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Research article

FUTURE FOODS DEVELOPMENT: EFFECT OF TEMPERATURE, FEED MOISTURE AND COCONUT ADDITION ON THE PHYSICOCHEMICAL PROPERTIES OF EXTRUDED CORN SNACKS

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Abstract
The study investigated the effect of temperature, feed moisture and coconut addition on the physicochemical properties of extruded corn snacks. The samples were processed, data collected and analyzed using standard methods. The results findings revealed that there were significant variations (P<0.05) in the proximate composition of the extruded corn-coconut snack samples. The ash, moisture, fire and fat contents ranged from 3.54-3.82%, 4.94-5.60%, 2.87-3.15% and 8.90-9.15%, respectively. The protein content of the extruded snack samples varied from 9.93 to 12.31%, while the carbohydrate content ranged from 66.36 to 69.40%. Carbohydrate content was highest in FGH (69.40%) and lowest in BCO (66.36%). The moderate fat content can aid in the absorption of fat-soluble vitamins (ADEK). Significant differences (p<0.05) were also observed in some of the functional properties of the extruded corn-coconut snacks with the emulsion stability ranging from 10.00 to 11.33%, while emulsion activity ranged from 9.14 to 9.91%. The oil absorption capacity, bulk density and foaming capacity ranged from 1.93-2.98%, 0.57-0.76% and 11.17-15.60%, respectively. Oil absorption capacity varied significantly (P<0.05), with NPO and BCO samples exhibiting the highest values (2.98 g/g), reflecting their potential for flavor retention and mouthfeel enhancement. Bulk density ranged from 0.57 to 0.76 g/cm³, where higher values of QRW and YXZ implied denser products, potentially influencing packaging and textural properties. Foaming capacity varied between 11.17% and 15.60%, with NPO demonstrating the most pronounced ability to entrap air, which is crucial for snack lightness and volume. The colour and physical properties of the extruded snacks also varied significantly (p<0.05) among the samples. The results of the sensory evaluation revealed that the sample VST was ranked the highest in terms of overall acceptability, while sample SOA was ranked least.

1. Introduction

In traditional Igbo society, snacks are taken as delicacy after each days' work. Other times, they are enjoyed by the extended family when a relation or family member return from travel. Some of the traditional snack foods include eating of maize with either maize, coconut, African black pea (*ube*) or palm kernel, eating of African salad (*Abacha*) with either palm kernel coconut, eating of African black with palm kernel, among others (Eke, 2025). The knowledge of snacking in traditional Igbo society may be used for new food product development in what may be referred to as the future foods. Other authors (Ikegwu, 2023) stated that the development of a new food product involves innovation which is the key for propagating and adopting new ideas. It is important that these novel product ideas are developed to meet international standard given that most of this traditional food practices are been given attention by other cultures due to globalization. It is therefore imperative that extrusion technology could be employed.

Development of traditional snack foods through extrusion cooking recognizes the thermomechanical processes for heat and mass transfer in ensuring that products meet desired expectations (Ikegwu, 2023). It was noted that maize/corn could be eaten fresh or in dried forms in Igboland and noted that the corn, coconut and ube snacking could earn Nigeria United Nation Cultural Status (Eke, 2025). The pear, when eaten with corn, could either be roasted or cooked. The use of maize-coconut for snack food production would encourage the global acceptance of the traditional food relics through pressure changes and shear which are combined to produce effects such as cooking, sterilization, drying, melting, texturizing, conveying, puffing, mixing and kneading. Extrusion is a combined high-temperature-short-time (HTST) process in a continuous operation to push material using a piston or a screw with pressure and shear through a die with a given shaper. The homogeneity and consistency of the thermal process permit the production of high-quality final products with minimum waste (An addendum to S5.06, Environmental Agency, Bristol). The extrusion process combines pumping, mixing, kneading, heating and cutting all in one process and can result in a preferred appearance and texture. Thus, extrusion technology is widely used in the food industry in cereals, snacks, pet food, feed, confectionery products, modified starches, baby food, and instant foods (Nwadi *et al.,* 2023; Offiah *et al.,* 2018). Extrusion is also a good way of processing pulses because of its versatility and flexibility, as well as the ability to reduce and inactivate bioactive factors that are naturally present in pulses and reduce cooking time when incorporated into products (Offiah *et al.,* 2018).

The feed moisture management is the key from an economic and feed quality point of view. The amount of moisture in bound form, brought by macro ingredients like corn, in a feed formula contributes to the production efficiency. Importantly, the moisture in compounded feed can assist cooking and conditioning, providing better machine efficiency (higher throughput at lower energy consumption), pellet quality, and feeding value (enhanced nutrient value). Kinetics of heat-moisture-steam application in feed processing and quality deterioration presents a completely new dimension for cost reduction during the feed formulation process, which does not depend only on the raw material cost but on the efficient production to enhance the feeding value for better product performance (Gurbuz, 2017; Inyang *et al.,* 2018). A sufficient moisture level is important as it reduces energy usage during the pelleting process and ensures that production runs more smoothly by lowering the risk of blockages. This is important for preventing nutrient losses due to excessive heat production. Furthermore, it guarantees good product quality at an optimal moisture level to positively affect product hardness. Extrusion technology has been used for snack production in starchy foods, whereby the temperature used at a definite time affects the quality and the characteristics of the snacks (Singh *et al*., 2017). Snacking have remained a part of the human diet for time immemorial and are its growth are been influenced be population, urbanization and the need for convenience foods with huge contribution to energy and nutrient intake (Ndife *et al.,* 2020; Ugwuanyi *et al.,* 2020). The demand for snacks is attributed to the rapid population and urbanization of both developed and developing countries (Ugwuanyi *et al.,* 2020). Snacks are important to many consumers' daily nutrient and caloric intake (Ibe *et al.,* 2025; Heitman *et al.,* 2023). The most widely consumed snacks are cereal-based products, generally low in nutrient density (Rehm and Drewnowski, 2017). They are generally regarded as convenience foods and have been part of the human diet for a long time (Hess *et al.,* 2016). Snack foods are cheap, easy to eat and readily available on the streets, shops and schools (Ugwuanyi *et al.,* 2020). Snack formulation from a blend of maize and coconut stems from the array of functional effects of coconut on food products. Coconut has dietary fiber and unsaturated fatty acids, which are very important in nutrition (Hewlings, 2020). Some researches on extruded snacks from either corn or coconut flour have focused on developing nutrient-rich food products, without recourse on the combination of the two ingredients for food product development (Table 1).

Table 1. Extruded snacks from Either Corn or Coconut

S/N	Research	Author
1.	Corn-Based Extruded Snacks Supplemented with Bilberry Pomace Powder: Physical, Chemical, Functional, and Sensory Properties	Blejan *et al.,* 2025
2.	Extruded snacks from industrial by products: a review	Grasso, 2020
3.	Extruded snacks with byproducts of coconut	Sali, 2024
4.	Amylose-lipid complex formation during extrusion cooking: effect of added lipid type and amylose level on corn-based puffed snacks	Thachil *et al.*, 2014
5.	Coconut Inflorescence Sap Honey: A Promising Supplementary Food among Tribals	Vadassery *et al.,* 2023
6.	The effects of feed moisture and dried coconut meal content on the physicochemical, functional, and sensory properties of gluten-free Riceberry rice flour-based extruded snacks	Piaura and Itthivadhanapong, 2023
7.	Development of extruded Ready-To-Eat (RTE) snacks using corn, black gram, roots and tuber flour blends	Reddy *et al.,* 2014
8.	Single Screw Extrusion Processing of Enriched Snacks at Various Levels of Brewers Spent Yeast and Soybean Meal	Olumurewa and Oladele, 2020

Coconut is rich in fiber (4.22%), vitamins, and minerals (Panoff, 2019). It is believed to be a "functional food" because it provides many health benefits beyond its nutritional content (Rachael, 2020). Coconut is low in digestible carbohydrates, contains no gluten, and is loaded with health-promoting fiber and important nutrients (Hewlings, 2020). Coconut flour is a soft, flour-like product made from the pulp of a coconut. Coconut flour is extremely high in fiber, with almost double the amount found in wheat bran. It contains more calorie-free fiber than other wheat alternatives and provides a good source of protein (Samarajeewa, 2024). Coconut provides many health benefits: it can improve digestion, help regulate blood sugar, protect against diabetes, help prevent heart disease and cancer, and aid in weight loss (Lalitha, 2014). Coconut is rich in energy-yielding fat (47.2%) and minerals (mg/kg) like phosphorus (184.2 mg/ kg), potassium (224.8 mg/kg), zinc (43.5 mg/kg), iron (37.9 mg/kg), magnesium (178.1 mg/kg), and about 50.0 mg/kg manganese (Amoo, 2004). The utilization of defatted coconut flour as a high protein and fiber ingredient in food formulations has been clearly reported (Samarajeewa, 2024; Usman *et al.,* 2015). The protein content of defatted coconut flour was in the range of 17.2–20.0% on dry weight basis (Adebowale and Komolafe, 2018; Pathirana *et al.,* 2020). Coconut protein fractions contain a substantial amount of glutamic acid, argentine, aspartic acid, and lysine, with values ranging from 17.0–24.9, 12.3–17.9, 5.6–9.3, and 3.5–4.1 g/ 100 g of protein, respectively (Pathirana *et al.,* 2020). Due to the array of nutritional benefits, coconut could be incorporated in snack foods involving corn to produce high-value food products. According to Mat *et al.* (2022), coconut could be utilized for various commercial products ranging from desiccated coconut, oil, raw kernels, milk, to coconut water thus serving as both oilseed and a source of food for the population due to its rich content of fibre and energy.

The major chemical component of the maize is carbohydrate, which provides up to 72 to 73% of the kernel weight (Sundaresan *et al.,* 2023). Maize is used as a basic food ingredient in its original or modified form. Maize grains are a rich source of starch (72%), ash (17%), protein (10.4%), fiber (2.5%), oil (4.8%), vitamins and minerals (Farhad *et al.,* 2009). The oil and protein contents are commercially valuable and used in food product manufacturing (Małecki *et al.,* 2021; Surjirtha and Mahendran, 2015). Its grains have great nutritional value and can be processed into various products such as cornmeal, grits, starch, flour, tortillas, snacks, and breakfast cereals. The percentage moisture content of all the maize varieties studied ranged from 11.10 to 13.96%; this is higher than the result recorded by Ape *et al*. (2016) whose moisture content was 7.16% for maize bought from the Ogbete market in Enugu, Nigeria. Crude fat is an important component of maize grains. Improvement in fat content aids good human health as they act as vehicle for fat-soluble vitamins.

Sali (2024) had instigated the production of snacks from extruded coconut by-products and barnyard millets. The findings revealed that the corn grits, coconut testa concentrate, coconut testa fibre and coconut fibre could be extruded for snack products and with barnyard millet. The findings of Sali (2024) nutritional, antioxidant, antimicrobial and functional properties. Sahu (2018) studied the storability of maize-millet based soy fortified extruded snack, while Edima-Nyah *et al.* (2022) evaluated the quality of maize-coconut snack bars enriched with different levels of malted African breadfruit seed flour. These studies indicated that snacks with coconut inclusion are rich in nutrients that could posit it a functional food in nutraceutical studies.

