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A QUANTITATIVE STUDY OF MICROMERITICS PROPERTIES OF CO-PROCESSED BINDER ON THE NUTRITIONAL AND MECHANICAL PROPERTIES OF EXTRUDED MEAT SNACKS

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Abstract
The mechanical and disintegration properties of tapioca starch-based extruded meat snacks formulated using tapioca starch and wheat flour as a binder was investigated with the aim of improving both the nutritional content and textural characteristics of the snacks. Five blends comprising tapioca starch, wheat flour, brown rice flour, soymeal and beef were formulated using response surface methodology framework and were subjected to flow and compaction analysis. The physicochemical, micromeritics and mechanical properties investigated revealed that protein content ranged from 24.34% to 25.63%, carbohydrate, 34.27% to 51.42%, fibre, 8.72% to 10.50%, fat, 8.72% to 17.03%, ash, 2.61% to 3.00%. moisture, 3.65% to 6.78%. Tapioca samples, TS3 and TS5, both with low angles of repose (24.82 and 24.14, respectively) indicated excellent flow properties, suggesting favourable powder handling characteristics in food processing applications. The mechanical property described the relationship between the compressive stress of the five samples and ranged from 2.80184 to 2.87783 for TS1 to TS5, respectively while the modulus of the five samples revealed the samples' structural integrity in texture, firmness, quality and ranged from 0.59180 to 2.87783 for TS1 to TS5, respectively. The results suggest that while tapioca starch may be useful as a binder, its application at a low concentration will improve the balance between the binding and disintegration properties of snacks when a faster disintegration is desired. Furthermore, it uses at a high concentration could serve the desire for a modified moderate texture food formulation. Pressure plays the most significant impact in reducing the frictional contact between individual particles as well as the Van der Waals force's influence on cohesion during tapping, leading to increase in flowability and subsequent improvement in the consolidation index**.** The research contributes to the creation of innovative, nutritious, and appealing extruded snacks, aligning with evolving consumer preferences.

Keywords: *Meat snack, micromeritics, extrusion, binders, mechanical property*

Introduction

The food industry continues to evolve in its pursuit of healthy and nutritious choices by developing new methods to increase both the amount of nutrients found in food and its sensory properties. For many decades, people have experienced difficulties in ensuring a healthy and tasty meal around the world. Therefore, food manufacturers needed to implement different methods which would improve the appearance of food products while also providing increased nutritional value and organoleptic properties (Nkhata *et al*., 2018). One of these methods is extrusion, which has become a well-known technique within the food industry for modifying or improving existing food products such as snack foods, breakfast cereals and meat alternatives. The application of temperature, pressure, moisture and shear forces to raw ingredients allows these ingredients to be changed into many types of different forms and textures and creates products that have more nutrients (Espinosa-*Ramirez et al*., 2021).

Snack foods are popular today, especially among young people, and their popularity has changed how we eat. Most of the world's population eats snacks every day (Adegunwa *et al*., 2017). Traditional types of grain-based snacks (usually called snack foods) are readily available and easy to find, but they normally do not have enough protein or other important nutrients (Kavitha *et al*.,2022). There is currently an increasing demand for healthier snacks that have improved flavour and higher nutritional value. Therefore, researchers are investigating how to add meat to extrudates, which will help make them more nutritious, as well as improve the taste and the amount of protein, minerals, and vitamins found in the snack. Tumuluru (2016) found that people consider snacks that do not have nutritional benefits as junk food and that the consumption of junk food is related to increased risk for heart disease, hypertension, and obesity. In addition, snack foods may be enhanced with functional ingredients (such as antioxidants) or by adding chemical antioxidants, which will increase the nutritional value of the snack food, such as protein and fibre.

Meat, as a staple component of many diets worldwide, provides a rich source of high-quality proteins, essential minerals, and vitamins. It is a rich source of macronutrients and micronutrients including iron, zinc, vitamins D, B1(thiamine), B2 (riboflavin), B3 (niacin), B5 (pantothenic acid), B6 (pyridoxin), B12 (cobalamin), and proteins (Robin *et al*., 2014; Laskowski *et al*., 2018; Kavitha *et al*.,2022). All these nutrients are important for human physiological functions and its inclusion in extruded snacks presents an opportunity to address nutritional deficiencies and elevate the health-promoting attributes of these products (Kavitha *et al*., 2022). Additionally, the utilization of whole grains such as wheat, brown rice, and soybean meal further enhances the nutritional profile of extruded snacks, offering antioxidant activity, bioactive compounds, dietary fibres, and other beneficial components. The consumption of plant-based proteins has attracted attention in recent years (Chauhan *et al*., 2019). Wheat is one of the few cereal grains that has a high gluten protein content that provides the characteristic binding and gas retention properties of bread dough (Jinapong et al., 2008; Chauhan et al., 2019). The composition of wheat includes: 2-3% germ, 13-17% bran and 80-85% endosperm with the majority of it being used to produce white flour (Anyika et al., 2009). Whole grain wheat contains 78% carbohydrate, 14.70% protein, 2.19% fat and 2.10% minerals, and also contains significant amounts of the vitamins thiamine and vitamin B (Gammoh et al., 2018). Flour made from wheat is useful for producing a variety of products, including bread, biscuits, confectionery, noodles, and for providing the gluten that is found in wheat.

