Potravinarstvo Slovak Journal of Food Sciences

Slovak Journal of Food Sciences

OPEN ACCESS

Received: 2.12.2023
Revised: 10.5.2024
Accepted: 2.6.2024
Published: 26.6.2024

Potravinarstvo Slovak Journal of Food Sciences
vol. 18, 2024, p. 633-653
https://doi.org/10.5219/1942
ISSN: 1337-0960 online
www.potravinarstvo.com

Development and quality cum nutritional assessment based on physical properties for corn extruded snacks enriched with protein and carbohydrates: A remedy to malnutrition for society

Muzammal Shafiq, Muhammad Waseem, Yaqoob Majeed, Muhammad Arslan Khalid, Tayyaba Nadeem, Maksim Rebezov, Mars Khairullin, Orynzhamal Sarsembenova

ABSTRACT

Malnutrition is one of the century's most pressing challenges. If malnutrition is not addressed early, people may suffer from non-communicable diseases. A proper, nutritious diet is necessary to overcome diseases like malnutrition. The technology like extrusion can develop rich fortified food products by retaining high nutrition content. In this study, extrusion technology was used to develop protein and carbohydrate snacks with proper nutrition based on the physical properties of commodities by combining different ratios of corn grits, apple pomace, and mung beans. The objectives of the study focused on the development of a food product based on engineering aspects and the quality cum nutritional evaluation of the finished product that can be used as a diet to combat malnutrition. Physical properties like color, rehydration ratio, porosity, bulk density, water solubility index, texture, sensory evaluation, hardness, and crispiness were studied in detail. The energy content of protein and carbohydrates was measured for nutritional assessment using Food Data Central as a standard, provided by the United States of America Department of Agriculture. Results reveal significant variations among treatments, with the addition of apple pomace impacting bulk density, water solubility index, and color attributes. Mung bean supplementation demonstrates a direct correlation with increased hardness and influences porosity. The rehydration ratio is positively affected by apple pomace. Sensory evaluation underscores the substantial impact on color, texture, crispiness, taste, and overall acceptability, providing valuable insights for snack formulation.

Keywords: extrusion, corn extruded snacks, malnutrition, extrudates, nutrient-enriched snacks

INTRODUCTION

The human diet has evolved from raw eating to processed foods **[1]**. Lack of access to healthy food results in one common and alarming condition called malnutrition. Among the young population, 22.1% suffer from mental disorders due to a lack of proper nutrients in the diet **[2]**. Proper nutrition intake helps decrease the effects of different diseases and prevent associated risks **[3]**. The body cannot regulate its functioning if nutrients are not supplied through a proper diet **[4]**. For adults, healthy food includes at least 400 g of fruits and vegetables, less than 10% intake of free sugar, and 30% intake of fats in a whole diet per day **[5]**. Protein, vitamins, carbohydrates, fats, minerals, and water are 6 essential nutrients. All dietary carbohydrates, and insoluble dietary fiber are considered as non-essential nutrients.

Malnutrition is a nutrition disorder that refers to deficits, excess, or imbalanced nutritional intake in a person's diet **[6]**. In both undernutrition and overnutrition, protein deficiency occurs along with other essential micronutrients such as iron, vitamins B6, B12, C, D, and calcium **[7]**. Malnutrition is a global concern. In developed countries, the excess intake of diet deficit in protein leads to obesity, whereas, developing countries are struggling with widespread micronutrient deficiencies that cause problems of maternal undernutrition, child stunting, and wasting **[8]**. The main causes of malnutrition in developing countries are due to poverty, low income, large family size, poor hygiene conditions, and food insecurity **[9]**. These bases of malnutrition result in stunted adults and increased risks of NCDs with the ultimate result of increased morbidity and mortality **[10]**. Essential nutrients are inevitable in the diet to overcome malnutrition. Among six, two are the most important i.e., protein and carbohydrates.

Protein is an essential macronutrient for the prevention of malnutrition. The deficiency of protein leads to acute malnutrition, a condition that specifically occurs due to low protein consumption. Jelliffe replaced the term "acute malnutrition" with "protein-calorie malnutrition" in 1959 **[11]**. European adults are at risk of protein-calorie malnutrition among 23% of the total population **[12]** and the United States of America adults have 2-3% of poor indication according to the Healthy Eating Index (HEI) **[13]**. Protein calorie malnutrition is the cause of one-third of mortalities among children under 5 years and those who survive that disease are at risk of intellectual or cognitive impairment **[14]**. Infants are at high risk of malnutrition due to low consumption of essential nutrients. For newborn children, 5g of protein intake per day is required to overcome the nutrient deficiency **[15]**. For older adults, 35 g of a healthy protein meal is necessary per day to prevent the risk of protein-calorie malnutrition **[16]**.