This present study is limited to the production, physical, proximate, functional, colorimetry and sensory properties of extruded snacks from maize-coconut. Further studies may wish to investigate the product optimization as well as carry-out animal studies to investigate the best economic product and the health effect of the consumption of the snack.

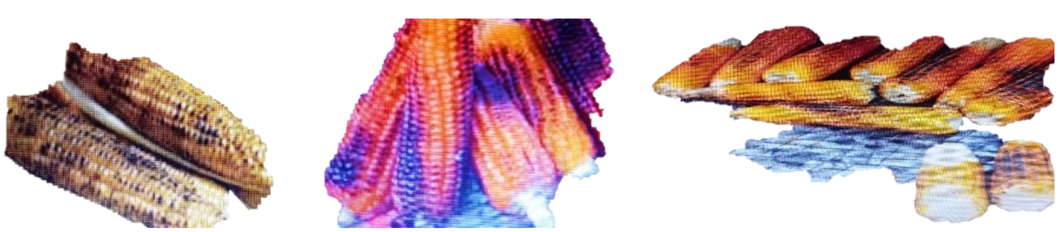

Figure 1. Corn with Maize

Figure 2. Extruded corn-coconut snacks

2. Materials and Methods

2.1. Source of Materials

Maize (dehulled) and mature coconut were purchased for extrusion at the Eke Awka local market, Awka South, Anambra State, Nigeria. All other chemicals used in this study were of reagent grade, purchased from reputable laboratory in Awka and Enugu State.

All extrudates were milled into flours using a hammer mill with a 1 mm diameter round whole perforated screen. Pre-cooked flours were composite flours combined from two extrusion runs. A pre-study was set up to determine the best blending ratio of the maize and coconut flours used in extrusion based on the protein quality.

2.2. Preparation of Raw Materials

The white corn grain and coconut were sorted to remove spoilt and defective ones as well as defective seeds to prevent the production of poor quality and unhealthy products. The grains and coconut were washed, cleaned and dried at ambient temperature to remove surface moisture. Below are the flowcharts for the preparation of the corn and coconut samples.

2.2.1. Procedure for the Preparation of Coconut Flour

Raw Material
↓
Husking
↓
Sorting and grading
↓
Dehulling
↓
Removal of water
↓
Washing
↓
Grating
↓
Sun Drying
↓
Grinding
↓
Coconut Flour

Figure 3. Flowchart for Processing of Coconut Flour

2.2.2. Procedure for The Preparation of Corn Flour

Raw Material
↓
Sorting and grading
↓
Washing and cleaning
↓
Sun drying
↓
Grinding
↓
Corn Flour

Figure 4. Flowchart for Corn Flour Processing

2.2.3. Production of extruded snacks

The washed and dried seeds and legumes were ground in industrial millers to grit sizes, packed in airtight containers and taken for extrusion. The seeds were fed into the extrusion machine with moisture and temperature, and the groundnuts varied at different levels. The extruded snacks were packed in zip-lock bags to prevent moisture absorption that could cause oxidative activities leading to rancidity.

2.2.4. Procedure for the production of corn-coconut-based extruded snacks

Raw material selection
↓
Sorting and grading
↓
Cleaning
↓
Size reduction (of maize and coconut to grit sizes)

Mixture formulation (50% maize, coconut: 5 – 31.81 g)
↓
Preconditioned blending (at moisture content: 5 - 23%)
↓
Transfer to feeder
↓
Extrusion cooking (80 – 133.73 °C)
↓
Cooling (at room temperature 30 min)
↓
Oven drying (60 °C for 30 min)
↓
Cooling (at room temperature 30 min)
↓
Packaging
↓
Extruded corn-coconut snacks

Figure 4. Extrusion of Snacks from Corn-coconut Blends

2.3. Proximate Analysis

The proximate analysis of the crude extract for moisture content and ash content was performed using the AOAC method (2021). The nitrogen content was calculated using the micro-Kjeldahl method, and the nitrogen content was multiplied by a factor of 6.60 to convert it to protein. After subtracting the total percent of other food nutrients from 100 percent, the total carbohydrate content was calculated.

2.3.1. Moisture Content (W%)

Moisture content basically implies water content. It is a commonly measured property in food products; legal and labelling requirements, cost of the product, microbial stability, food quality and food processing operations are why moisture content is essential in food products (NIMALSIRI, 2015). The moisture content will be determined by measuring the mass of food before and after the water has been removed (MOORE, 2020). Moisture content is defined through the following equation: %mixture = $(M_{water}/M_{sample}) \times 100$.

2.3.2. Determination of Moisture Content

Pre-weighed empty crucible was labelled (W_1). Exactly 3 g of the crude extract was weighed into the pre-weighed empty crucible (W_2) and dried for 3 h at 105°C in a hot drying oven. The crucible was removed and weighed after cooling in desiccators. The drying, cooling, and weighing process was repeated until the weight (W_3) was constant. The weight loss caused by moisture was measured.

$$\text{Moisture (\%)} = \frac{W_2 - W_3}{W_2 - W_1} \times 100 \quad (1)$$

Where: W_1= weight of the empty crucible
W_2= weight of empty crucible+ crude extract
W_3= weight of empty crucible + dried crude extract

2.3.3. Determination of Ash Content

The pre-weighed empty crucible was labelled (W_1). Three (3 g) grammes of the crude extract was weighed into a pre-weighed empty crucible (W_2) and heated at 550°C for 5 h in a lenton muffle furnace. The ash was weighed after cooling in a desiccator (W_3). The difference between the pre-weighed crude extract and the ash in the crucible was used to calculate the weight of the ash. Percentage ash was calculated using the equation below:

$$\text{Ash (\%)} = \frac{W_2 - W_3}{W_2 - W_1} \times 100 \quad (2)$$

Where: W_1= weight of empty crucible
W_2= weight of empty crucible+ crude extract
W_3= weight of empty crucible + ash

2.3.4. Determination of Crude Protein

The micro-Kjedahl technique was used to determine the crude protein content of the crude extract. In a micro-Kjedahl digestion flask, the sample 2 g was weighed along with 20 cm^3 of distilled water. It was shaken and left to rest for a while. Following the addition of one selenium catalyst tablet, 20 cm^3 concentrated sulphuric acid was added. The flask was cooked at 100°C for 4 h on the digestion block until the digestion was clear. The flask was taken off the block and set aside to cool. The contents were transferred to a 50 cm^3 volumetric flask and diluted with water to the desired concentration. An aliquot of the digest 10 $cm^3$was transferred to another micro-Kjedahl flask with 20 cm^3 of distilled water and placed in the micro-Kjedahl distillation unit's distilling outlet. Under the condenser outlet, a conical flask containing 20 cm^3 of boric acid indicator was inserted. By opening the funnel stopcock, a 40% sodium hydroxide solution 20 cm^3 was added to the contents of the Kjeldahl flask. To minimize sucking back, the distillation process was started with heat supplied and regulated. The distillation was terminated when all of the accessible distillate had been collected in 20 cm^3 of boric acid. By titrating with 0.01N H_2SO_4, the nitrogen in the distillate was determined; the end point was reached when the color of the distillate changed from green to pink. Protein content was determined by multiplying total nitrogen content by a constant, 6.60, based on the assumption that protein contains roughly 16% nitrogen, which includes both real protein and non-protein nitrogen and does not distinguish between available and unavailable protein. The crude protein was calculated by using the equation below:

$$\text{Crude protein (\%)} = \text{\% Nitrogen} \times 6.60 \quad (3)$$

The nitrogen content of the sample is given by formula below:

$$\text{Nitrogen (\%)} = \frac{T_V \times Na \times 0.014 \times V_1}{G \times V_2} \times 100 \quad (4)$$

Where: Tv = titre value of the acid
Na = normality of acid
V_1 = volume of distilled water used for distillation of the digest
V_2 = volume of aliquot used for distillation
G = original of sample used

2.3.5. Determination of crude fibre:

Crude fibre was determined by the method of JAMES (2015). The processed sample (5.0 g) (W_1) was boiled in 150 mL of 1.25% H_2SO_4 solution for 30 min under reflux. The boiled sample was washed in several portions of hot water using a two-fold cloth to trap the particles. It was returned to the flask and boiled again in 150 mL of 1.25% NaOH for another 30 min under same condition. After washing in several portion of hot water, the sample was allowed to drain dry before being transferred quantitatively to a weighed crucible where it was dried in the oven at 105°C to a constant weight. It was thereafter taken to a muffle furnace where it was burnt, only ash was left of it (W_2). The weight of the fibre was determined by difference and calculated as a percentage of the weight of sample analyzed thus:

$$\text{Crude fiber (\%)} = \frac{W_1 - W_2}{W_1} \; x \; \frac{100}{1} \quad (5)$$

Where:
W_2 = Weight of crucible +sample after washing, boiling and drying
W_3 = Weight of crucible +sample of ash

2.3.6. Determination of crude fat

This was determined by solvent gravimetric extraction method described by KIRK and SAWYER (2016). Five gram of sample (W_1) was wrapped in a porous paper (whatman filter paper) and put in a thimble. The thimble was put in a soxlet reflux and mounted into a weighted extraction flask containing 200 mL of petroleum ether. The upper of the reflux flask was connected to a water condenser.

The solvent (petroleum ether) was heated, boiled vaporized and condensed into the reflux flask filled. Soon the sample in the thimble was covered with the solvent until the reflux flask filled up and siphoned over, carrying its oil extract down to the boiling flask. This process was allowed to go on repeatedly for 4 h before the defatted sample was removed, the solvent recovered and the oil extract was left in the flask. The flask (containing the oil extract) was dried in the oven at 60°C for 30 min to remove any residual solvent. It was cooled in desiccator and weighed (W_2). The weight of oil (fat) extract was determined by difference and calculated as a percentage of the weight of sample analyzed thus:

$$\text{Fat (\%)} = \frac{W_1 - W_2}{W_1} \; x \; \frac{100}{1} \quad (6)$$

Where:
W_1 = weight (g) of empty extraction flash
W_2= Weight of flash oil (fat) extract

2.3.7. Determination of Carbohydrate

The total carbohydrate proportion in the crude extract was calculated using the percentage dry method. This is done by subtracting the total percent of other food nutrients from 100%. This is done by using the equation below:

Carbohydrate (%) = 100% - (% crude protein + % ash + % moisture + % fiber + % fat) (7)

2.4. Physical Analysis

2.4.1. Determination of thickness

Thickness of biscuits was determined by measuring the diameter of four biscuit samples placed edge to edge with a digital Vernier caliper. An average of six values was taken for each set of samples. Average value for thickness was reported in millimeter.

2.4.2. Determination of diameter

The diameter was determined by placing the edge of the samples on edge and measuring it with a digital Vernier caliper. An average of six values was taken for each set of samples. The average value for diameter was reported in millimetres.

2.4.3. Determination of weight

The weight of the sample was measured as average values of six individual samples with the help of an analytical weighing balance. The average value for weight was reported in grams.