There are several reasons why mixing meat and whole grains together will yield new food product opportunities for consumers; however, there are limited published studies evaluating their micrometric and mechanical properties. Research studies are needed to fully understand the composition, structure, and functional characteristics of extruded meat and whole grain snack items to assist in the development of innovative ways to produce healthy snack choices. As a continuation of these research efforts, the focus of this particular study will evaluate the micrometrics of the snack item and assess the quantitative influence of adding co-processed binders on the mechanical properties of extruded beef snacks. This study will help to identify those factors that influence the development of extruded meat and whole grain snacks, resulting in healthier and more nutritious snack options that meet changing consumer expectations and preferences.

Methodology

Materials

Whole wheat grain (WWG), soybean meal (SBM), and tapioca starch were sourced from Farm Support, Akure, Ondo State. Brown rice was obtained from Ceci Supermarket in Akure. Whole wheat flour, dry yeast, chicken, and beef were purchased from the Oja Oba local market in Akure, Nigeria. All additional chemicals and reagents used for the analysis were of analytical grade.

Sample preparation

Processing of brown rice, whole wheat meal, soybeans, tapioca starch and yellow corn

The method reported by Hardeep et al. (2007) was adopted to process brown rice, as shown in flow diagram in Figure 1, to produce fine particles that had a target size of 85 μm prior to the extrusion cooking. The rice was ground with an attrition mill and conditioned to a moisture level of 16% before being stored at room temperature until used for cooking (extrusion). The production of wheat flour started from the selection of the right quality of wheat grain. The entire process flow diagram followed to produce wheat flour can be seen in Figure 2. The first steps in producing wheat flour include cleaning and sorting of grains, which includes removing all contaminants from the wheat grain. Once the wheat grain was cleaned, the wheat grains were soaked in hot water for 2 hours to allow the grain to absorb the moisture. The soaking of the wheat grain is the first step in the germination process. The process of germination is used to activate the enzymes within the wheat which improves the nutritional value and enhances the properties of the grain after germination has occurred and takes approximately 72 hours. After the wheat grains have been germinated, they are dried in an oven at 60º C so that they would have the appropriate amount of moisture. The last step in producing wheat flour was milling the wheat grain into a fine powder and then sieved to produce flour with uniform size distribution of the particles.

