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ORIGINAL ARTICLE

Effects of extrusion on nutritional and non-nutritional properties in the production of multigrain ready to eat snacks incorporated with NUA45 beans

Arlene Rachael Andirigu, Loveness Kuziwa Nyanga , Prosper Chopera *

University of Zimbabwe. Faculty of Science. Department of Nutrition Dietetics and Food Science. Post Office Box, 167 Mount Pleasant, Harare, Zimbabwe. arleneandrico@gmail.com / nyangael@yahoo.com / pchopera@science.uz.ac.zw

ABSTRACT

Background: Extrusion technology, used in producing a variety of food products, including ready-to-eat snacks, has become a popular and reputable industrial method. Snacks have been occupying an important part of the diet for the world's population. However, the effects of extrusion on nutritional and non-nutritional properties in the production of snacks using traditional grains incorporated with legumes are not fully understood. **Objective**: To determine the effects of extrusion on nutritional and non-nutritional qualities of multigrain puffs from white sorghum, pearl millet and NUA45 beans. **Methods**: White sorghum, pearl millet and NUA45 beans were blended in the ratios 50:30:20, 50:20:30 and 50:10:40% to select the best composite for snack production. Selected nutritional and non-nutritional quality parameters were compared before and after extrusion. **Results**: The extrusion process caused a significant increase ($p < 0.05$) in the content of fat (2.22 to 2.61%, 1.73 to 2.40 and 2.75 to 3.29% for the blends 1, 2 and 3 (50:30:20, 50:20:30 and 50:10:40% respectively), while causing a decrease in protein content, 14.44 to 13.34%, 16.63 to 13.34% and 20.56 to 16.41% in the multigrain puffs. Extrusion also increased iron, zinc and sodium content significantly ($p < 0.05$) while decreasing calcium. Magnesium and phosphorus had no change. Furthermore, extrusion improved the multigrain puffs' nutritional value and antioxidant activity. The extrusion process caused a significant decrease in tannins (6.82 to 6.01%, 7.82 to 2.17% and 5.74 to1.17%) and phytates contents (2.82 to 2.43%, 3.01 to 1.55% and from 2.92 to 0.37%) of the resultant multigrain puffs from blends 1,2 and 3 respectively. Total phenolic content increased (18.56 to 172.22, 24.38 to 144.61, and 65.87 to 180.44 mg GAE/100g). **Conclusion**: Extrusion enhances selected nutrients while decreasing anti-nutrients. Based on the composite feeds of white sorghum, pearl millet and NUA45 beans analyzed, the composite blend in the ratio 50:10:40% can be used to develop an acceptable novel healthy extruded traditional grain-based snack.

Keywords: Extrusion, ready-to- eat snacks, multigrain puffs, nutrients, anti-nutrients, white sorghum, pearl millet, NUA45 beans.

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* **Corresponding authors:** Prosper Chopera, pchopera@science.uz.ac.zw / pchopera@gmail.com
Tel. (+263) 242 303211

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1 Introduction

Extrusion processing has become a reputable industrial method with a wide range of uses in the food and feed industries; however, levels of nutrients such as carbohydrates, proteins, minerals, and several other non-nutrient vital components of the resultant food can be altered, with favorable and non-favorable effects on health. This is concerning when extrusion technology is being used to make foods for vulnerable groups, such as weaning foods for infants [1]. Extrusion cooking is a method used to produce a variety of products by pressurizing raw ingredients to flow through a created hole (die) at a set rate. Raw food ingredients undergo structural, chemical, and nutritional changes during extrusion. These include starch gelatinization and breakdown, protein denaturation, lipid oxidation, taste creation, improved mineral bioavailability, and dietary fiber solubility [2]. Additionally, it reduces a number of undesirable anti-nutritional chemicals and enzymes. It also increases the quantity of soluble fiber in fibrous materials like hulls, cereal and legume brans, and materials rich in plant cell walls [3, 4].