2.4.4. Determination of spread ratio

The spread ratio was calculated by dividing diameter by thickness.

2.4.5. Hardness (HD)

Hardness will be measured as the maximum force (N) applied to break the extrudates. Hardness will be measured using a TMS-2000 Texture press (Food Technology Corporation, Sterling, VA, USA) equipped with a 1,334 N load cell and thin blade shear compression cell (Model CS-2) using a transducer speed of 0.33 cm/s. Measurements will be repeated six times for each moisture temperature treatment and reported as mean ± standard deviation (n = 2).

2.4.6. Expansion ratio (ER)

The expansion ratio is the ratio between the diameter of the extrudates and the diameter of the extruder die office (3 mm). An electronic digital caliper (Model 62379-521, Traceable Products, TX, USA) will be used. Measurements will be repeated 4 times on extrudates from each moisture temperature treatment and reported as mean ± standard deviation (n = 2).

2.4.7. Bulk density (BD)

Bulk density will be determined by measuring the weight of extrudates required to fill a 1000 mL container, recorded in g/L. Extrudates are randomly added into the container and shaken a few times during filling. Measurements will be repeated 6 times for each moisture-temperature treatment and reported as mean ± standard deviation (n = 2).

2.4.8. Specific mechanical energy (SME)

Specific mechanical energy will be determined by the twin-screw extruder computer control system and recorded during extrusion. Measurements will be repeated twice for each moisture temperature treatment and reported as mean ± standard deviation (n = 2).

2.5. Determination of Functional Properties

2.5.1. Determination of Swelling Index

The swelling index (SI) was determined using the method described by TAKASHI and SIEB ((2011) with slight modification. Exactly 1 g of sample was mixed with 10 ml distilled water, and the slurry was heated at a constant temperature (60, 70, 80, and 90°C) in a water bath for 15 min, centrifuged at 3,000*g* for 10 min, and the SC was expressed as a percentage increase in sample weight.

2.5.2. Determination of Water Absorption Capacity

One gram of sample was mixed with 10 mL distilled water and allowed to stand at ambient temperature (30 ± 2 °C) for 30 min, then centrifuged for 30 min at 3,000 rpm or 2000 × g. Water absorption was examined as per cent water bound per gram sample.

2.5.3. Determination of Oil Absorption Capacity

One gram of sample was mixed with 10 mL sample oil (Sp. Gravity: 0.9092) and allowed to stand at ambient temperature (30 ± 2 °C) for 30 min, then centrifuged for 30 min at 300 rpm or 2000 × g. Water absorption was examined as percent water bound per gram sample.

2.5.4. Determination of emulsification

One (1) g sample, 10 mL distilled water and 10 mL soybean oil was prepared in a calibrated centrifuge tube. The emulsion was centrifuged at 2000 × g for 5 min. The ratio of the height of the emulsion layer to the total height of the mixture was calculated as emulsion activity in percentage.

The emulsion stability was estimated after heating the emulsion contained in the calibrated centrifuged tube at 80 °C for 30 min in a water bath, cooling for 15 min under running tap water and centrifuging at 2000 × g for 15 min. The emulsion stability expressed as percentage was calculated as the ratio of the height of the emulsified layer to the total height of the mixture.

2.5.5. Determination of Foam Capacity

The foam capacity (FC) and Foam stability (FS) by (Narayana and Rao, 1982) were determined as described with slight modification. The 1.0 g sample sample was added to 50 mL distilled water at 30 ± 2 °C in a graduated cylinder. The suspension was mixed and shaken for 5 min to foam. The volume of foam at 30 s after whipping was expressed as foam capacity using the formula:

Foam capacity (%) = *volume of foam−Volume of foam volume of foam BW*×100 (8)

Where, AW = after whipping, BW = before whipping

The volume of foam was recorded 1 h after whipping to determine foam stability as per percent of initial foam volume.

2.6. Samples encoding

Table 2. Samples encoding

Code	Formulation
NPO	85% maize, 15% coconut, 15% feed moisture and baked at 133.64 °C
BCO	95% maize, 5% coconut, 20% feed moisture and baked at 120 °C
COA	95% maize, 5% coconut, 10% feed moisture and baked at 80 °C
UST	85% maize, 15% coconut, 23.4% feed moisture and baked at 100 °C
YXZ	95% maize, 5% coconut, 20% feed moisture and baked at 120 °C
QRW	75% maize, 25% coconut, 10% feed moisture and baked at 120 °C
QWU	68.18% maize, 31.82% coconut, 15% feed moisture and baked at 100 °C
VST	75% maize, 25% coconut, 10% feed moisture and baked at 80 °C;
SOA	75% maize, 25% coconut, 20% feed moisture and baked at 120 °C
ABC	85% maize, 15% coconut, 6.59% feed moisture and baked at 100 °C
KSI	85% maize, 15% coconut, 15% feed moisture and baked at 100 °C
SOP	95% maize, 5% coconut, 20% feed moisture and baked at 80 °C
FGH	75% maize, 25% coconut, 20% feed moisture and baked at 80 °C

3. Results and Discussion

3.1. Proximate Composition of the Samples

The proximate composition of the samples are shown in Table 4. The moisture content of the maize-coconut snack ranged between 4.94 % and 5.60 %. This index is presumed as one of the most important determinants for the shelf-stability of food products. The result showed a significant ($p<0.05$) increase in the dependency in linear terms of blending ratio and feed moisture content. However, temperature as a linear independent variable, blending ratio, and feed moisture interactions had no significant effect in the quadratic model. The moisture content of the maize-coconut extruded snack increased with the feed moisture levels at all the studied levels. The damaged starch could be the reason for higher values in moisture content in prepared snack foods. These results agreed with Asare *et al*. (2012). Krishnasree *et al.* (2023) reported that higher moisture input in peanut extrusion also reported the high moisture content of the final product. The present results supported those previous findings, where a rise in feed moisture increased the moisture content of the extruded product.

The protein content of all combination products of maize-coconut extruded snacks ranged from 9.93% to 12.31%. There was a significant difference ($p<0.05$) in the protein content of the samples; the result of this study was similar to Kayacier *et al.* (2014), who reported 15.5 per cent crude protein from wheat and legumes (chickpea, soy and pea) blend. Awolu *et al.* (2015) reported 15.9-24 per cent crude protein from rice, cassava, and Kersting's groundnut blends. Tiwari *et al.* (2011) reported 15.3 per cent to 18.8 per cent of crude protein from broken rice pieces and legumes by-products blend. However, the result of the present study was observed to be less than the reported value (27.7-29.2 per cent) of Wani and Kumar (2016) research on ready-to-eat snacks from rice, cassava and Kersting's groundnut composite flours.

The fat content of the extruded snacks in this study ranged from 8.90% to 9.16%. The result showed a significant ($p < 0.05$) difference in the fat content of the final product. These findings suggest that 10-20 per cent of coconut addition to the maize system would considerably raise the overall fat content.

Table 3. Proximate Composition of the Samples (%)

Samples	Ash	Moisture	Fiber	Fat	Protein	Carbohydrate
NPO	3.82^{a}±0.03	5.60^{a}±0.14	2.87^{c}±0.03	8.90^{c}±0.00	11.13^{b}±0.01	67.69^{l}±0.00
BCO	3.79^{ab}±0.01	5.50^{ab}±0.14	3.02^{b}±0.01	9.03^{b}±0.04	12.31^{a}±0.28	66.36^{l}±0.00
COA	3.75^{b}±0.02	5.40^{abc}±0.14	3.05^{b}±0.01	9.12^{a}±0.01	10.26^{e}±0.20	68.43^{k}±0.01
UST	3.73^{b}±0.03	5.30^{bc}±0.14	3.05^{b}±0.02	9.15^{a}±0.01	10.30^{cd}±0.00	68.48^{j}±0.00
YXZ	3.73^{b}±0.02	5.20^{c}±0.14	3.05^{b}±0.04	9.16^{a}±0.01	10.30^{cd}±0.14	68.85^{f}±0.00
QRW	3.65^{c}±0.05	4.96^{d}±0.03	3.05^{b}±0.05	9.14^{b}±0.02	10.40^{cd}±0.14	68.82^{g}±0.00
QWU	3.65^{c}±0.04	4.96^{d}±0.01	3.15^{a}±0.05	9.14^{a}±0.03	10.60^{b}±0.14	68.52^{i}±0.00
VST	3.65^{c}±0.02	4.97^{d}±0.01	3.15^{a}±0.04	9.07^{b}±0.01	10.25^{de}±0.07	68.93^{e}±0.00
SOA	3.65^{c}±0.01	4.97^{d}±0.02	3.15^{a}±0.02	9.06^{b}±0.04	10.65^{c}±0.35	68.54^{h}±0.01
ABC	3.57^{d}±0.04	4.97^{d}±0.02	3.15^{a}±0.01	9.06^{b}±0.03	9.96^{e}±0.05	69.32^{d}±0.00
KSJ	3.56^{d}±0.03	4.95^{d}±0.03	3.14^{a}±0.01	9.06^{b}±0.01	9.96^{e}±0.04	69.34^{c}±0.00
SOP	3.55^{d}±0.03	4.95^{d}±0.04	3.14^{a}±0.03	9.05^{b}±0.01	9.93^{e}±0.03	69.38^{b}±0.00
FGH	3.54^{d}±0.03	4.94^{d}±0.04	3.14^{a}±0.04	9.04^{b}±0.02	9.95^{e}±0.04	69.40^{a}±0.00

Values are mean ± standard deviation of triplicates. The values with the same letter down a column are not significantly different at $p< 0.05$.

The interaction of barrel temperature and feed moisture has a significant negative effect on the fat content of extruded products. The results of this study were higher, with Sharma *et al.* (2016) that reported 3.19 % crude fat in expanded snack food processed from maize, sorghum, bengal gram, rice and soya chunks. Similarly, Tumuluru *et al.* (2013) observed that 0.19 to 1.30 per cent of crude fat from rice flour and fish co-extrudates. However, the result of this study is lower (8.1-15.7 per cent) than Awolu *et al.* (2015), which prepared the ready-to-eat snack food from rice, cassava and kersting's groundnut composite flours by extrusion technique. This may be due to the differences in crop types and the processing methods employed during the flour formulation.

Crude fiber content of the prepared snack food ranged from 2.87-3.15 %. Fiber particles usually hinder the product's expansion by rupturing the cell walls before the gas bubbles expand to their full potential. Consequently, extruded products with high fiber content are usually compact, tough, non-crispy, and have undesirable textures (Liu *et al.*, 2000). The fiber value of the snack food of this study was similar to the investigations of P´erez-Navarrete *et al.* (2006); they were reported fiber content of 1.7

to 3.2 per cent in a blend of maize and lima bean snack food. However, the results of this study were lower than that obtained by Chanvrier *et al.* (2013) which were reported to be 5.4-16.9 per cent in processed ready-to-eat starch-based extruded cereals snack food from whole wheat, wheat flour and corn flour. Barrel temperatures and moisture contents had no significant effect on the crude fiber content of resultant snacks.