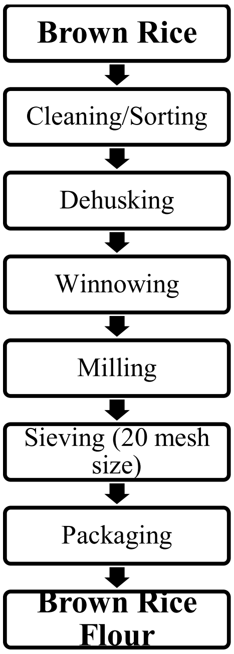


Figure 1: Flowchart to produce brown rice flour

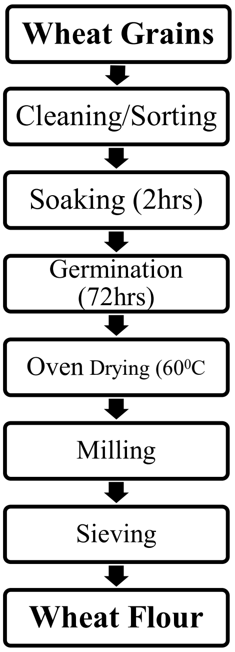


Figure 2: Flowchart to produce wheat flour

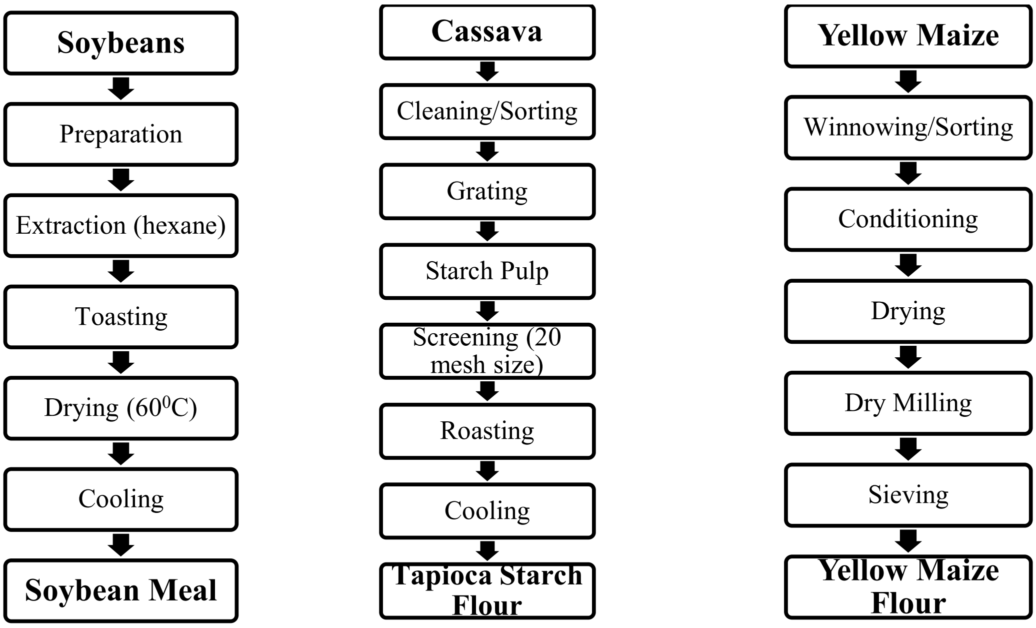


Figure 3: Flowchart for the production of soybean meal, Tapioca starch flour and Yellow maize flour

The whole production chain of soybean meal, depicted in Figure 3, commences with the procurement of high quality soybeans. In the first step the soybeans were cleaned thoroughly to remove impurities. The next process was the solvent extraction of oil from the soybeans, using the same method as described by (Harada et al., 2019; Kim et al., 2021; Oluwajuyitan et al., 2021). The remaining material were then toasted to decrease anti-nutritional factors, as well as increase the nutritional value and digestibility of soybean meal. This was followed by the drying of the soybeans at a temperature of 55° C in an oven for 12 hours to reach the proper moisture content. The soybeans were then cooled to room temperature before being blended together to create a uniform mixture, thus ensuring a uniform nutritional profile of the finished product. The process for making tapioca flour start with obtaining properly harvested and intact cassava roots. The pretreatment steps in preparing cassava roots for processing into tapioca flour were sorting and washing to free them from any foreign material. They are then grated or shredded by grater or shredding machine to extract the starch pulp from the roots and concentrate the starchy components into a pulp form. Figure 3 depicts the starch pulp after having been screened with a 20 mesh to effectively reduce the size of the particles to a uniform size while removing additional particles that are not related to starch content. The starch pulp was then roasted to develop the taste and texture of the starch for cooking and thereafter allowed to cool before being blended to form a single batch of tapioca flour. Blending was necessary to ensure that each batch of tapioca flour has the same composition and quality. After blending, the tapioca flour is adjusted to the desired moisture content by spraying distilled water onto the flour at premeasured amounts and mixing the water into the tapioca flour for 15 minutes. The mixtures of tapioca flour are then packaged in plastic bags for refrigeration overnight to equalize the moisture content of all samples. The samples are brought to room temperature and then subjected to extruded cooking. The corn was treated by removing dirt, any foreign material that may have adhered to the dried yellow corn through washing. An attrition mill was then utilized to mill the cleaned corn into powder. The milled corn was then put in a clean, dry plastic container until it was ready to be extruded and cooked.

Processing of beef meat

Meat piece from cows slaughtered under hygienic conditions was obtained. The meat was cut into smaller pieces and placed in a large steel cooking pot. Sufficient water was added without any salt or spices, and the meat was cooked on a gas cooker for about 15 to 20 min. After cooking, the meat pieces were removed from the pot and allowed to cool for approximately 30 min. The meat was further cut into smaller sizes to increase its surface area, facilitating rapid drying. The meat was then dried in a cabinet dryer at a temperature of 70 to 80 ºC for 16 to 18 hours. After drying, the meat was cooled and ground using a fabricated hammer mill (Hosokawa Alpine, Augsburg, Germany).

Extrusion Process

Extrusion *was* performed using a fabricated single-screw extruder, equipped with a motor coupled to a speed reducer, facilitating extrusion by mechanical friction. The raw flour blend was extruded at 21% moisture content, with a barrel temperature of 140 °C, a barrel diameter of 140 mm, and an extruder length of 440 mm. The extruder featured a hydraulic cooling system for temperature control, variable speed settings, and a capacity of 50 kg/h. During the extrusion process, a portion of the next test material was used to purge the extruder. Table 1 illustrates the formulation of extruded meat snack.

