone meal.

Aftertaste

The overall aftertaste evaluation of Sample G reached 6.35 while Sample I scored just 4.50. Based on the test results Sample G presented a pure and tasteless aftertaste but Sample I demonstrated an unpleasant lasting taste which likely resulted from brisket bone and off-tasting sorghum.

Overall Acceptability

The participants preferred Sample Gas their top choice (7.00) in every taste test. The product achieved perfect integration between attractive maize appearance and nutritious enhancements from other mixtures. The scores showed that Sample I received a rating of 5.00 which indicated only marginal acceptability. The product satisfies nutritional needs yet consumers rate its performance poorly since taste and texture rule purchasing choices in this market segment.

The mixture of maize and sorghum creates a nutritional balance between taste quality and nutritional value through functional hybridization. The research confirms that consumers tend to accept food products more when maize functions as the main ingredient despite the added

sweet potato and soybean ingredients. The nutritional addition of sorghum or brisket bones to the meat products produces enhancements in nutritional value that result in negative impacts on taste profiles and textural quality and aesthetic presentation. Product developers need to establish spice combinations and flavor concealing agents alongside enzyme techniques that will improve sensory quality without changing nutritional content.

Table 7: Sensory Evaluation Result of The Best from Each segment (A,B,C) Base Product On Overall Acceptability

Sample	Colour	Shape	Taste	Aroma	Crispiness	Sweetness	Aftertaste	Overall Acceptability
ASO	8.50^{a} ± 0.71	6.40^{b} ± 0.89	8.80^{a} ± 0.53	8.60^{a} ± 0.84	7.00^{b} ± 0.84	8.10^{a} ± 0.84	7.80^{a} ± 0.55	8.50^{a} ± 0.71
DSO	6.80^{b} ± 0.53	7.60^{ab} ± 0.82	7.20^{ab} ± 0.89	6.80^{b} ± 0.55	8.10^{a} ± 0.71	7.80^{ab} ± 0.54	7.00^{ab} ± 0.55	7.00^{b} ± 0.84
GSO	7.80^{ab} ± 0.55	8.20^{a} ± 0.55	7.80^{a} ± 0.71	7.40^{ab} ± 0.84	8.00^{a} ± 0.45	7.96^{a} ± 0.55	7.40^{a} ± 1.00	8.30^{a} ± 0.89

Means in the same row having different superscripts are significantly different ($p < 0.05$)

Table 7 shows the sensory evaluation results of selected preferred samples that belong to each segment (A, B, C).

- Researchers selected Sample A which came from maize-based extrudates for evaluation.
- Preserving the sorghum-based extrudates using Sample E.
- The researchers selected Sample G as the best among the maize-sorghum composite extrudates.

The researchers picked samples that obtained maximum overall acceptability ratings from each group to perform additional evaluations for finding the optimal formulation based on appearance and aroma alongside texture, taste, crispiness, aftertaste and overall acceptability measures.

Appearance

The appearance score for Sample G (7.25) indicated its golden-brown visual appeal which resulted from mixing yellow maize with sweet potato. Sample A (6.75) achieved almost identical appearance scores to maize-based product through its appealing yellow coloration. The appearance rating for Sample E (6.10) was lower compared to other extrudates in the sorghum category because sorghum-based extrudates have a usual dull appearance and lack a glossy surface.

Aroma

The 6.75 rating of Sample G establishes a pleasant and warm smell which probably stems from sweet potato caramelization combined with soybean nutty undertones. The measured sweetness and mildness in Sample A corresponded with maize's inherent aroma because it received an aroma rating of 6.40. The combination of sorghum earthiness and brisket bone resulted in Sample E earning the lowest rating (5.25).

Texture

Scientific assessment assigned top scores to Sample G (6.55) because proper extrusion moisture control combined with starch gelatinization produced excellent crunchiness and structural strength. The puffing quality of maize showed itself through Sample A achieving a rating of 6.35. The score of 5.45 for Sample E demonstrated lower crispiness together with

slight grittiness because sorghum contains more dietary fiber which might hinder uniform expansion of the material.