The ash content increased and ranged between 3.54 and 3.82%. The extrudates with the addition of lupine showed higher ash content, which was directly proportional to the number of lupine amounts added. The ash content in extruded snacks was significantly ($p < 0.05$) different. Barrel temperature and moisture content were not showed a significant effect on the ash content of prepared snacks. A similar result (1.5 to 3.8 per cent) was reported by Awolu *et al*. (2015) in ready-to-eat extruded snacks produced from composite flour with rice, cassava and Kersting's groundnut flours.

The carbohydrate contents in the maize-coconut extruded snacks ranged from 66.36% to 69.40 %. The highest carbohydrate content was observed in sample FGH. The least carbohydrate content was observed in sample BCD. The carbohydrate content of the extrudates was significantly ($p <0.05$) different. Processing methods of whole grain flour may increase the carbohydrate content in snack food, especially rapidly digestible starch (Sterbova *et al.,* 2016). Similar results were reported by Oliveira *et al*. (2017), who reported 57.27-83.76 per cent of carbohydrates in extruded products from maize flour and whole grain wheat flour. Barrel temperature and moisture content had no significant effect on the total carbohydrate content of resultant snacks.

3.2. Functional Composition of the Samples

The Bulk density of the extruded product of this study ranged from 0.57 to 0.76 g/cm^3. Bulk Density was significantly ($p<0.05$) dependent linearly on the blending ratio and barrel temperature. It was also observed that elevated Bulk Density is desirable for superior ease of dispensability and decline of paste thickness in the extrusion process (Awolu *et al*., 2015). The bulk density values of the product in this study were higher than reported studies on the extrusion of different maize and legume-based products. This higher Bulk Density may be attributed to the difference in blending ratios, crop types and usage of whole-grain maize flour. In the present study, increased BD can correlate to an increased maize flour.

Table 4. Functional Properties of the Samples

Samples	ES (%)	EA (%)	OAC (g/ml)	BD (g/cm^3)	FC (%)
NPO	11.33^a±0.02	10.80^a±0.14	2.98^a±0.01	0.57^g±0.01	15.60^a±0.14
BCO	11.31^a±0.01	9.85^b±0.04	2.98^a±0.01	0.66^e±0.0	14.60^b±0.28
COA	11.12^b±0.01	9.86^b±0.04	1.93^b±0.02	0.62^f±0.01	12.60^c±0.42
UST	11.07^{bc}±0.04	9.90^b±0.12	1.94^b±0.02	0.68^d±0.01	12.55^c±0.64
YXZ	11.07^{bc}±0.02	9.91^b±0.12	1.95^b±0.02	0.76^{ab}±0.05	11.17^e±0.04
QRW	11.07^{bc}±0.02	9.90^b±0.10	1.95^b±0.01	0.76^a±0.03	12.70^c±0.14
QWU	11.05^{cd}±0.01	9.90^b±0.08	1.96^b±0.01	0.75^{abc}±0.02	12.80^c±0.14
VST	11.04^{cde}±0.02	9.90^b±0.06	1.97^b±0.01	0.70^{bcd}±0.03	12.60^c±0.14
SOA	11.03^{cde}±0.02	9.58^{bc}±0.40	1.98^b±0.01	0.71^{abc}±0.03	12.75^c±0.21
ABC	11.00^{de}±0.03	9.54^{bcd}±0.47	1.94^b±0.01	0.74^{bc}±0.01	12.75^c±0.07
KSJ	11.01^{cde}±0.03	9.14^d±0.02	1.94^b±0.04	0.70^{cde}±0.02	11.76^d±0.02
SOP	10.00^{de}±0.04	9.15^{cd}±0.02	1.96^b±0.02	0.71^{abc}±0.02	11.73^{de}±0.02
FGH	10.99^e±0.04	9.15^{cd}±0.01	1.93^b±0.08	0.72^{abcd}±0.02	11.72^{de}±0.01

Values are mean ± standard deviation of triplicates. The values with the same letter down a column are not significantly different at $p< 0.05$.

The higher concentrations of the fiber and protein may influence the starch gelatinization process and the rheological properties of the raw materials used in the extrusion process (Yagci and Gögüs, 2008). Feed with higher moisture levels may lead to a high Bulk density of the product (Saini, 2015). This trend may be due to the temperatures used in extrusion cooking is not sufficient to cause moisture vaporization, and moisture retained in extruded products may reduce the puffing and result in high BD of the product (Asare *et al*., 2012). The heat generation in the extrusion process can convert moisture into vapour when the product exits from the die; this leads to a flash-off the moisture quickly and results in an expanded structure with large alveoli and lower BD. This process leads to crumples in cell organization, which usually disintegrates up on cooling of the product (Filli *et al.,* 2013).

The emulsion activity index indicates the ability of the proteins to induce the formation of the newly created dispersed particles in emulsions, and in this study, the values ranged from 9.14-10.80%, there was a significant difference in the emulsion activity of the extrudates, whereas Emulsion stability value reflects the ability of food protein to form an emulsion that can withstand stress and remain unchanged over a stipulated period of time, under specific conditions (Hoang, 2024). There was a significant decrease in the emulsion stability as the temperature increased. The emulsion properties depend on the type, concentration and solubility of the proteins (Lima *et al*., 2023).

Foam capacity of the composite sample blends progressively ranged from 11.17 to 15.60%, and there was a significant ($p<0.05$) increase. Foam capacity is the ability of the flour to foam when water and heat are applied and is dependent on soluble proteins (Samaila *et al.,* 2017). The significant variation in the foam capacity of the composite blends could be attributed to differences in the samples solubilized protein and polar and non-polar lipids. High foam capacity in extruded snacks is undesirable; however, preparation at reduced pressure minimizes its formation (Samaila *et al.,* 2017). The values obtained for foam capacity in this study were higher than 6.67 to 10.33 % reported for wheat and cocoyam flour blends (Anon *et al*., 2021) and 8.20 - 11.28 % reported for finger millet, wheat, soybean and peanut flour blends (Okache *et al*., 2020). These variations could be attributed to differences in the composite flour blends.

Oil absorption capacity (OAC) increased from 1.93 to 2.98 g/ml. The highest oil absorption capacity recorded could be attributed to the lipid binding capacity of the hydrophobic proteins present in the flour. The values obtained were, however, lower than the range (1.61-1.79 g/g) reported by Orisa and Udofia (2020). This could be attributed to differences in the method employed and the proportion of the raw materials used. Oil absorption capacity has been attributed to the physical entrapment of oil. Samples with high oil content are an indication of high level of energy and calories. Previous researchers have shown that the frequency of some diseases associated with high-fat diets, including diabetes and obesity, is on the increase (Honerlaw *et al*., 2019).

The data obtained led to the classification of the extruded corn-coconut snacks into three groups; high, medium and low functionality (Table 5). The classification was further corroborated by the results of the principal component analysis (Fig. 1) in which the clustering of the samples within some ranges were used to classify them. Alefew *et al.* (2024) advocated the enriching of snack foods as part of a diet-based remedy for reducing malnutrition in the population. Thus, the use of coconut known for its fibre and other rich bioactive components along with maize produced extruded snacks with high functional properties.

Table 5. Classification of the samples based on the Functional Properties

Sample	Classification	Functional Characteristics
NPO	High Functionality	Excellent emulsion, oil retention, and foaming
BCO	High Functionality	High oil absorption, good emulsion properties
QRW	Medium Functionality	Dense texture, average oil and air retention
YXZ	Medium Functionality	Similar to QRW, moderately functional
KSJ, FGH	Low Functionality	Poor oil and air retention, low emulsion performance

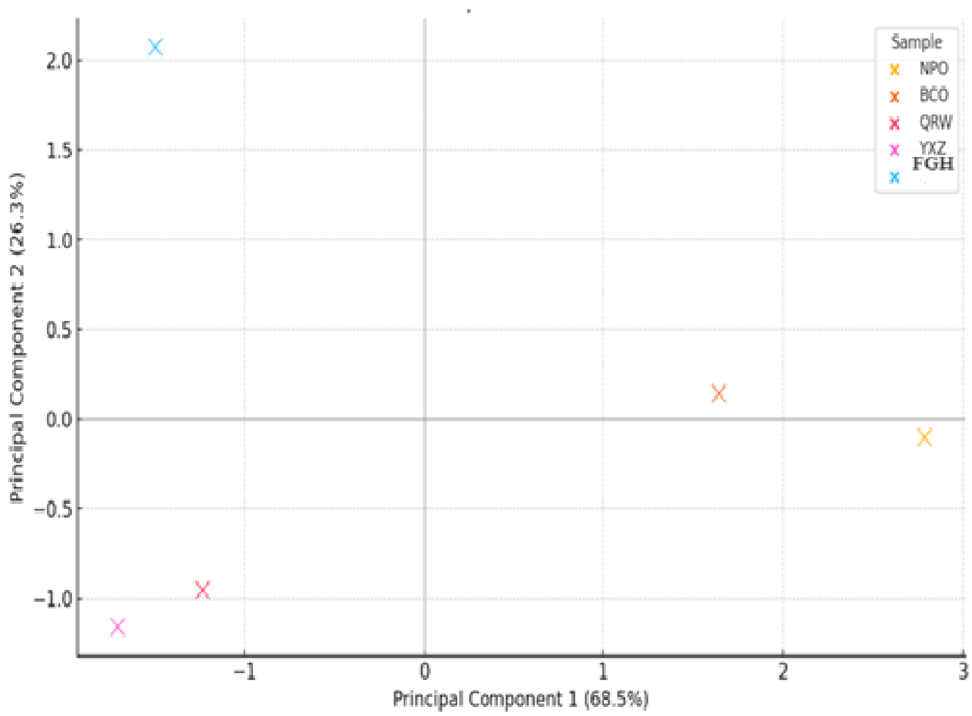

Figure 5. Principal Component Analysis (PCA) of the Functional Properties of Extruded Corn-Coconut Snack samples

The principal component analysis (PCA) showed that NPO and BCO closely clustered, indicating similar functional profiles (Fig. 5). They showed high emulsion stability, high oil absorption capacity, and strong foaming capacity. Thus, their position in the top-right quadrant reflects high scores across multiple variables, especially those positively loading on both PC1 and PC2 as a functionally rich samples ideal for light, flavourful snacks, with good fat-binding capability. It was evident that percentage contribution of coconut. The barrel temperature and feed moisture of the extruded corn-coconut snack influenced the functional properties.

The graph also showed that QRW and YXZ are at the middle to right-centre and could be classified in the medium functionality. The NPO and BCO are very close to each other but at a distant from NPO/BCO. Therefore, QRW and YXZ possessed moderate oil absorption with higher bulk density, which likely pulled them apart from the high-functionality classification. The samples appear to align more with bulkier, denser products, potentially suitable as crunchy or compact snacks rather than aerated ones.

The bottom of the graph showed a clear separation from the other samples, exhibiting least values in oil absorption, foaming capacity and emulsion stability. Since it is at the bottom of the graph, it could be described as a separate and weaker in functional profile classification which could be attributed to lower protein or fat interaction effects. The FGH sample might be best suited for formulations where minimal oil and air retention is preferred (e.g., dry snacks or flour blends).