Table 1: Formulation of extruded meat snack.r

Code	Tapioca [%]	Soymeal [%]	Whole wheat [%]	Brown rice [%]	Meat [%]
TS1	23.634	14.610	19.880	17.580	24.280
TS2	24.000	14.020	19.040	18.000	24.950
TS3	24.000	15.000	19.030	17.940	24.038
TS4	23.950	15.000	19.050	17.010	25.000
TS5	23.040	15.000	19.060	18.000	24.890

Handling of the Pelletized Snacks

The emerging extrudates, formed as pellets at the die nozzle, were collected and spread under a fan on a laboratory table at room temperature (28 ± 2°C) for 3 hours. The extrudates were then dried in an air convection oven (Gallenkamp, England) at 60°C for

10 hours. The resulting dried extrudates were packaged in coded high-density polyethylene bags. A few grams needed for laboratory analysis were taken, milled in a Brabender roller mill (Germany), and sieved through a 75 µm opening. The resulting extrudate flour was packaged in coded high-density polyethylene bags and stored at room temperature (28 ± 2°C) until needed for analysis.

Proximate analysis

The proximate composition of the flour blend samples was determined using AOAC (2012) methods. The samples were analyzed for moisture, ash, crude fibre, crude protein, and crude fat, while carbohydrate content was calculated by difference. Energy values were estimated as the sum of carbohydrate, protein and lipid kilocalories according to Atwater system described in Equation 1

$$\text{Energy (kcal)} = [(4 \times \text{carbohydrate}) + (4 \times \text{protein}) + (9 \times \text{fat})] \quad (1)$$

Determination of mineral composition

The mineral analysis of iron, calcium, magnesium, zinc, potassium, sodium, phosphorus and copper was conducted with atomic absorption spectroscopy as described by AOAC (2012). The samples were dry-ashed in a muffle furnace at 550 °C for 6 hour. The minerals were extracted from ash with 20 mL of 2.50% HCl and heated in a steam bath to reduce the volume to 8.0 mL, which was transferred quantitatively to a 50 mL volumetric flask and diluted to volume using deionized water. The extracts were stored in dry, clean plastic sample bottles, and the mineral concentrations were determined using an atomic absorption spectrophotometer. Potassium was determined with the flame photometric method of AOAC (2012) using a low temperature direct reading single channel emission flame photometer. Vitamin B composition was determined by homogenizing 5 g of sample with 50 ml ethanoic sodium hydroxide. It was filtered into a 100 ml conical flask. 10 ml of the filtrate was pipette and the colour was developed by addition of 10 ml of 1%potassium dichromate and read the absorbance at 360 nm. A blank solution is also prepared (AOAC, 2012).

Statistical Analysis

Data was carried out in triplicate. The quality of the fit of the model was evaluated using analysis of variance (ANOVA). Results were analysed using SPSS statistical package (Version 17.0) through the analysis of variance (ANOVA), Duncan New multiple range test was used to determine significant differences in mean of the samples at $p < 0.05$. All values were expressed as mean SD.

Result and Discussion

Micrometric Properties of the Flour

Micrometrics encompass the study of particles and their properties in powders, suspensions, and emulsions. The micrometric properties of milled flour and components such as particle shape and size, surface area, bulk density, and porosity play an important role in packaging and food product development by influencing their effect on handling flow properties, mixing, and stability. The bulk density of the flour samples ranged from 0.50 – 0.60 g/cm^3 as summarized in the Table 2. Although there was no significant different between the samples, the variation in the bulk density may be because, the finer particles pack more loosely than larger granules due to differences in surface roughness and shape factors. This agrees with the work of Siliveru et al. (2016) and Adeoye et al. (2023) who noted that the finer particles are comparatively rough and have a wide range of shapes when compared to larger particles.

The tapped density of the flour samples ranged from 0.57 – 0.77 g/cm^3 having sample TS1 (23.634% Tapioca, 14.61% soybean, 19.88% whole wheat, 17.58% brown rice, 24.28% meat) ranking the lowest with 0.57 g/cm^3 and sample TS4 (23.95% Tapioca, 15% soy bean, 19.05% whole wheat, 17.01% brown rice, 25% meat) ranking the highest with the value 0.77 g/cm^3. There was a significant difference between sample TS4 and TS1 and no observable significant difference between samples TS2, TS3 and TS5 respectively.

The relative density as shown in the Table 2 reveals a range of 0.23 – 0.35 g/cm among all the samples as TS2 (24% Tapioca, 14.02% soybean, 19.04% whole wheat, 18% brown rice, 24.95% meat) ranged the lowest with 0.23 g/cm and TS1 (23.634% Tapioca, 14.61% soybean, 19.88% whole wheat, 17.58% brown rice, 24.28% meat) with 0.35g/cm as the highest. There was no significant difference between samples TS1, TS3, and TS5. The same scenario was observed in samples TS3, TS4 and TS5 when grouped. Samples TS2, TS3 and TS4 also revealed negligible differences. A lower relative density in TS2 could indicate a more porous or loosely packed structure, possibly affecting textural attributes, while the higher density in TS1 may imply a denser matrix, influencing the product’s overall sensory and mechanical characteristics (Da Silva et al., 2014).