Carbohydrates are the second most vital essential macronutrient for the proper body growth. Since the start of the 21st century, low intake of carbohydrates in the diet has been trending for weight loss in adults. This low intake results in poor growth and improper functioning of organs which makes it a high risk of different diseases including malnutrition. The amount of energy that carbohydrate has in foods is usually 4 kcal/g **[17]**. To overcome the carbohydrate deficiency <10% i.e., a 20-25 g/day diet is necessary for infants, 130 g/day for toddlers, and 250-300 g/day for adults **[18]**. Carbohydrates that have plant-based origin consist of fibers. The risk of certain diseases like cancer, obesity, and diabetes can be reduced by consuming a fiber-rich diet **[19]**. Highly rich fiber diets are good for health, such as grains, nuts, fruits, and vegetables because their effects are associated with a lower incidence of various diseases. Fiber can be used (women with 9.6 g/day and men with 10.3 g/day) in various functional foods, such as baked goods, beverages, and meat **[20]**.

The rush in economic development around the globe is a major concern for food security which relates to malnutrition, as for processed food, the waste is increasing due to the use of destructive technologies implemented during operating procedures. This waste directly relates to food security **[21]**. The growth of the world's population is an alarming concern. To increase the production of foods, researchers and scientists are working to introduce new varieties of different foods to overcome the issues of food insecurity. To ensure food security, reliable and inexpensive sources are needed, which will help to reduce malnutrition risks. The food commodities enriched with protein, carbohydrates, and other essential nutrients readily available for people can be processed to get proper nutritional value. The lack of complete nutritional values from a single food source prompted researchers around the globe to explore different processing techniques to produce nutrient-rich products. To fulfill that purpose, it is inevitable to process a combination of more than one nutritious food commodity to get a healthy, balanced, and complete nutrient-enriched diet. Numerous technologies have the potential for the processing of foods to improve nutritional density, nutrient bioavailability, food safety, and storage stability. Processed food can be prepared by using these technologies, like roasting, fermentation, germination, grinding, spraying, baking, drying, and extrusion **[22]**. Extrusion is a productive procedure in the sense of remedy for malnutrition. Many food-derived by-products contain potential nutrient content such as pomace, oil seed, grits, peels, etc. which can be processed for value-addition purposes. Extrusion technology has the high potential to utilize these by-products' nutrients and get nutrient-rich extruded snacks **[23]**. Extrusion is a standard food manufacturing method that involves mixing, shaping, texturing, and heating to create a unique food product. It is a modern food processing technology used to create various snacks and supplemental meals. It can help to efficiently utilize the by-products (i.e., corn grits and apple pomace, etc.) to convert them into highly nutritious snacks that have a high melting temperature, enhanced physical appearance, reduced bulk density, and crispiness **[24]**. Using maximum screw speed during extrusion operation for apple pomace results in high bulk density and starch degradation, lower expansion ratio, porosity, and moisture **[25]**. The (HTST) high-temperature short-time extrusion process made it novel from other technologies as it ensures product safety with maximum nutrient retention **[26]**. Extrusion technology's flexibility enables the creation of nutritionally dense extruded foods using diverse raw materials and serves as a mechanism for value addition. Extruded commodities have a low moisture content, a longer shelf life, and resistance to microbial activity. Additionally, many methods exist to create value-added and fortified extruded products by combining various raw ingredients **[27]**. It's a food-processing technology that employs a single or more screws to shove raw & mixed food ingredients through a narrow opening. Extrusion cooking in HTST, combined with pressure, temperature, and shear force to obtain the starch and protein from the raw products, is used widely. This technology's adaptability allows the manufacturer of rich fortified foods and value-added products to use various low-cost raw ingredients. Nutritional food is unavailable for everyone by using expensive raw materials with irrelevant and old-fashioned processing operations and technologies. Extrusion is just a very flexible device procedure that can be placed on several delicacy steps. The product's versatility along with high quality with new food productivity and low processing time allows us to meet the demand for enriched products for remedy against malnutrition. Loss of nutritional quality occurs at unstable temperatures; therefore, technology like extrusion, which operates at high temperatures, is used for this research. Food processed from the extruders is rich in dietary fibers and antioxidants **[28]**.

Carbohydrate and protein-enriched snacks prepared with different commodities like chickpeas and sour gum lack nutritional value. Researchers have prepared these snacks and are being used just as a general diet **[29]**. Extruded snacks evaluated on a physical basis like adhesiveness and factorability are suggested by researchers for improvements **[30]**. In other previous literature, Zhang and Liu **[31]** consider only the temperature and moisture content as decisive factors for the physical properties of snacks. Cueto et al. **[32]** consider expansion rate and density for physical attributes of snacks, and Jozinović et al. **[33]** state expansion ratio, bulk density, and water solubility index solely as parameters. The use of nutrients according to body need which has the potential to overcome malnutrition based on engineering cum nutritional assessment, has not been addressed yet. The primary goal of this study is to develop snack products by combining food commodities in specific ratios using extrusion technology by keeping in mind the physical properties and making a comprehensive quality assessment that has proper nutritional value, which will help communities overcome malnutrition by consuming it with low processing cost and by using raw material that is readily available with high protein and other nutrients. These prepared snacks have been evaluated based on daily energy requirements in a diet compared to food data central as standard, provided by the United States Department of Agriculture. The essential nutrient availability and energy content with a specific ratio of commodities give a solution to malnutrition. Our research focused on the apparent ratio mix expertise of perfect diet ingredients to use them effectively to develop a healthy product. The main objective of our research was to develop corn-based extrudates, fortified with fibre cum carbohydrate and proteins, and to evaluate the quality characteristics and energy content of prepared extrudates that have a standard nutritional value which will help children to meet the demand of nutrition to get rid of malnutrition.