3.1.3. Colour Composition of the Samples

The Colour composition of the samples are presented in Fig. 6. Colour is an important attribute in food acceptability, being an indicator of quality, conservation state, flavour expectation and commercial value (Fradique *et al.*, 2010). The results of ΔE (Total colour change, TCC) ranged from 38.34 to 55.13. LEB 18 in the extruded snacks caused the reduction of a*, b*, C* and luminosity (L*). The results were like those obtained in other studies that evaluated the influence of the addition of coconut on the colour of foods (Fradique *et al.,* 2010; Joshi *et al.,* 2014). Colour is one of the most important characteristics of extruded products since it shows the extent of thermal treatment. Changes in colour can be used as an indicator of the extent of browning reactions for example caramelization, maillard reactions, degree of cooking plus pigment degradation that take place during extrusion cooking (Serge *et al*., 2011).

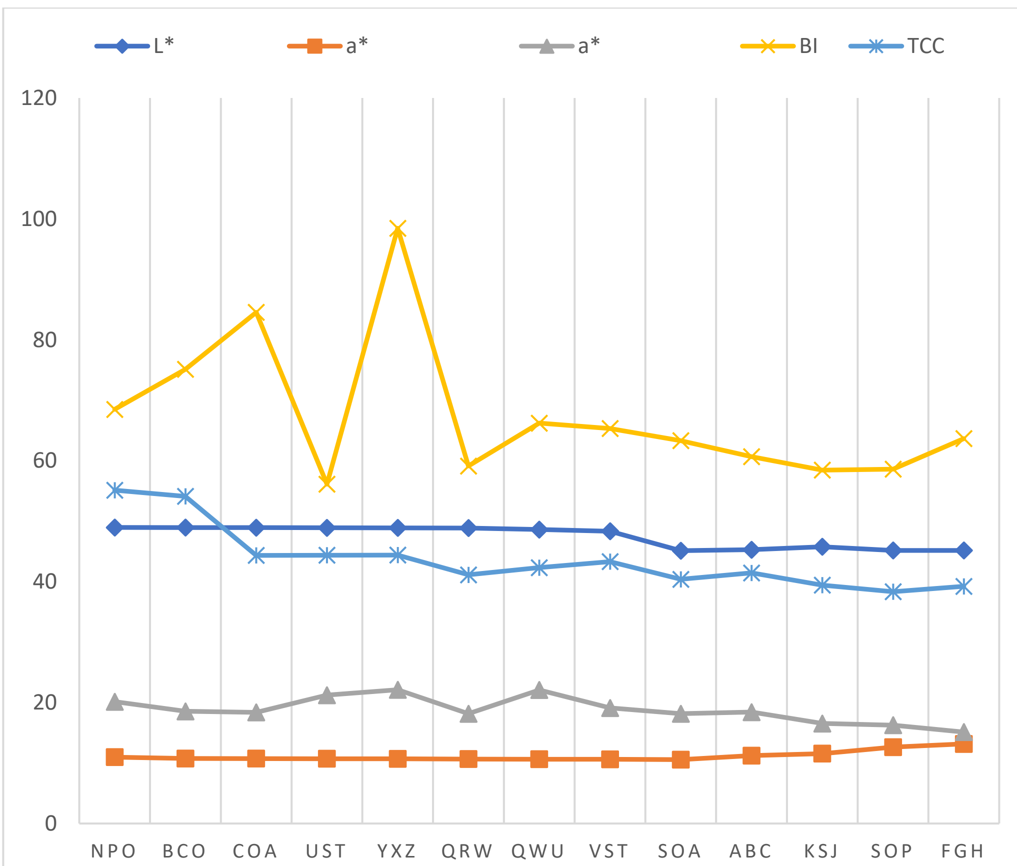

Figure 6. CIEL Colour Classification of the Snack samples

Colour parameters are important because they are used to assess changes in raw material and formulation due to boiling within the extruder barrel (Mjoun and Rosentrater, 2011); therefore, colour is important because it is the first attribute perceived by consumers, and it determines the acceptance or rejection of a product (Rampersad *et al*., 2003). The increased ΔE could be due to the increased PSF concentration, which causes the snacks to have a darker formulation colour. To compare the values of different formulations, ΔE was observed at a temperature range of 120 to 180 °C. The extrusion process caused a significant decrease (P <0.05) in ΔE. It is known that redox reactions between sugars and proteins (amino acids) in foods at high temperatures can promote non-enzymatic browning (Maillard reaction), resulting in the darkening of the final product (Nayak *et al.,* 2011). Therefore, the observed decrease in ΔE values can be attributed to the Maillard reaction as a result of the extrusion process. This effect is consistent with what has been reported by other researchers (Norfezah *et al.,* 2011).

Furthermore, pigment degradation due to extrusion temperatures could have generated products of the Maillard reaction that promoted changes in colour values, as observed in the extruded and unprocessed (raw) products. Therefore, it can be concluded that changes in the colour of the ready-to-eat snacks are due to increasing concentrations of PSF and the processing conditions.

3.4.a. Physical Properties of the Samples

The volumes of the samples were considered. Overall, there was no significant (p<0.05) difference in the volume. It is important to note that higher Volume is mostly obtained at lower feed moisture contents. This increase in VP could be related to dough rheology.

The minimum and maximum hardness values were 4.07 and 4.86. This may be due to the generation of shear pressure inside the barrel while increased the rate of gelatinization of dough. The hardness was also influenced by moisture content. Hardness was positively correlated with feed moisture. A similar effect was observed by Seth *et al.* (2015). Inside the extruder, the starch-based material gets plasticized due to the reduction of viscosity and dissipation of mechanical energy with increasing feed moisture; hence, extrudates become denser and harder with compressed bubbles.

Table 6a. Physical Properties of the Samples

Samples	Volume	Specific volume	Density	Hardness	Height
NPO	1.92^{a}±0.03	0.42^{g}±0.00	2.40^{a}±0.00	4.85^{a}±0.07	1.40^{a}±0.14
BCO	1.94^{a}±0.01	0.57^{b}±0.01	2.21^{b}±0.01	4.50^{ab}±0.42	1.46^{a}±0.18
COA	1.96^{a}±0.02	0.49^{de}±0.00	2.00^{j}±0.00	4.50^{ab}±0.41	1.45^{a}±0.18
UST	1.96^{a}±0.04	0.49^{cde}±0.00	2.02^{g}±0.00	4.50^{ab}±0.38	1.44^{a}±0.18
YXZ	1.96^{a}±0.05	0.50^{cd}±0.00	2.01^{h}±0.00	4.50^{ab}±0.36	1.49^{a}±0.01
QRW	1.96^{a}±0.06	0.49^{cde}±0.00	2.01^{h}±0.00	4.49^{ab}±0.34	1.44^{a}±0.04
QWU	1.92^{a}±0.06	0.24^{h}±0.00	2.01^{h}±0.00	4.50^{ab}±0.34	1.46^{a}±0.05
VST	1.92^{a}±0.09	0.50^{c}±0.00	2.01^{h}±0.00	4.50^{ab}±0.33	1.45^{a}±0.06
SOA	1.92^{a}±0.12	0.49^{cde}±0.01	2.00^{ij}±0.01	4.12^{b}±0.01	1.31^{a}±0.25
ABC	1.90^{a}±0.10	0.49^{cde}±0.00	2.03^{f}±0.00	4.09^{b}±0.01	1.44^{a}±0.07
KSJ	1.90^{a}±0.08	0.49^{e}±0.00	2.05^{d}±0.00	4.07^{b}±0.03	1.42^{a}±0.06
SOP	1.90^{a}±0.10	2.04^{a}±0.00	2.04^{e}±0.00	4.22^{ab}±0.01	1.41^{a}±0.06
FGH	1.89^{a}±0.07	0.48^{f}±0.00	2.07^{c}±0.00	4.10^{b}±0.01	1.33^{a}±0.01

Values are mean ± standard deviation of triplicates. The values with the same letter down a column are not significantly different at p < 0.05.

Li (2021) posited that smaller air cells in extrudates, caused by increased breaking strength, lead to higher hardness. Nur-Adibah *et al.* (2024) obtained a hardness value that ranged from 9.74 kg to 25.71 kg for a fibre-rich okara-based expanded snack which established that the hardness of snacks were inversely related to the expansion ratio (r = 68.7%). The increase in feed moisture resulted in a significant increase ($p < 0.05$) in the hardness of the extrudate.

This effect is because higher moisture content decreases the shear of the plasticized mass inside the extruder, reducing the gelatinized starch and preventing the growth of air bubbles in the snacks. This is lower than 16.2 to 43.4 N reported by Joshi *et al.* (2014) on corn extrudates added with microalga.

The specific volume of the snack products was about 0.42–2.04%. Results agree with previous findings. Fleischman et al. (2016) observed that increasing wheat bran content in wheat extrudates resulted in a less expanded and more compact structure with smaller air bubbles. Recently, including 16% common bean flour in optimized corn-based snacks gave a Vs reduction of 23% (Felix-Medina *et al.,* 2020).

The density of the snack products was about 2.00–2.40 g/cm3. Feeding temperature during extrusion had a significant inverse effect on snack density, whereas feeding moisture did not. (Ruiz-Armenta *et al*., 2018) obtained low Density (103 – 204 g /L). Ruiz-Armenta *et al.* (2018) reported the density (168 – 260 kg /m^3) of rice and beer industry waste second-generation snacks. Tovar-Jimenez *et al.* (2015) reported Density (approximately 150 –260 kg /m^3) on third-generation snacks from potato starch, corn starch, milled oranges and monoglycerides.

The height of the snack ranged between 1.33 cm and 1.49 cm, with sample FGH having the lowest value and sample YXZ the highest. There was a significant ($p<0.05$) difference in the height of the samples.

3.4.b. Physical Properties of the Samples

The results for the physical properties of the maize-coconut-based snacks are summarized in Table 4.1.4b. The diameter values ranged from 4.91 to 5.93; there was a significant ($p < 0.05$) difference. The findings indicate that the diameter of extrudates increased with an increase in temperature at all the coconut/maize mixing ratios. This may be because increasing barrel temperature could increase the degree of gelatinization and the extent of superheated steam that causes the snack to expand more (Korkerd *et al.,* 2016; Sue *et al.,* 2015). Temperature determines the vapour pressure of the moisture and, thus, the degree of puffing. This is probably due to the stretching of the molecules at higher temperatures, which causes a higher degree of gelatinization Guha and Ali (2006). Low moisture conditions and an increase in barrel temperature led to increased expansion (Leonel *et al.,* 2009).

The mean wall thickness was obtained and ranged between 0.42 to 0.54, respectively. However, some pellets had a higher expansion; significant differences ($p < 0.05$) were obtained between the different extrusion temperatures or feed moisture contents in the porosity (%) or in the mean wall thickness of the expanded products. Indicating that expanded products with higher porosity tended to have thinner walls, regardless of the conditions that were used (extrusion temperature and feed moisture content).