The range observed for the Hausner ratio was 1.35 – 1.44 as sample TS1 (23.634% Tapioca, 14.61% soybean, 19.88% whole wheat, 17.58% brown rice, 24.28% meat) ranked the lowest and samples TS2 – TS4 ranked the highest, showing an intermediate fluidity as stated by Jinapong *et al.* (2008). There was an observable significant difference between all the samples except for sample TS2 – TS4. The

Hausner's ratio is indicative of particle friction, Carr's compressibility percentage index is considered indirect measures of flour flow property and shows the material's ability to decrease volume (Adeoye et al., 2023). Porosity of the flour samples ranged from 0.68 – 0.77 with sample TS5 (23.04% Tapioca, 15% soybean, 19.06 whole wheat, 18% brown rice, 24.89% meat) – TS2 (24% Tapioca, 14.02% soybean, 19.04% whole wheat, 18% brown rice, 24.95% meat) having both the lowest and highest value respectively. Angle of Repose of the flour samples as shown in the Table 2 ranged between 24.14 – 32.51 respectively as TS3 (24% Tapioca, 15% soybean, 19.03% whole wheat, 17.94% brown rice, 24.038% meat) ranked the lowest and TS2 (24% Tapioca, 14.02% soybean, 19.04% whole wheat, 18% brown rice, 24.95% meat) ranked the highest. The implication of this is the improvement of flow properties as angle of repose declines (AOAC, 2012; Adeoye *et al*., 2023). TS3 and TS5, both with low angles of repose (24.82 and 24.14, respectively), indicate excellent flow properties, suggesting favourable powder handling characteristics in food processing applications.

Table 2: Micrometric properties of the tapioca starch based extruded meat snack.

Sample	Bulk Density [g/cm^{3}]	Tapped Density[g/cm^{3}]	Relatve Density[g/cm]	Hausner ratio	Carr's Compressibility index	Bulkiness [cm^{3} /g]	Porosity [%]	Angle of repose
TS1	0.60 ± 0.07^{a}	0.57 ± 0.01^{c}	0.35 ± 0.04^{a}	1.35 ± 0.00^{c}	25.68 ± 0.00^{c}	1.82 ± 0.00^{a}	0.72 ± 0.06^{a}	31.91 ± 0.02^{b}
TS2	0.50 ± 0.00^{a}	0.73 ± 0.01^{b}	0.23 ± 0.00^{c}	1.44 ± 0.00^{a}	30.91 ± 0.00^{a}	1.93 ± 0.07^{a}	0.77 ± 0.00^{a}	32.51 ± 0.02^{a}
TS3	0.52 ± 0.00^{a}	0.75 ± 0.1^{b}	0.30 ± 0.00^{a}	1.44 ± 0.00^{a}	30.81 ± 0.04^{b}	1.92 ± 0.00^{a}	0.69 ± 0.00^{a}	24.82 ± 0.04^{d}
TS4	0.53 ± 0.00^{a}	0.77 ± 0.00^{a}	0.25 ± 0.00^{b}	1.44 ± 0.00^{a}	30.37 ± 0.00^{c}	1.85 ± 0.00^{a}	0.76 ± 0.00^{a}	27.91 ± 0.04^{c}
TS5	0.53 ± 0.00^{a}	0.74 ± 0.00^{b}	0.32 ± 0.00^{a}	1.38 ± 0.00^{b}	28.16 ± 0.00^{d}	1.88 ± 0.00^{a}	0.68 ± 0.00^{a}	24.14 ± 0.14^{e}

Values are mean ± STD. Same alphabet within the column are not significantly different (p < 0.05)
TS1 = 23.634% Tapioca, 14.61% soybean, 19.88% whole wheat, 17.58% brown rice, 24.28% meat
TS2= 24% Tapioca, 14.02% soybean, 19.04% whole wheat, 18% brown rice, 24.95% meat
TS3= 24% Tapioca, 15% soybean, 19.03% whole wheat, 17.94% brown rice, 24.038% meat
TS4= 23.95% Tapioca, 15% soy bean, 19.05% whole wheat, 17.01% brown rice, 25% meat
TS5= 23.04% Tapioca, 15% soybean, 19.06 whole wheat, 18% brown rice, 24.89% meat

Proximate Composition of Extruded Snacks

The proximate composition of the extruded snacks from different composite materials is presented in Table 3. The moisture content in food is an important parameter because it determines the product's quality, acceptability, and shelf life. The moisture content of the extruded beef ranged from 4.15 ± 0.07 to 6.78 ± 0.01 for NA1 to NA5 respectively. All the sample were within the range recommended for moisture content of food product (FAO, 2020). Thus, reduction in moisture content has an advantageous because it reduces the proliferation of spoilage organisms especially mold, and thereby, improving the shelf stability of the product.