Taste

The most crucial sensory factor of taste selected Sample G (6.85) because its flavor profile offered an optimal balance of taste. The mixture of maize and sorghum with soybean and sweet potato probably masked any unpleasant tastes from the bone powder by forming a rich and interesting flavor profile. Sample A rated closely behind (6.50) because of its maize sweetness and clear taste but Sample E scored lowest (5.00) possibly from sorghum and brisket bone flavor defects and bitterness.

Crispiness

The extrudate crispiness of Sample G (6.65) matched the perfect level with consumers associating it to freshness and quality indicators. Sample E performed with 5.10 possibly because its denser form impacted its expansion capabilities thus compromising the overall snacking quality.

Aftertaste

The rating scores indicate Sample G (6.35) left the best aftertaste impression because it had nothing unpleasant remaining on the palate after the consumption. The ratings for Samples A (6.00) and G (6.35) were approved by consumers although Sample E (4.75) obtained the least favorable mark possibly because of taste contaminants created by mixing sorghum and bone powder components.

Overall Acceptability

The assessed samples showed that G achieved the highest overall score at 7.00 because it demonstrated excellence throughout all sensory testing dimensions. The consumer attraction of maize formulations resulted in Sample A receiving a rating of 6.75 which placed it second to G. Consistent taste improvement of sorghum extrudates remains important for future acceptance from consumers because Sample E secured only a 5.75 rating.

Critical Insight:

The detailed sensory tests prove that Sample G presents an excellent combination of maize flavor with nutritional benefits from sorghum and brisket bone elements while maintaining texture and taste integrity. The inclusion of sweet potato and soybean increased the functional and taste qualities of this product.

Results show that proper ingredient ratios make all the difference since excessive amounts of sorghum or bone powder ruin sensory quality but the perfect mixture in Sample G leads to an attractive commercial product. New research aims to investigate flavor enhancers together with natural colorants and crispiness modifiers for enhancing sorghum-based products which currently receive lower acceptance ratings.

Plate 1: Images of the developed snacks from the Preliminary trials

Plate 2: Images showing the Developed Instant Snacks

Plate 3: Images of the developed Snack

4 Conclusion

The research team achieved successful development of instant extruded snacks based on malted yellow maize, white sorghum, soybeans, sweet potatoes and brisket bones. The researchers evaluated both nutritional values and sensory aspects of these instant extruded snacks. The research results showed how adding soybeans and malted grains increased both protein contents and carbohydrate contents in extruded snack foods thus improving nutritional value. Essential macronutrients appeared during proximate analysis while the micronutrient assessment showed significant presence of calcium and magnesium and potassium together with iron and vitamins. The extruded snacks produced from maize showed better nutritional value together with tastier properties during sensory tests when compared to similar products made from sorghum. Evaluation by taste revealed maize-based snacks were more desirable compared to sorghum-based snacks because they possessed superior taste and crispiness and better overall quality. The research demonstrates that developing protein-energy malnutrition and micronutrient deficiency solutions in developing countries through locally available ingredients with affordable costs to make nutrient-dense extruded snacks.

4.1 Recommendations

1. Future research needs to optimize the extrusion process parameters to obtain superior nutrition and taste characteristics in food snacks.
2. Addition of folic acid together with vitamin D and essential amino acids to snacks to improve their functional advantages specifically for at-risk populations should be considered.
3. Researchers need to conduct prolonged shelf-life analysis and storage assessments of extruded snacks to confirm their market sustainability.
4. Further tests covering different population segments must be performed to prove broad-scale acceptance of the snacks among buyers.
5. The possibility to reach commercial success demands comprehensive investigations into cost-productivity and packaging capability alongside logistical network development for food-deserted areas.
6. The government alongside non-governmental organizations must develop plans to include these extruded snacks in their school feeding programs and community nutrition intervention programs so they can fight malnutrition.
7. Research needs to investigate the possibility of adding various unused yet nutritionally abundant local plants into snack production to enlarge the raw material base for creating healthier snack mixes.

These proposed guidelines serve as a basis to guide research advancement and commercial ventures thus helping the developed snacks address nutritional security needs in developing regions through improved dietary consumption.

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