Weight ranged from 3.86 – 4.55 g/cm^3. Gasparre *et al*. (2020) reported weight ranging from 1.35-1.54 g/cm^3 in rice-based gluten-free extruded snacks blended with tiger nut flour. The higher weight (3.86 – 4.55 g/cm^3) obtained in this study could be attributed to feed moisture and feed blends. Weight is the constant value for matter and the mass of a food particle divided by its volume, excluding open and closed pores (Shefali and Florian, 2017).

Table 6b. Physical Properties of the Samples

Samples	Diameter	Thickness	Spread ratio	Weight
NPO	5.93[a]±0.04	0.54[a]±0.01	10.98[e]±0.01	4.55[a]±0.21
BCO	5.46[b]±0.68	0.53[a]±0.02	10.41[j]±0.01	4.30[b]±0.14
COA	5.04[bc]±0.10	0.49[b]±0.01	10.28[k]±0.00	3.95[c]±0.05
UST	5.04[bc]±0.11	0.46[bc]±0.01	10.96[f]±0.00	3.95[c]±0.03
YXZ	5.06[bc]±0.15	0.44[cd]±0.01	11.47[d]±0.00	3.94[c]±0.03
QRW	5.03[bc]±0.13	0.48[b]±0.00	10.43[i]±0.00	3.94[c]±0.01
QWU	4.95[c]±0.06	0.48[b]±0.00	10.26[l]±0.00	3.87[c]±0.04
VST	4.96[c]±0.02	0.42[d]±0.01	11.80[a]±0.00	3.86[c]±0.01
SOA	4.96[c]±0.02	0.43[cd]±0.01	11.52[c]±0.00	3.86[c]±0.02
ABC	4.97[c]±0.02	0.44[cd]±0.01	11.55[b]±0.00	3.87[c]±0.02
KSJ	4.98[bc]±0.02	0.46[bc]±0.02	10.93[g]±0.00	3.89[c]±0.08
SOP	4.91[c]±0.08	0.47[bc]±0.02	10.45[h]±0.00	3.88[c]±0.06
FGH	4.92[c]±0.08	0.48[b]±0.01	10.25[m]±0.00	3.93[c]±0.02

Values are mean ± standard deviation of triplicates. The values with the same letter down a column are not significantly different at p< 0.05.

The spread ratio of the snack ranged between 10.25 and 11.80, with sample FGH having the lowest value and sample VST the highest. There was a difference ($p < 0.05$) in the spread ratio of the samples.

The probability plot of the residuals of the physical properties determined against spread ratio showed that some of the data were skewed either to the left or right of the graph indicating non-normal distribution (Fig. 7).

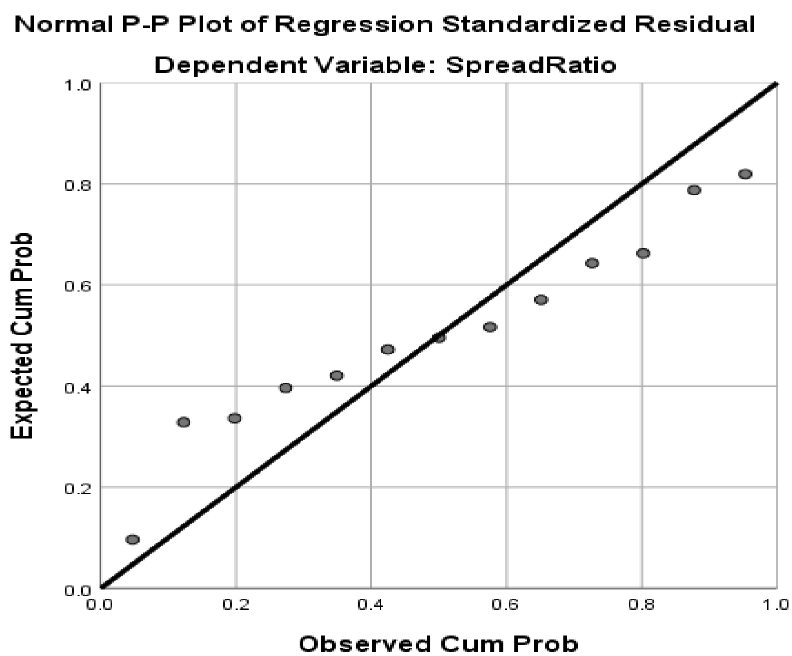

Figure 7. Normal Probability Plot of Regression Standardized Residual Vs Spread Ratio

Pearson correlation indicates that an increase in spread ratio of the samples would lead to non-significant ($p>0.05$) decrease in the volume of the extruded snacks ($r^2 = 0.003481$). The spread ratio was negatively correlated with specific volume, density, hardness, diameter, thickness and weight of the extruded snacks, but positively correlated with the extruded snacks height. Thus, a higher spread ratio implied that the snack has expanded more during the extrusion process which would lead to an increase in the height of the snacks. Therefore, Fig. 7 clearly portrays the trend as normal distribution was not expected in the results findings.

Furthermore, the weight of the extruded snacks was strongly correlated to the density (r = 0.966), hardness (r = 0.658), diameter (r = 0.988) and thickness (r = 0.830) of the extruded snacks, but negatively corelated with spread ratio (r = -0.150) and specific volume (r = -0.024) of the corn-coconut extruded snacks.

3.5. Sensory Evaluation Score of Samples

Sensory Composition of Samples is shown in Table 7. The texture of the maize-coconut extrudates indicate that the mean force required to puncture the extruded sample reduced with increased barrel temperature.

Table 7. Sensory Evaluation Score of Samples

Samples	Colour	Texture	Taste	Flavor	Overall Acceptability
NPO	$6.00^{a}\pm2.42$	$5.12^{a}\pm1.90$	$5.88^{abcd}\pm2.43$	$5.68^{a}\pm2.41$	$5.56^{ab}\pm2.28$
BCO	$5.72^{a}\pm1.95$	$5.60^{a}\pm1.87$	$5.96^{abc}\pm2.70$	$5.92^{a}\pm2.48$	$4.92^{ab}\pm2.12$
COA	$5.40^{a}\pm1.96$	$5.76^{a}\pm2.26$	$5.72^{abcd}\pm2.17$	$5.32^{a}\pm2.43$	$5.52^{ab}\pm2.38$
UST	$5.00^{a}\pm1.91$	$5.92^{a}\pm2.25$	$4.96^{bcd}\pm2.47$	$5.28^{a}\pm2.81$	$5.28^{ab}\pm2.48$
YXZ	$4.84^{a}\pm2.09$	$5.68^{a}\pm2.43$	$4.88^{bcd}\pm2.39$	$5.04^{a}\pm2.19$	$5.04^{ab}\pm2.17$
QRW	$5.92^{a}\pm2.12$	$5.64^{a}\pm1.63$	$5.00^{bcd}\pm2.48$	$5.20^{a}\pm1.88$	$5.32^{ab}\pm2.54$
QWU	$5.28^{a}\pm2.30$	$5.88^{a}\pm1.92$	$4.36^{d}\pm2.46$	$5.16^{a}\pm2.70$	$5.64^{ab}\pm2.83$
VST	$5.68^{a}\pm2.54$	$6.40^{a}\pm2.14$	$6.40^{ab}\pm2.08$	$5.24^{a}\pm2.71$	$6.32^{a}\pm1.75$
SOA	$5.24^{a}\pm2.73$	$5.68^{a}\pm2.48$	$4.84^{cd}\pm2.54$	$4.48^{a}\pm2.54$	$4.52^{b}\pm2.12$
ABC	$5.52^{a}\pm1.78$	$5.88^{a}\pm1.74$	$4.80^{cd}\pm2.29$	$5.52^{a}\pm2.00$	$5.84^{ab}\pm2.49$
KSJ	$5.56^{a}\pm1.36$	$5.28^{a}\pm1.69$	$5.64^{abcd}\pm2.43$	$5.36^{a}\pm1.75$	$5.32^{ab}\pm2.49$
SOP	$5.60^{a}\pm1.83$	$5.92^{a}\pm2.08$	$5.84^{abcd}\pm2.19$	$5.60^{a}\pm2.45$	$5.84^{ab}\pm2.37$
FGH	$6.08^{a}\pm2.02$	$5.52^{a}\pm2.33$	$6.84^{a}\pm1.55$	$6.00^{a}\pm2.22$	$5.84^{ab}\pm1.78$

Values are mean ± standard deviation of triplicates. The values with the same letter down a column are not significantly different at $p< 0.05$.

The flavour acceptance of the blended extruded snack food was found between 4.48 - 6.0. The addition of coconut significantly affected the flavour acceptability of maize-coconut snacks. This may be due to higher cooking temperatures (120°C to 150°C), which were key in modifying and eliminating the off flavours to improve their sensory properties (Simons *et al.,* 2015).

The taste of the extruded snacks was also influenced by the lupine incorporation, up to 20 per cent. However, the addition of 40 to 50 per cent of lupine flour significantly decreased the taste of the final product. It resulted in a lower taste score, as Jayasena and Nasar-Abbas (2012) reported. Liu *et al.* (2000) described high-fiber extruded cereal products with low expansion, hard texture, and rough, uneven skins as features that make products unappealing to potential end users.

Overall acceptability scores of the extruded snack demonstrated no significant ($p>0.05$) difference. The overall acceptability results of extruded foods in this study agreed with that of Hall and Johnson (2004). Even though higher colour scores were recorded, the overall acceptability was decreased.

4.Conclusion

This study demonstrates that extrusion parameters, specifically temperature and maize-to-coconut ratios, significantly impact the physicochemical properties and sensory acceptability of maize-coconut extruded snacks. Higher extrusion temperatures led to increased expansion and reduced hardness of the extrudates, enhancing their sensory appeal. Snacks with higher maize content exhibited more significant expansion and lower hardness, resulting in higher sensory rankings. The proximate analysis revealed that the snacks possess desirable nutritional qualities, with carbohydrate content ranging from 66.36% to 69.40%, protein content from 9.93% to 12.31%, and fat content from 8.90% to 9.16%. Both processing variables and ingredient composition influenced functional properties such as bulk density, emulsion activity index, foam capacity, and oil absorption capacity. Notably, while foam capacity increased significantly, high foam capacity is undesirable in extruded snacks and should be optimized. The colorimetric properties underscore the importance of visual appeal in consumer acceptance. Overall, optimizing extrusion conditions and ingredient ratios is crucial for developing maize-coconut snacks with improved physical characteristics, nutritional value, and consumer acceptability. Future research should focus on refining these parameters to enhance product quality and explore the commercial viability of these snacks.

5. Reference:

Adebowale, O. J. and Komolafe, O. M. (2018). Effect of Supplementation with Defatted Coconut Paste on Proximate Composition, Physical and Sensory Qualities of a Maize-Based Snack. *Journal of Culinary Science & Technology*, 16:1, 40-51, DOI: 10.1080/15428052.2017.1315322.

Alefew, Y. D., Tiruneh, A. T., & Yehuala, T. F. (2024). Optimization of extrusion conditions for development of high-quality rice-lupin-pumpkin based extruded snack food. *Heliyon,* 10(24): e40913. https://doi.org/10.1016/j.heliyon.2024.e40913.