The crude fat content ranged from 11.99 to 17.17% in the extruded snacks product formulated. The decrease of lipid during extrusion process could be due to oxidation degradation of fatty acid induced by the high temperatures reached during the process. Riaz (2000) reported that the lipid could be loss when the food material leaves through the extruder die by the flash-off effect, like the way in which water is lost as vapour. Results also showed that the crude fibre ranged from 8.71 to 10.50 in the extruded snacks formulated. The reduction of the crude fibre in the extruded product could be due to cleavage of the fibre macromolecules and conversion into small molecules caused by the severity of the heating and shearing during the process (Jinapong *et al*., 2008).

The ash content ranged from 2.64 to 3.61%. The protein content of the extruded beef ranged from 24.23 ± 0.00% to 25.37 0± 0.04% for NA1 and NA4 respectively. The addition of meat to the samples increased the protein content of the extruded snack thereby making it more efficient and acceptable for commercial consumption, Furthermore, meat is a rich source of high-quality proteins, minerals like iron and zinc and various vitamins, especially B complex vitamins. Based on the results of the analysis performed, the carbohydrate value obtained does not meet the SNI standard of 60% minimum. This might be due to the frying process, not a drying process, thus the results show a remarkable carbohydrate content in all the samples.

Table 3: Proximate composition of extruded snacks

Sample	Moisture content %	Ash%	Crude fat [%	Crude fibre %	Protein %	Cho %
NA1	4.15 ± 0.07^{e}	3.04 ± 0.01^{bc}	11.99 ± 0.14^{d}	8.71 ± 0.07^{c}	24.23 ± 0.00^{d}	47.86 ± 0.13^{a}
NA2	4.43 ± 0.02^{d}	2.88 ± 0.04^{c}	13.83 ± 0.07^{c}	9.28 ± 0.07^{b}	25.24 ± 0.01^{a}	44.32 ± 0.23^{b}
NA3	5.45 ± 0.00^{c}	3.61 ± 0.07^{a}	14.37 ± 0.23^{c}	9.46 ± 0.02^{b}	24.83 ± 0.04^{b}	42.26 ± 0.11^{c}
NA4	5.76 ± 0.00^{b}	2.64 ± 0.00^{d}	16.28 ± 0.07^{b}	10.38 ± 0.06^{a}	25.37 0± 0.04^{a}	39.67 ± 0.00^{d}
NA5	6.78 ± 0.01^{a}	3.16 ± 0.07^{b}	17.17 ± 0.07^{a}	10.50 ± 0.08^{a}	24.50 ±0.07^{c}	37.88 ± 0.14^{e}

Values are mean ± STD. Same alphabet within the column are not significantly different ($p<0.05$)
NA1 = 23.634% Yellow corn, 14.61% soybean, 19.88% whole wheat, 17.58% brown rice, 24.28% meat
NA2= 24% yellow corn, 14.02% soybean, 19.04% whole wheat, 18% brown rice, 24.95% meat
NA3= 24% yellow corn, 15% soybean, 19.03% whole wheat, 17.94% brown rice, 24.038% meat
NA4= 23.95% yellow corn, 15% soy bean, 19.05% whole wheat, 17.01% brown rice, 25% meat
NA5= 23.04% yellow corn, 15% soybean, 19.06 whole wheat, 18% brown rice, 24.89% meat