Naturally, traditional grains are climate smart, rich in nutrients and phytochemicals hence consuming such snacks will ensure children are not subsisting on empty calories as with the usual available snacks. Legumes such as beans though high in protein content are unpopular with under 5s hence value addition may improve acceptability in this population group. The use of legume flour, fiber and starch has the potential to be used in several food products as puffed, extruded snack foods to accomplish the target of achieving consumer satisfaction [4].

Most age groups have experienced an increase in snack food consumption over the past 25 years. Children in particular, have benefited from the affordable, ready-to-eat foods. Snack foods comprise about 25% of a child's daily caloric intake. They are frequently produced using extrusion technology and have become a significant component of people diets all over the world [5]. The most popular extruded products in the market are corn snacks. These are not considered healthy snacks because they have a high glycemic index and do not satisfy recommended nutrient intakes for children [6]. Thus, legumes are frequently used in the fortification of extruded products since they are a good source of protein, vitamins, and minerals like potassium, iron, zinc, calcium, and magnesium [7, 8].

A number of researchers have attempted to increase the nutritional value of extruded food products by using germinated grains, including legumes, without experiencing any negative consequences. Sorghum and pearl millet are smart climate crops that can be exploited. Earlier works have reviewed the use of sorghum and other cereals as human food and reported the various forms in which they are consumed. These include porridges, expanded snacks, cookies and ethnic foods [9]. The feasibility of making puffed snacks using sorghum and millets in cooperated with nu45 beans to add to the Zimbabwean cuisine has not been explored yet. Therefore, in order to create a snack product that is nutritionally stable using composite flours of dehulled white sorghum, pearl millet, and NUA45 beans, the effects of extrusion on the nutritional and non-nutritional properties are examined in the current research.

2 Material and Methods

2.1 Ingredients

White sorghum (*Sorghum bicolor* L), pearl millet (*Pennisetum glaucum* (L.) R. Br.) and NUA45 beans (*Phaseolus vulgaris* L) devoid of mechanical damage were obtained from Farmers in Buhera (19.3211° S, 31.4399° E) in Zimbabwe.

Flour preparation from white sorghum, pearl millet and NUA45 beans

White sorghum, pearl millet and NUA45 beans were manually cleaned and separated by winnowing (apart from NUA45 beans) and sieving (mesh size 10). Five hundred milliliters of water per 5 kg of grains were added during dehulling. The grains were pounded using a wooden pestle and mortar until the bran and endosperm were separated. Before fully dehulled grains were obtained, the pounding and winnowing procedures were repeated numerous times. After that, the grains were dried in an oven at 100°C for 15 minutes. A ball mill from Ruzha brands (Harare, Zimbabwe) was used to grind the grains and beans into coarse flour.

2.2 Formulation of multigrain puffs

Preliminary trials were conducted to develop and recommend the composite flours that give the best extruded multigrain puffs considering its nutritive and expected sensory attributes using different ratios of white sorghum, pearl millet and NUA45 beans. After the trials, three composite flour ratios of 50:30:20, 50:20:30, and 50:10:40% for the white sorghum, pearl millet, and NUA45 bean flours, respectively were selected, tagged, and kept in zip-lock bags at 25 °C for further usage and evaluation.

2.3 Extrusion processing of composite flours to produce multigrain puffs

The composite multigrain flour samples were extruded using a small laboratory single-screw extruder (Ranmao, China). Before starting the testing runs, the extruder was allowed to operate until the temperature, screw speed and output product stabilized (approximately 180°C, 2000psi) to allow for cooking to ensure an edible product is formed; using white sorghum, pearl millet and bean flour. The barrel was then fed with raw composite flour of white sorghum, pearl millet and NUA45 beans. The extrusion screw turned the material into a semi-solid, plasticized mass as the feed kept moving down the barrel. The multigrain puffs were pushed through the die at the barrel's discharge end. The resulting multigrain puffs were dried at 110°C for 5 minutes, to reduce moisture content generated during extrusion and thereby improving product texture and shelf life in an oven dryer before equilibrating for 30 minutes at room temperature.