Anon, A. H., Fagbohoun, J. B., Koffi, A. G., Anno, H. F. A. and Kouamé, L. P. (2021). Functional Properties of Composite Flours Produced with Ivorian Taro (Colocasiaesculenta L. CvFouê) Corms Flour and Wheat (Triticumaestivum L.) Flour. GSC Biological and Pharmaceutical Sciences, 15(03): 164–176.

Ape, D., Nwogu, N. A., Uwakwe, E. I. and Ikedinobi, C. S. (2016). Comparative Proximate Analysis of Maize and Sorghum Bought from Ogbete Main Market of Enugu State, Nigeria. *Greener Journal of Agricultural Sciences*, 6 (9): 272-275. *http://doi.org/10.15580/GJAS.2016.9.101516167*

Asare, E.K., Samule, S.D., Emmmanuel, O.A., Esther, S.D., & Agnes, S.B. (2012). Extrusion cooking of rice-groundnut-cowpea mixtures-effects of extruder characteristics on nutritive value and physico-functional properties of extrudates using response surface methodology. *Journal of Food Processing and Preservation*, 36(5), 465-476

Awolu, O.O., Oluwaferanmi, P.M., Fafowora, O.L., & Dseyemi, G.F. (2015). Optimization of the extrusion process for the production of ready-to-eat snack from rice, cassava and kersting's groundnut composite flours. LWT – *Food Science and Technology*, 64(1), 18-24.

Awoyale, W., Maziya-Dixon, B., Sanni, L. O., & Shittu, T. A. (2011). Nutritional and sensory properties of a maize based snack food (kokoro) supplemented with treated distillers' spent grain (DSG). International Journal of Food Science and Technology, 46(8): 1609-1620.

Blejan, A. M., Nour, V., Corbu, A. R., & Codină, G. G. (2025). Corn-Based Extruded Snacks Supplemented with Bilberry Pomace Powder: Physical, Chemical, Functional, and Sensory Properties. *Applied Sciences*, *15*(5), 2468. https://doi.org/10.3390/app15052468.

Chakraborty, S. K., Singh, D. S., Kumbhar, B. K., & Chakraborty, S. (2011). Millet–legume blended extrudates characteristics and process optimization using RSM. *Food and Bioproducts Processing,* **89**(4), 492-499.

Chanvrier, H., Desbois, F., Perotti, F., Salzmann, C., Chassagne, S., Gumy, J-C.

and Blank, I. (2013). Starch-based extruded cereals enriched in fibers: A behavior of composite solid foams. *Carbohydrate Polymers,* 98(1): 842-853. https://doi.org/10.1016/j.carbpol.2013.07.005.

Dumchaiyapoom, K., Hannanta-anan, P. and Phongpipatpong, M. (2019). Effect of extrusion conditions on the physical properties of coconut rice-based extrudates. The 12th TSAE International Conference on Earth and Environmental Science, 2019. doi:10.1088/1755-1315/301/1/012056.

Eke, L. (2025). *Roasted corn, coconut and 'Ube': Proudly Nigerian superfood that can gain UN cultural status.* Business Day, June 1, 2025. https://businessday.ng/life/article/roasted-corn-coconut-ube-proudly-nigerian-superfood-that-can-gain-un-cultural-status/. Accessed on June 2, 2025.

Fang, Q., Hanna, M., & Lan, Y. (2003). Extrusion system components. In: Heldman D. R. Ed., Encyclopedia of Agricultural, Food, and Biological Engineering, (301-305). CRC Press.

Farhad, M., Khan, M. A. and Shafiq, M. (2009). Proximate composition and mineral analysis of different maize varieties. *Pakistan Journal of Botany*, 41(4), 2049-2054.

Felix-Medina, J.V., Montes-Avila, J., Reyes-Moreno, C. et al. (2020). Second-generation snacks with high nutritional and antioxidant value produced by an optimized extrusion process from corn/common bean flours mixtures. *LWT-Food Science & Technology*,124, 109172.

Filli, K. B., Nkama, I. and Jideani, V. A. (2013). The effects of extrusion conditions on the physical and functional properties of millet-Bambara groundnut based fura. *American Journal of Food Science and Technology*, 1(4): 87-101.

Gasparre, N., Pan, J., da Silva Alves, P. L., Rosell, C. M. and De J. Berrios, J. (2020). Tiger Nut (*Cyperus esculentus*) as a Functional Ingredient in Gluten-Free Extruded Snacks. *Foods*, *9*(12): 1770. https://doi.org/10.3390/foods9121770.

Grasso, S. (2020) Extruded snacks from industrial by products: a review. *Trends in Food Science & Technology*, 99: 284-294. doi: 10.1016/j.tifs.2020.03.012 Available at https://centaur.reading.ac.uk/89591/.

Guha, M. and Ali, S. Z. (2006). Extrusion cooking of rice: effect of amylose content and barrel temperature on product profile. *Journal of Food Processing and Preservation,*30(6): 706-716. https://doi.org/10.1111/j.1745-4549.2006.00099.x.

Gurbuz, Y. (2017). Heat applications in feed and food processing. Proceedings of 72nd The IRES International Conference, Mecca, Saudi Arabia, 23rd-24th June 2017.

Heitman, K., Thomas, S. E., Kelly, O., Fanelli, S. M., Krok-Schoen, J. L., Luo, M., & Taylor, C. A. (2023). Snacks contribute considerably to total dietary intakes among adults stratified by glycemia in the United States. PLOS Glob Public Health 3(10): e0000802. https://doi.org/10.1371/journal.pgph.0000802.

Hess, J. M., Jonnalagadda, S. S. and Slavin, J. L. (2016). What Is a Snack, Why Do We Snack, and How Can We Choose Better Snacks? A Review of the Definitions of Snacking, Motivations to Snack, Contributions to Dietary Intake, and Recommendations for Improvement. Advances in Nutrition, 7:466–75. doi:10.3945/an.115.009571.

Hewlings, S. (2020). Coconuts and Health: Different Chain Lengths of Saturated Fats Require Different Consideration. *Journal of Cardiovascular Development and Disease*, *7*(4), 59. https://doi.org/10.3390/jcdd7040059.

Hoang, N. (2024). Improving Food Texture and Stability Through Emulsion Science. *African Journal of Food Science and Technology,* 15(6): 01-02. DOI: http:/dx.doi.org/10.14303//ajfst.2024.088.

Honerlaw, J.P., Ho, Y.L., Nguyen, X.X.T., Cho, K., Vassy, J. I., Gagnon, D.R., & Djousse, L. (2019). Fried food consumption and risk of coronary artery disease: The million-veteran program. *Clinical Nutrition*, 39: 1203-1208.

Ibe, P. C., Agu, H. O., Ikegwu, T. M., Ishiwu, C. N. and Nwokeke, B. C. (2025). Assessment of sensory properties of optimized wheat-white yam composite cookies using response surface methodology. *International Journal of Food Science and Nutrition,* 10, 2: 12-22.

Inyang, U., Oboh, I. and Etuk, B. (2018). Kinetic Models for Drying Techniques—Food Materials. *Advances in Chemical Engineering and Science*, **8**, 27-48. doi: 10.4236/aces.2018.82003.

James, S., Akosu, N. I., Maina, Y. C., Baba, A. I., Nwokocha, L., Amuga, S. J., Audu, Y., & Omeiza, M. Y. M. (2018). Effect of addition of processed bambara nut on the functional and sensory acceptability of millet-based infant formula. *Food science & nutrition*, *6*(4), 783–790. https://doi.org/10.1002/fsn3.618.

Kayacier, A., Yüksel, F. And Karaman, S. (2014). Simplex lattice mixture design approach on physicochemical and sensory properties of wheat chips enriched with different legume flours: An optimization study based on sensory properties. *LWT - Food Science and Technology,* 58(2): 639-648. https://doi.org/10.1016/j.lwt.2014.03.032.

Korkerd, S., Wanlapa, S., Puttanlek, C., Uttapap, D. and Rungsardthong, V. (2016). Expansion and functional properties of extruded snacks enriched with nutrition sources from food processing by-products. *Journal of Food Science and Technology*, 53(1): 561–570. doi:10.1007/s13197-015-2039-1.

Krishnasree, V., Gopinath, P.P., Mohan, G., Binitha, N.K., Jasna, V.K., Seenath, P., Shamna, N., Sajayan, A. and Sujatha, R. (2023). Optimization of Extruded Snack Enriched with Coconut Inflorescence Sap Honey: A Promising Supplementary Food among Tribals. Asian Journal of Dairy and Food Research. DOI: 10.18805/ajdfr.DR-2067.

Kwon, K., Park, K. H., & Rhee, K. C. (1996). Fractionation and characterization of proteins from coconut (*Cocos nucifera*). *Journal of Agriculture and Food Chemistry* 44:1741–1745.

Lalitha, K. (2014). Nutritional properties of coconut: Low digestible carbohydrates, gluten-free, and rich in fiber and nutrients". *Journal of Nutritional Science,* 13(1): 45-52.

Leonel, M., Freitas, T. S., & Mischan, M. M. (2009). Physical characteristics of extruded cassava starch. Scientia Agricola, 66(4), 486–493. doi:10.1590/S0103-90162009000400009.

Li, X. (2021). Effects of Extrusion Cooking on Physical and Nutritional Quality of Puffed Snacks Made from Blends of Barley and Green Lentil Flours. A Thesis submitted to the Faculty of Graduate Studies of The University of Manitoba, Department of Food and Human Nutritional Sciences, University of Manitoba Winnipeg, Manitoba.

Lima, R. R., Stephani, R., Perrone, Í, T. and de Carvalho, A. F. (2023). Plant-based proteins: A review of factors modifying the protein structure and affecting emulsifying properties. *Food Chemistry Advances,* 3: 100397. https://doi.org/10.1016/j.focha.2023.100397.

Liu, Y., Hseih, F., Heymann, H. and Huff, H. E. (2000). Effect of Process Conditions on the Physical and Sensory Properties of Extruded Oat-Corn Puff. *Journal of Food Science,* 65(7): 1253-1259. https://doi.org/10.1111/j.1365-2621.2000.tb10274.x

Małecki, J., Muszyński, S., & Sołowiej, B. G. (2021). Proteins in Food Systems-Bionanomaterials, Conventional and Unconventional Sources, Functional Properties, and Development

Opportunities. *Polymers*, *13*(15), 2506. https://doi.org/10.3390/polym13152506.

Mat, K., Abdul-Kari, Z., Rusli, N.D., Che Harun, H., Wei, L.S., Rahman, M.M., Mohd-Khalid, H.N., MohdAli-Hanafiah, M.H., Mohamad-Sukri, S.A., Raja-Khalif, R.I.A., Zin, Z. M., Mohd-Zainol, M. K., Panadi, M., Mohd-Nor, M. F. and Wen-Goh, K. (2022). Coconut Palm: Food, Feed, and Nutraceutical Properties. *Animals*, 12: 2107. https://doi.org/ 10.3390/ani12162107

Nayak, B., Berrios, J.J., Powers, J.R., & Tang, J. (2011). Effect of extrusion on the antioxidant capacity and color attributes of expanded extrudates prepared from purple potato and yellow pea flour mixes. *Journal of Food Science* 76, C874-C883.