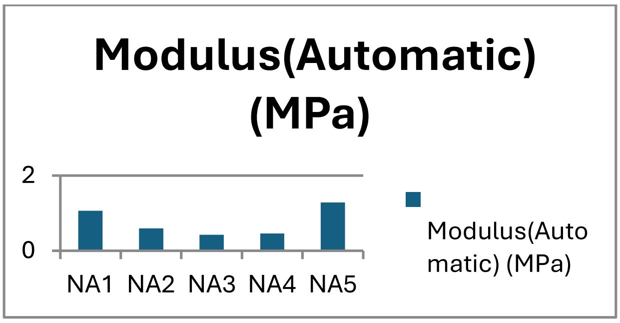


Figure 4: Modulus of the extruded snack

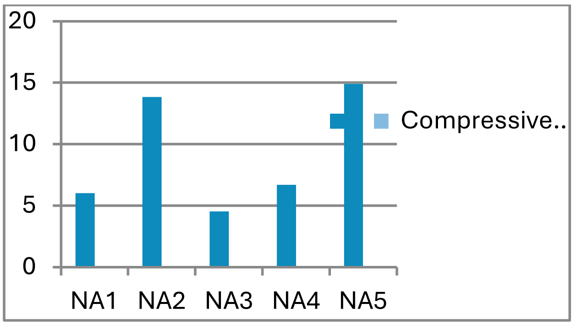


Figure 5: Compressive stress of the extruded snack

Mechanical Properties of Extruded Snacks

The modulus and compressive stress of the extruded snack were shown in Figures 4 and Figure 5 respectively. The sample NA5 showed the higher magnitude of modulus and compressive stress compared to other samples, this could be due to the higher stiffness and stress pattern of the sample because the higher the modulus the more stress is required to ascertain the compressive strain. Furthermore, sample NA1 was observed to be higher in modulus after NA5 which implies higher stiffness but the tensile strength of the sample is low which amount to the low magnitude of the compressive stress. Sample NA2, NA3 and NA4 were low in modulus and compressive stress due to the inability to withstand the compression and elongation with respect to their length.

Proximate Composition of the Tapioca Starch Based Extruded Meat Snacks

This analysis provides crucial insights into the overall composition, nutritional quality, and potential storage stability of food products. According to Table 4, the proximate composition of tapioca starch-based extruded meat snacks (TS1 to TS5) provides a comprehensive understanding of the nutritional attributes influenced by varying raw material compositions. The moisture content exhibits a gradual increase from 3.65% in TS1 to 6.78% in TS5, showcasing the impact of formulation on product texture.

Table 4: Proximate composition of the tapioca starch based extruded meat snacks.

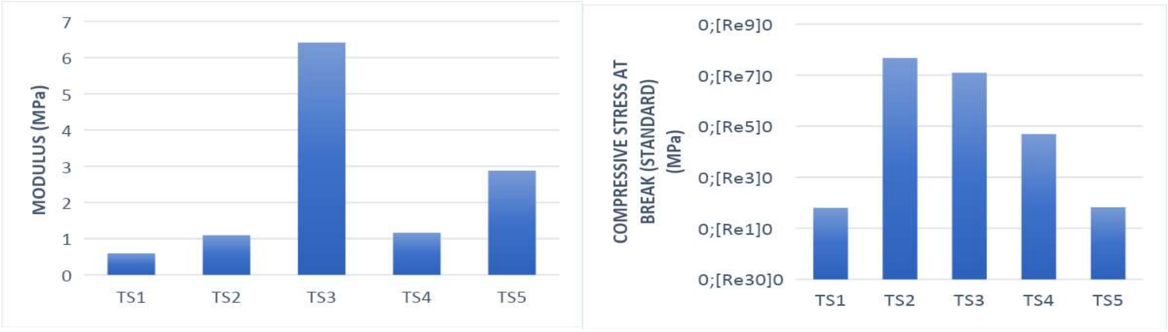
Sample	Moisture %	Ash %	Fat %	Fibre %	Protein %	Carbohydrate %
TS1	3.65±0.25^{d}	3.00±0.01^{a}	8.72±0.05^{e}	18.72±0.0^{e}	24.50±0.0^{d}	51.42±0.2^{a}
TS2	4.40±0.00^{c}	2.91±0.02^{b}	14.35±0.01^{d}	9.29±0.06^{d}	25.28±0.05^{b}	43.78±0.04^{b}
TS3	5.56±0.01^{b}	2.77±0.01^{c}	15.39±0.05^{c}	9.47±0.02^{c}	24.840±0.06^{c}	41.99±0.01^{bc}
TS4	5.74±0.05^{b}	2.65±0.01^{d}	16.34±0.01^{b}	10.39±0.05^{b}	25.63±0.02^{a}	34.27±5.0^{d}
TS5	6.78±0.01^{a}	2.61±0.01^{e}	17.03±0.02^{a}	10.50±0.06^{a}	24.34±0.01^{e}	38.75±0.1^{c}

Values are mean ± STD. Same alphabet within the column are not significantly different (p<0.05)
TS1 = 23.634% Tapioca, 14.61% soybean, 19.88% whole wheat, 17.58% brown rice, 24.28% meat
TS2= 24% Tapioca, 14.02% soybean, 19.04% whole wheat, 18% brown rice, 24.95% meat
TS3= 24% Tapioca, 15% soybean, 19.03% whole wheat, 17.94% brown rice, 24.038% meat
TS4= 23.95% Tapioca, 15% soy bean, 19.05% whole wheat, 17.01% brown rice, 25% meat
TS5= 23.04% Tapioca, 15% soybean, 19.06 whole wheat, 18% brown rice, 24.89% meat

Table 5: Mineral Composition of the Tapioca Starch Based Extruded Meat Snacks.