2.4 Proximate analysis

The Association of Official Analytical Chemists (AOAC, 1990) methods were used to perform the proximate analysis of the composite and multigrain puffs for moisture (AOAC 925.40), crude protein (AOAC 984.13), crude fiber (AOAC 978.10), ash (AOAC 942.05), and fat (AOAC 963.15). The difference method was used to determine the amount of carbohydrates as follows: The weight remaining after removing the totals for water, protein, ash and fat was the total amount of carbohydrates.

2.5 Proximate analysis

Nitric acid (Merck, Gauteng, South Africa) was used to break down the sample for mineral analysis. A computer-controlled Atomic Absorption Spectrometer (AAS Model AA-6701F), made by Shimadzu in Japan, was used to determine the concentration of each mineral. Mineral content was reported in mg/100 g sample and every determination was made in triplicate. The listed minerals are sodium, calcium, magnesium, phosphorus, zinc and iron. They were chosen based on their public health nutritional importance especially in children under 5 years.

2.6 Anti-nutrient analysis

Anti-nutrient analysis was carried out because these impair the digestion and absorption of various nutrients such as proteins and minerals. A lower amount of antinutrients is desirable in food products.

Phytates

Phytates were measured using the procedure outlined by Lakshmi et al in 2014 [10]. Separately shaken in 2.4% HCl (Merck, Gauteng, South Africa) for three hours at room temperature were 0.5 g of the composite samples. About 0.5 ml of the supernatant was combined with 0.2 ml of $FeCl_3$ (Skylabs, Johannesburg, South Africa) 1N HCl (Merck, Gauteng, South Africa) and 0.5 mL of 2.4% HCl (Merck, Gauteng, South Africa). Then for 30 minutes, the tubes were incubated in a bath of boiling water. They were then moved to an ice bath until they warmed up to room temperature. Approximately 0.25 mL N/2, HCl (Merck, Gauteng, South Africa) 0.5 mL 10% KCNS (Sisco Research Laboratories, Maharashtra, India) and 2.5 mL N/6 HCl (Merck, Gauteng, South Africa) were added to 1 mL of supernatant. Using a spectrophotometer, the absorbance of the produced blood red color was measured at 540 nm (Biobase BK-D560, China). Phytate concentration was given as µg/kg.

Tannins

Tannins were determined using the method by Wani and Kumar [1]. Each of the three composite samples weighed (1g) into a beaker separately. To extract tannins, each sample was immersed in a solvent solution (80 mL of acetone (Merck, Gauteng, South Africa) and 20 ml of glacial acetic acid (Acechem, Johannesburg, South Africa) for five hours. The samples were run through a double layer of filter paper to acquire the filtrates, which were then kept for later use. Tannic acid (Fizmerk Research Chemicals, Hapur, India) was created as a standard solution in concentrations ranging from 10 ppm to 30 ppm. On a spectrophotometer, the absorbances of the standard solutions and the filtrates were measured at 500 nm. The concentration of tannins were expressed as mg/100g.

Total phenolic compounds

Total phenolic content was determined in the extracts by the method of Sihag et al. [11]. To 1.5 mL of freshly diluted (10-fold) Folin Cioculteau reagent (Fizmerk Research Chemicals, Hapur, India), 0.2 mL of extract was added. After letting the liquid sit for five minutes, 1.5 mL of sodium carbonate (Glassworld, Johannesburg, South Africa) (60 g /L) was added. The mixture was then incubated for 90 minutes in the dark, after which the absorbance was measured at 725 nm. Gallic acid (Nice Chemicals, Kerala, India) served as reference while acetone water (4:1, v /v) served as the blank. For each 1 g of material, the results were represented as mg gallic acid equivalent

2.7 Statistical analysis

All the data was acquired in duplicate. SPSS version 27 was used to analyze the data. Paired T tests were used to compare means (same samples before and after processing). $p \leq 0.05$ was used as the significance level.

3 Results

3.1 Effect of extrusion on proximate composition white sorghum, pearl millet and NUA45 bean blends

According to Table 1, there was a significant ($p < 0.05$) increase in carbohydrate content after extrusion for blend 1 (3.64%), blend 2 (8.41%) and blend 3 (10.5%). There was also an increase in fat content for blends 1 to 3, (17.61%; 38.7% and 19.49 %) respectively.