Ndife, J., Abasiekong, K. S., Nweke, B., Linus-Chibuezeh, A., & Ezeocha, V. C. (2020). Production And Comparative Quality Evaluation of Chin-Chin Snacks From Maize, Soybean And Orange Fleshed Sweet Potato Flour Blends. *FUDMA Journal of Sciences, 4 (2), 300 – 307*. DOI: https://doi.org/10.33003/fjs-2020-0402-220.

Norfezah, M.N., Hardacre, A., & Brennan, C.S. (2011). Comparison of waste pumpkin material and its potential use in extruded snack foods. *Food Science and Technology International* 17, 367-373.

Nur-Adibah, L., Nor-Afizah, M., Wan-Zunairah, W.I. and Syed-Muhammad, S.K. (2024). Development of fibre-rich okara-based expanded snack via single screw extrusion. *Food Research* 8 (2): 48 – 56.

Nwadi, O.M.M., Uchegbu, N.N. and Okonkwo, T. M. (2023). Use of Cereals and Egg Products in Extruded Foods: A Review. *Pakistan Journal of Nutrition,* 22: 1-10. 10.3923/pjn.2023.1.10.

Offiah, V., Kontogiorgos, V., & Falade, K. O. (2018). Extrusion processing of raw food materials and by-products: A review. *Critical Reviews in Food Science and Nutrition*, *59*(18), 2979–2998. https://doi.org/10.1080/10408398.2018.1480007.

Okache, T. A., Agomuo, J. K. and Kaida, I. Z. (2020). Production and Evaluation of Breakfast Cereal Produced from Finger Millet, Wheat, Soybean, and Peanut Flour Blend. Research *Journal of Food Science & Quality Control*, 6(2): 9-19.

Okeke, E. C., Ene-Obong, H. N., Uzuegbunam, A. O., Ozioko, A., Umeh, S. I., & Chukwuone, N. (2009). The Igbo traditional food system documented in four states in southern Nigeria. In: Indigenous Peoples' Food Systems: the many dimensions of culture, diversity and environment for nutrition and health (Eds), Food and Agriculture Organization of the United Nations Centre for Indigenous Peoples' Nutrition and Environment, Rome 2009.

Okeke, E.C., Eneobong, H.N., Uzuegbunam, A.O., Ozioko, A.O., & Kuhnlein, H. (2008). Igbo Traditional Food System: Documentation, Uses and Research Needs. *Pakistan Journal of Nutrition,* 7(2): 365-376.

Oliveira, L. C., Schmiele, M. and Steel, C. J. (2017). Development of whole grain wheat flour extruded cereal and process impacts on color, expansion, and dry and bowl-life texture. *LWT- Food Science and Technology,* 75: 261-270. http://dx.doi.org/10.1016/j.lwt.2016.08.064.

Orisa, C. A. and S. U. Udofia. (2020). Functional and Pasting Properties of Composite Flours from Triticum durum, Digitaria exilis, Vigna unguiculata and Moringa oleifera Powder. *Asian Food Science Journal*, *19*(2): 40–49. https://doi.org/10.9734/afsj/2020/v19i230237.

Panoff, L. (2019). What Is Coconut Meat, and Does It Have Benefits? Healthline. https://www.healthline.com/nutrition/coconut-meat. Accessed on December 2, 2025.

Pathirana, H. P. D. T. H., Lakdusinghe, W. M. K., Yalegama, L. L. W. C., Chandrapeli, C. A. T. D., & Madusanka, J. A. D. (2020). Evaluation of Nutritional Composition of Defatted Coconut Flour Incorporated

Biscuits. *CORD*, *36*, 33-39. https://doi.org/10.37833/cord.v36i.427.

P´erez-Navarrete, C., Gonz´alez, R., Chel-Guerrero, L. and Betancur-Ancona, D. (2006). Effect of extrusion on nutritional quality of maize and Lima bean flour blends. *Journal of the Science of Food and Agriculture,* 86: 2477-2484. DOI: 10.1002/jsfa.2661.

Piayura, S. and Itthivadhanapong, P. (2023). The effects of feed moisture and dried coconut meal content on the physicochemical, functional, and sensory properties of gluten-free Riceberry rice flour-based extruded snacks. *Frontiers in Sustainable Food System*, 7: 1194594. https://doi.org/10.3389/fsufs.2023.1194594

Prinyawiwatkul, W., Beuchat, L.R., & Phillips, R.D. (1995), "Modelling the effects of peanut flour, feed moisture content, and extrusion temperature on physical properties of an extruded snack product", International Journal of Food Science and Technology, Vol. 30 No. 1, pp. 37-44.

Rachael, E. (2020). Functional aspects of coconut: Beyond nutritional content. *Nutrition Reviews* 78(3):145-156.

Rehm, C. D., & Drewnowski, A. (2017). Replacing American Breakfast Foods with Ready-To-Eat (RTE) Cereals Increases Consumption of Key Food Groups and Nutrients among US Children and Adults: Results of an NHANES Modeling Study. *Nutrients*, *9*(9), 1010. https://doi.org/10.3390/nu9091010.

Ruiz-Armenta X. A., Zazueta-Morales, J. de J., Aguilar-Palazuelos, E. et al. (2018). Effect of extrusion on the carotenoid content, physical and sensory properties of snacks added with bagasse of naranjita fruit: optimization process. *CyTA - Journal of Food* 16(1), 172-180.

Sahu, C., Patel, S. and Khokhar, D. (2018). Studies on storability of maize-millet based soy fortified extruded snacks. *International Journal of Agricultural Engineering* 11 (Sp. Issue): 46-52, DOI: 10.15740/HAS/IJAE/11.Sp. Issue/46-52.

Sali, A. (2024). Extruded snacks with byproducts of coconut. A Master in Vocation Dissertation in the Department of Traditional Foods and Applied Nutrition, St. TERESA'S COLLEGE (Autonomous), ERNAKULAM Mahatma Gandhi University, Kottayam, Kerala.

Samarajeewa, U. (2024). Coconut: Nutritional and Industrial Significance. IntechOpen. doi: 10.5772/intechopen.1004173.

Serge, E. O., Gu, B. J., Kim, Y. S., & Ryu, G. H. (2011) Effects of feed moisture and barrel temperature on physical and pasting properties of cassava starch extrudate. *Korean Journal of Food Preservation* 18(3), 271–278.

Sharma, N. P., Sharma, T. and Agarwal, M. N. (2016). Measuring employee perception of performance management system effectiveness: Conceptualization and scale development. *Employee Relations,* 38(2): 224–247. https://doi.org/10.1108/ER-01-2015-0006

Shefali, B. and Florian, G. (2017). What is the difference between bulk density, tapped density and true density of a food product? https://www.researchgate.net/post/accessed June 2022.

Singha, P., Muthukumarappan, K., & Krishnan, P. (2017). Influence of processing conditions on apparent viscosity and system parameters during extrusion of distiller's dried grains-based snacks. *Food Science and Nutrition,* 6: 101–110.

Sterbova, L., Bradova, J., Sedlacek, T., Holasova, M., Fiedlerova, V., Dvoracek, V. and Smrckova, P. (2016). Influence of technological processing of wheat grain on starch digestibility and resistant starch content. *Starch/Stärke*, 68: 593–602. DOI 10.1002/star.201500162.

Sue, S. L., Sulaiman, R., Sanny, M. and Hanani, Z. A. (2015). Effect of extrusion barrel temperatures on residence time and physical properties of various flour extrudates. *International Food Research Journal*, 22(3): 965-972.

https://www.cabidigitallibrary.org/doi/pdf/10.5555/20153195074.

Surjirtha, N. and Mahendran, T. (2015). Use of Defatted Coconut Flour as a Source of Protein and Dietary Fibre in Wheat Biscuits. *International Journal of Innovative Research in Science, Engineering and Technology,* 4,8: 7344-7352.

Sundaresan, T., Subramaniam, S., Chinnapa, V. and Rajoo, B. (2023). Effect of defatted coconut flour on functional, nutritional, textural and sensory attributes of rice noodles. *International Journal of Food Science & Technology,* 58, 10: 5077-5088**.** https://doi.org/10.1111/ijfs.16606.

Thachil, M. T., Chouksey, M. K., & Gudipati, V. (2014). Amylose-lipid complex formation during extrusion cooking: effect of added lipid type and amylose level on corn-based puffed snacks. *International Journal of Food Science and Technology*, 49(2): 309-316. https://doi.org/10.1111/ijfs.12333.

Tiwari, U., Mary, G., Jaganmohan, R., Alagusundaram, K., & Towari, B.K. (2011). Quality characteristic and shelf-life studies of deep-fried snack prepared from rice brokens and legumes by-product. *Food and Bioprocess Technology*, 4(7), 1172-1178.

Tumuluru, J.S., Sokhansanj, S., Bandyopadhyay, S. and Bawa, A. S. (2013). Changes in Moisture, Protein, and Fat Content of Fish and Rice Flour Coextrudates during Single-Screw Extrusion Cooking. *Food and Bioprocess Technology,* 6: 403 – 415.

Ugwuanyi, R. G., Eze, J.I., & Okoye, E.C. (2020). Effect of soybean, sorghum and African breadfruit flours on the proximate composition and sensory properties of chin-chin. *European Journal of Nutrition and Food Safety,* **12**(1), 85-98.

Usman, G. O., Ameh, U. E., Alifa, O. N., & Babatunde, R. M. (2015). Proximate composition and anti-nutritional properties of breakfast cereal made from blends of local rice, soya bean and defatted coconut flours. *Nutrition and Food Science*, S11(006): 27–31. doi:10.4172/ 2155-9600.1000S11006.

Vadassery, K., Pratheesh, G. P., Gayathri, M., Binitha, N.K., Jasna, V.K., Seenath, P.K., Shamna, N., Arya, S., & Sujatha, R. (2023). Optimization of Extruded Snack Enriched with Coconut Inflorescence Sap Honey: A Promising Supplementary Food among Tribals. *Asian Journal of Dairy and Food Research* 42(4): 495-503. doi: 10.18805/ajdfr.DR-2067.

Wani, S. A., and Kumar, P., "Nutraceutical properties of ready-to-eat snack from rice, cassava, and kersting's groundnut composite flours". *Journal of Saudi Society of Agricultural Science* 17.2 (2016) 97-106.

Yagci, S. and Gogus, F. (2008. Influence of fiber and protein concentrations on starch gelatinization and rheological properties in extrusion cooking. *Journal of Food Science* 73.5 (2008): E227-E233.

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Conceptualization, TMI; methodology, CCU; software, TMI; validation, HOA; formal analysis, CCU; investigation, CCU; resources, CCU; TMI; writing—original draft preparation, CCU; writing—review and editing, MCE; visualization, HOA; supervision, TMI; project administration, CCU. All the authors pull resources together for the research. All authors have read and agreed to the published version of the manuscript."

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The authors declare no conflict of interest.