Samples	Na	K	Ca	Mg	P
TS1	31.5±0.15^{b}	95±0.5^{c}	23.5±0.2^{d}	42±0.5^{b}	13±0.3^{b}
TS2	27.5±0.15^{d}	110±0.6^{a}	28.3±0.3^{b}	37.5±0.14^{d}	10.54±0.03^{b}
TS3	36±0.15^{a}	97±0.2^{b}	20.8±0.15^{e}	37.4±0.15^{d}	15.34±0.05^{a}
TS4	30.7±0.10^{b}	89.5±0.2^{e}	31±0.15^{a}	45.2±0.3^{c}	9.65±0.2^{d}
TS5	27.8±0.2^{d}	90.3±0.25^{d}	27.5±0.15^{c}	40.2±0.35^{c}	10.53±0.01^{b}

Values are mean ± STD. Same alphabet within the column are not significantly different (p<0.05)
TS1 = 23.634% Tapioca, 14.61% soybean, 19.88% whole wheat, 17.58% brown rice, 24.28% meat
TS2= 24% Tapioca, 14.02% soybean, 19.04% whole wheat, 18% brown rice, 24.95% meat
TS3= 24% Tapioca, 15% soybean, 19.03% whole wheat, 17.94% brown rice, 24.038% meat
TS4= 23.95% Tapioca, 15% soy bean, 19.05% whole wheat, 17.01% brown rice, 25% meat
TS5= 23.04% Tapioca, 15% soybean, 19.06 whole wheat, 18% brown rice, 24.89% meat



(a) (b)

Figure 6: (a) Modulus and (b)Compressive stress of Tapioca Starch Based Extruded Meat Snacks

Importantly, the lower moisture content in TS1 aligns with desirable storage stability, crucial for extended shelf-life and reduced susceptibility to microbial growth, highlighting the significance of controlled moisture levels (Brown and Richards, 2013). The ash content decreases from 3.00% in TS1 to 2.61% in TS5, indicating potential removal of other components during processing and influencing the overall mineral content. This decline aligns with expected variations based on raw material proportions, emphasizing the intricate relationship between formulation choices and ash content. The fat content experiences a progressive increase from 8.72% in TS1 to 17.03% in TS5, driven by the elevated soybean content. Despite the rise, all fat values remain within a safe range (0.12% to 0.34%), mitigating the risk of rancidity and ensuring product quality. This highlights the meticulous balancing act required for flavour enhancement without compromising stability. The crude fibre content, ranging from 8.72% in TS1 to 10.50% in TS5, reflects the impact of non- dehulled soybean during processing, influencing the product texture and nutritional value.

Protein content ranged from 24.34% in TS5 to 25.63% in TS4, correlating with varying soybean content. This correlation underscores the significance of raw material composition in determining protein levels, positioning these snacks as a potentially valuable protein source. Simultaneously, carbohydrate content decreases from 51.42% in TS1 to 34.27% in TS4 and 38.75% in TS5 respectively, demonstrating the inverse relationship with soybean content. Despite the reduction, carbohydrate levels remain sufficient for these snacks to serve as a substantial energy source. The analysis of proximate composition components sheds light on the intricate interplay between raw material composition and the nutritional characteristics of tapioca starch-based extruded meat snacks. These findings are vital for informed product development, aligning with consumer preferences for both nutritional content and prolonged storage stability.

The mineral composition of the extruded product shown in Table 5 was higher in Na (32.90 mg/ g) for NA4, k (112 mg/ g) for NA3, Ca (30.00mg/ g) for NA2, Mg (40.70 mg/g) for NA5, P (13.12 mg/g) for NA1.

The modulus bar shown in Figure 6 revealed that the higher the modulus, the more stress is needed to create the same amount of strain. TS3(6.41601) shows a higher modulus which implies that a material with high stiffness and resistance to deformation. This variation may be due to the composition of the product. TS1(0.59180) shows a low modulus which tends to be softer and less resistant to deformation. A good modulus often implies a material with high stiffness and resistance to deformation. To test this, force is applied to the material and the results recorded using material testing machine INSTRON. The compressive stress at break bar shows the maximum stress a material can withstand in compression before it takes or fails. TS2 (8.67011) shows the highest compressive stress at break which can withstand compression before it breaks. TS1 (2.80184) shows a low compressive stress at break which cannot withstand compression before it breaks.

Conclusion

The findings of this study indicated notable variations in proximate composition across the samples, shedding light on the relationship between raw material proportions and the snacks' nutritional composition. The evaluation of micromeritics properties further contributed to understanding the flow and compaction behaviours of the flours. TS3 and TS5 shows the best formulation, TS3 indicating excellent flow properties with low angle of repose of 24.82 and TS5 indicating excellent flow properties. A comprehensive understanding of snacks nutritional and functional attributes was also established.

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