A significant decrease in protein content was observed after extrusion in all blends (8.24%; 19.78% and 20.18%) in comparison to raw composite samples. Extrusion of

Table 1. Proximate composition of multigrain (white sorghum, pearl millet and Nua45 beans) composite flour and their corresponding extrudates (% per dry matter)

	Treatment	Moisture	Ash	Crude protein	Crude fibre	Carbohydrate	Fat
Blend 1 (W5:P3:N2)	Raw composite	9.78 ± 0.06	2.08 ± 0.02	14.44 ± 0.003	1.71 ± 0.03	69.77 ± 0.3	2.22 ± 0
	Extrudate	8.75 ± 0.06	1.51 ± 0.06	13.34 ± 0.01	1.48 ± 0.09	72.31 ± 0.1	2.61 ± 0.01
	p-value	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
Blend 2 (W5:P2:N3)	Raw composite	9.67 ± 0.09	2.24 ± 0.01	16.63 ± 0.003	1.81 ± 0.03	67.92 ± 0.2	1.73 ± 0.03
	Extrudate	7.29 ± 0.03	2.09 ± 0.01	13.34 ± 0.01	1.25 ± 0.03	73.63 ± 0.1	2.4 ± 0.01
	p-value	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
Blend 3 (W5:P1:N4)	Raw composite	9.78 ± 0.03	2.3 ± 0.01	20.56 ± 0	2.22 ± 0.06	62.39 ± 0.3	2.75 ± 0.0
	Extrudate	9.73 ± 0.9	0.02 ± 0.00	16.41 ± 0.01	1.66 ± 0.06	68.92 ± 0.5	3.29 ± 0.01
	p-value	> 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05

key: W- white sorghum, P- pearl millet, N- nua45 beans; NB: Means significantly different ($p \leq 0.05$) by Paired T test

composite blends of white sorghum, pearl millet and NUA45 beans also resulted in a decrease in crude fiber content in all the blends tested (13.5%; 30.94% and 25.23%). More so, significant decreases in ash content after extrusion were observed (27.40%; 6.7% and 99.13%) when compared to the raw blends. Extrusion also resulted in significant reduction of moisture for blends 1 (10.53%) and 2 (24.61%) while causing no significant reduction in blend 3 (0.51%).

However, there was an increase in protein, crude fiber and fat after increasing dehulled NUA45 beans in all the blends.

3.2 Effect of extrusion on mineral composition of white sorghum, pearl millet and NUA45 beans blends

Iron content increased significantly ($p < 0.05$) after extrusion in blends 1 to 3 (28%; 86.71% and 53.5%) compared to their raw composites (Table 2). Zinc content also increased significantly ($p < 0.05$) after extrusion (50%; 18% and 27.6%) while the raw blends had lower contents. Extrusion also caused a significant increase in sodium content (20.21%; 50% and

Table 2. Mineral composition of multigrain (white sorghum, pearl millet and Nua45 beans) composite flour and their corresponding extrudates mg/100g)

	Sample	Fe	Zn	Mg	Na	Ca	P
Blend 1 (W5:P3:N2)	Raw composite	5.13 ± 0.1	1.73 ± 0.81	233 ± 8.82	127 ± 14.5	357 ± 13.01	320 ± 17.32
	Extrudate	6.57 ± 0.15	2.6 ± 0.12	240 ± 11.53	140 ± 8.82	190 ± 5.77	350 ± 5.77
	p-value	< 0.05	< 0.05	> 0.05	< 0.05	< 0.05	0.324
Blend 2 (W5:P2:N3)	Raw composite	4.07 ± 0.12	2.53 ± 0.12	257 ± 17.63	120 ± 11.55	365 ± 2.89	340 ± 5.77
	Extrudate	7.6 ± 0.12	2.13 ± 0.33	260 ± 11.53	180 ± 5.77	280 ± 5.77	360 ± 11.55
	p-value	< 0.05	< 0.05	0.92	< 0.05	< 0.05	0.074
Blend 3 (W5:P1:N4)	Raw composite	4.97 ± 0.15	2.25 ± 0.81	263 ± 3.33	153 ± 8.82	410 ± 5.77	370 ± 6.67
	Extrudate	7.63 ± 0.18	2.87 ± 0.33	310 ± 8.82	170 ± 5.77	290 ± 5.77	375 ± 8.82
	p-value	< 0.05	< 0.05	0.07	< 0.05	< 0.05	0.225

key: W- white sorghum, P- pearl millet, N- nua45 beans. NB: Means significantly different ($p \leq 0.05$) by Paired T test

11.11%) for blends 1 to 3. Calcium content decreased significantly after extrusion for all the blends (46.82%; 23.3% and 29.3%) compared to raw composite blends. No effect of extrusion was observed on magnesium and phosphorus contents.

3.3 Effect of extrusion on non-nutritional composition white sorghum, pearl millet and NUA45 beans blends

Extrusion was found (Table 3) to reduce significantly ($p < 0.05$) tannin content in blend 1, blend 2 and blend 3 (by 11.88, 72.3 and 79.63% respectively) compared to their corresponding raw samples. A significant decrease in phytates content was also observed in all blends (by 13.8% 48.5% and 87.33%) after extrusion. However, extrusion caused a significant increase in total phenolic compounds as shown in table 3 for blend 1 to blend 3 (by 827.91%, 493.21% and 173.9%).

making it an ideal for a shelf-stable product. If the percentage is higher than 14%, mould and bacterial will develop [13]. It follows from the findings that extrusion lowers moisture content [14]. Extrusion was found to reduce protein content from 11.96 to 11.46%, 13.20 to 12.81%, and 15.15 to 14.81% in a study that investigated the effects of extrusion in rice grain mixes [5]. This is comparable to the findings of this study, which were, for the respective blends 1, 2, and 3 (50:30:20, 50:20:30 and 50:10:40 respectively). The high temperature, short time (HTST) treatment during extrusion changes the product's nutrients' thermophysical properties. This is through the Maillard reaction, which occurs during the extrusion process, where the carbonyl group of the reducing sugar reacts with the amino group of the amino acid, producing N-substituted glycosylamine and water. carbohydrate and protein molecules [15, 16].

Carbohydrate content was found to increase significantly after extrusion in all blends 1, 2 and 3 (50:30:20, 50:20:30 and 50:10:40 respectively). This is primarily because of starch

Table 3. Non-nutritional composition of multigrain (white sorghum, pearl millet and Nua45 beans) composite flour and their corresponding extrudates

	Sample	Tannins g/100g	Phytates µg/kg	Total phenolic compounds mg GAE/100g
Blend 1 (W5:P3:N2)	Raw composite	6.82 ± 0.01	2.82±0.02	18.56±0.02
	Extrudate	6.01±0.01	2.43±0.02	172.22±0.02
	P value	<0.05	<0.05	<0.05
Blend 2 (W5:P2:N3)	Raw composite	7.82±0.02	3.01±0.01	24.38±0.01
	Extrudate	2.17±0.01	1.55±0.02	144.61±0.02
	P value	<0.05	<0.05	<0.05
Blend 3 (W5:P1:N4)	Raw composite	5.74±0.02	2.92±0.01	65.87±0.01
	Extrudate	1.17±0.01	0.37±0.01^a	180.44±0.01
	P value	<0.05	<0.05	<0.05

key: W- white sorghum, P- pearl millet, N- nua45 beans; GAE- Gallic Acid Equivalent; NB: Means significantly different ($p \le 0.05$) by Paired T test

4 Discussion

The proximate composition of composite mixtures of white sorghum, pearl millet, and NUA45 beans is shown in Table 1 for both raw and extruded forms. The resultant composite blends and multigrain puffs both had moisture contents below 10%. When comparing raw composite blends to multigrain puffs, there was a significant decrease. However, for blend 3, no significant decrease was observed. The amount of moisture significantly affects the shelf life of a food product. The water evaporation during extrusion cooking may be the cause of the considerable decrease in moisture content [12]. Low moisture content in particular, allows for shelf-stable storage and product viability for multigrain puffs, gelatinization and its digestibility is enhanced. Results similar to this study were also reported by Rashid et al. [17] from 68.92 to 71.63 in the extrusion of gluten-free flours based on chickpea and rice.

In addition, there was a significant increase in the fat content of the multigrain puffs compared to the raw composite flour blends. This result was different from that obtained by Saleh et al. [18] who observed a decrease in fat content of 7.17% and 11.75% for the blends used. The increases could result from some lipids being reduced during the intricate chemical mechanisms that take place during extrusion [19]. Another explanation for the elevated lipid level is that the temperatures prevented the development of any complexes with amylose or protein [20, 21]. Therefore, free unbound lipids are found in the product. More so, extrusion causes the inactivation of the hydrolytic enzymes such as lipase, lipoxygenase, and peroxidase. Their inactivation prevents rancidity, thereby enhancing the shelf life of the product.

Ash and crude fiber decreased significantly. This contradicts what was described by Pradeep et al. [22], that fiber increases upon extrusion. The decrease in crude fiber in this study might be attributed to an increase in low molecular weight soluble fiber. Results in this study were similar to those reported by Sedl [23], who observed a reduction from 1.15 to 1.08%. In another study, variations were observed with different extrusion conditions [17]. In terms of ash, in a study by Sundarrajan [24] no effect of ash content was noted. However, higher fiber and ash levels can be achieved by controlling extrusion conditions, such as temperatures, solid feed rate, and screw speed combinations [25].

Increasing the dehulled NUA45 bean flour in all formulations significantly increased the protein, carbohydrate, and fat contents while significantly decreasing ash, moisture and fiber contents when added at amounts of 20, 30, and 40% flour.

Iron and zinc increased significantly in this study. The extrusion process increases the availability of zinc and iron in extruded foods based on grains. This was reported by Albarracín et al. [5]. in a study to evaluate the effect of soaking and extrusion on whole brown rice. Iron content in their extrudates increased from 11.21 to 14.50 mg/100g, whereas zinc went from 11.46 to 14.60 mg/100g. Extrusion cooking results in products with various physicochemical properties and improved antioxidant activity. It also enables production of products with superior zinc and iron bioavailability [26]. Iron is essential for children's physical and mental development, good health as well as synthesis of adequate hemoglobin. For children from 6 months and older, the recommended nutritional consumption range for iron is 1.7 to 11 mg/day [27]. Zinc is essential for human health because it has critical structural and functional roles in systems that are involved in gene expression, cell division and growth and immunologic and reproductive functions therefore high but adequate levels are required as per life cycle stage. Its Recommended Daily Intake (RDI) is 5mg/day for children under 5 years. Therefore, 100 grams of the multigrain puffs are sufficient to satisfy an infant's RDI for zinc [28, 29].

In this study, sodium also increased significantly following extrusion for formulations 1 to 3 respectively. Research by Wani and Kumar [1]. to assess the impact of extrusion on snacks also revealed an increase, that is, from 5 – 11.9 mg/100g sodium and calcium from 30 to 39.7 mg/100g. Calcium however decreased in this study for formulations 1 to 3 respectively. Calcium is necessary for bone health and its RDI ranges 800 mg/day for children under 5 years [27]. Sodium is an essential nutrient in the regulation of blood pressure, fluid electrolyte and electrolyte balance as well as cellular homeostasis. Its RDI is 260mg/day for children under five [28]. However, low sodium levels are desirable as high intakes are associated with disorders of the circulatory system. The decrease in calcium in our study is similar to results from a study by Kumar et al. [30], in their study to evaluate the effect of extrusion on pearl millet-based flour. Their results were decreased from 345 mg/100g to 68.74, 94.3 and 120 mg/100g for composite with 10, 20 and 30% incorporated pearl millet flour. No effect of extrusion was noted on magnesium and phosphorus. Magnesium is useful for healthy bones, proper nervous system functioning and energy metabolism. Phosphorus is important for all tissues and cells for their growth, maintenance and repair, as well as for the synthesis of genetic material. The RDI for magnesium is at least 75mg/day for children from 6months of age, whereas that of phosphorus is 275 mg/day [27]. An investigation by Gulati and Rose [31] nevertheless, revealed an increase in magnesium and phosphorus, from 637 to 880.3mg/100g for magnesium and from 1917.8 to 2338.2 mg/ 100g for phosphorus. An increase in magnesium, phosphorus content after the extrusion of beans was also recorded by Tadesse et al. [32]. Minerals are important for the overall function of the biological systems in the human body, including growth and development [33].

It has been hypothesized that the increase in minerals during extrusion may result from both the minerals from the extruder barrel and the water used to equilibrate the food to be extruded [21]. More so, since extrusion causes phytates to be hydrolyzed at high temperatures, it was suggested that this phenomenon was the cause of the increased mineral availability such as phosphorus [34].

Phytic acid, tannic acid, etc., are anti-nutrients that commonly serve to reduce the nutritious quality of cereal-legume mixes. Anti-nutrients can form insoluble complexes with minerals such as zinc, iron, magnesium and calcium thereby reducing their absorption. This may cause severe mineral ion deficiency in humans [35]. In this study, extrusion resulted in a significant decrease in tannins and phytates concentration of the multigrain puffs, for blends 1, 2 and 3 (50:30:20, 50:20:30 and 50:10:40) respectively. This reduction is because the structure is weakened and broken into fractions of penta- and tetra-phosphate [24]. The results for tannin content are similar to those of Alam et al. [3]. The tannin content in their study dropped from 1677 mg/100 g in the raw blend to between 551 and 1093 mg/100 g in the extrudates, although the phytate amount (248 – 286 mg/100 g) was unaltered by extrusion. Ultimately, it was discovered that the anti-nutritional tannin from sesame meal could be significantly reduced using extrusion cooking technology. Tannin concentration and phytates also decreased when compared to the findings of this investigation.

Antioxidants are compounds that keep molecules from oxidizing, when they are present in foods that include fat. Most often, phenolic compounds are what give most foods their antioxidant action. In this study, the composites of white sorghum, pearl millet, and NUA45 beans were tested for their total phenolic content (expressed in milligram Gallic Acid Equivalent/100 grams -mg GAE/100g). The results revealed that the extrusion procedure significantly increased the total phenolic content of the multigrain puffs. An increase in phenolic content was also recorded for rice bran in a study by Ti et al. [36]. Through increased gelatinization of starch, denaturation of protein that binds these phytochemicals and dissolution of many complexes in which these compounds are embedded or entrapped, extrusion improves food matrix disruption and increases the bioavailability of total phenolic compounds [36]. Extrusion increases the quantity of total phenolic compounds that can be extracted, which can be used as a sign of improved bio-accessibility [21]. Furthermore, the creation of Maillard browning pigments can also serve as antioxidants. This is due to the production of melanoidin and Amadori rearrangement products [35]. Zhang et al. [37]. determined the total phenolic content of the extruded brown rice. The study found a considerable rise in total phenolic content. This is identical to the findings of this study, which were for formulations 1 to 3, respectively.

5 Conclusion

Extrusion enhances selected nutrient content while decreasing anti-nutrients. It can also be concluded that blending various ingredients can be explored to improve food's nutritional and non-nutritional quality. Based on the conducted research, formulation 2 (50: 20: 30%) white sorghum, pearl millet and NUA45 beans can be selected for snack production. The opportunity, therefore, exists for extruded multigrain and legume combination snacks to replace nutrient-poor single grain only snack foods.

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Authors' Contribution: A.R.A conceived and designed the study, undertook the literature research carried out the experiments, data acquisition statistical analysis, prepared drafted and reviewed the manuscript. L.K.N. conceptualized the study and reviewed the manuscript. P. C. conceptualized the study, reviewed the manuscript. All authors approved the final version before submission. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest: none to declare.

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