Scientific Hypothesis

Adding supplements, apple pomace, and mung bean significantly enhances the physical properties and increases the nutritional value of the engineered food product. Using different ratios of supplements, we expect to get the best of these two parameters, i.e., physical properties and nutritional value.

MATERIAL AND METHODOLOGY

Samples

The research was performed at the extrusion laboratory of the Department of Food Engineering, University of Agriculture, Faisalabad. Apple pomace, mung bean, and corn grits were used as raw commodities because of their high nutritional values and easy availability in commercial markets worldwide. Combining these three commodities with the best nutritional value can potentially be used as a remedy for malnutrition.

Apple pomace: Apple (*Malus Sylvestris*) belongs to the *Rosacea* family and is the fourth highest produced in the fruits market globally after red grapes and bananas **[34]**. It contains a balanced ratio of phytochemical soluble and insoluble solids **[35]**. Juicing operations are done to obtain pomaces from the apples. Apple pomace is a nutritious food ingredient **[36]**. It contains protein, fat, ash, and phenolic content **[37]**. Pomace from apples is the main by-product of juice extraction. It contains 6.8% cellulose, 5.3% proteins, 0.38% ash, 3.6% sugars, and 0.42% acid **[38]**. Total carbohydrate is 44.5-57.4%, Simple carbohydrates such as fructose and glucose make 44% and 18.1-18.3% mass of pomace respectively. Total fiber, insoluble fiber, and soluble fiber constitute 4.4-47%, 33.8-60%, and 13.5-14.6% respectively **[39]**.

Mung bean: Beans are a good source of protein. Worldwide, it is called green gram and golden gram. Its seeds contain 24.3% protein and 0.67% fats **[40]**. Mung bean (*Vigna radiate* (L.)) belongs to legumes, been processed for more than 2,000 years in the world **[41]**. Amino acid composition in mung bean protein isolate has the highest efficiency of (73.25%) i.e., 0.5 g/ml, pH 9.0 **[42]**. Mung beans comprise protein, fiber, minerals, vitamins, and biologically active compounds and are considered functional food **[43]**. The macronutrient composition of mung bean consists of moisture 9.80 (g/100g), crude protein 23.8 (g/100g dm), crude lipid 1.22 (g/100g dm), crude fiber 4.57 (g/100g dm), ash 3.51(g/100g dm), carbohydrate 61.0 (g/100g dm), energy 344 (Kcal/100g dm) **[44]**.

Corn grits: Corn grits are the fundamental snacks that help them gain specific size, shape, and texture after extrusion. Corn grits are endosperm particles **[45]** low in fiber content and have about 1% oil **[46]**. Corn grits are inevitable for snack extrudates and fortified with other nutrients that can meet the demand of the nutritional status of the body **[33]**. The nutritional value of corn comprises 9% protein, 0.37% potassium, 0.29% phosphorus, 0.11% magnesium, 50% iron, and 21% zinc **[47]**.

The potential availability of nutrients in these readily available commodities made it possible to use them as inexpensive snack products to fulfill the nutritional needs of children.

Chemicals

All chemical reagents were of analytical grade and utilized as per described standards. Glass Beads: Used as a displacement moderator for volumetric displacement methodology (diameter of 1 mm) En1423 Origin China.

Animals, Plants and Biological Materials

Apple (*Malus Sylvestris*) has 6.8% cellulose, 5.3% proteins, 0.38% ash, 3.6% sugars, and 0.42% acid. Mung bean (*Vigna radiate* (L.)) with moisture 9.80 (g/100g), crude protein 23.8 (g/100g dm), crude lipid 1.22 (g/100g dm), crude fiber 4.57 (g/100g dm). Corn grits with 9% protein, 0.37% potassium, 0.29% phosphorus, and 0.11% magnesium.

Instruments

Lab scale twin screw extruder having a 3 mm diameter of die with 102 rpm was used to get extrudate by using different concentrations of apple pomace, mung bean, and corn grits. The steady pumping mechanism in the twin screw extruder comprises to generate high die pressure by using a motor having 2.5 kW power. A mixed sample with a specific mixing ratio (Table 1) was placed into an extruder hopper, which passed to the barrel that cooked the raw material under pressure and shear at high temperature, The mass was forced through a die and cut into individual pieces of particular shapes and collected into food grade stainless steel bin. After extrusion processing, extrudates were cooled at 20 to 22 ℃ (room temperature) and sealed into bags for further analysis. The chosen ratios (as outlined in Table 1) were designed to investigate the impact of varying proportions of apple pomace and mung bean on extruded snacks' physical and sensory attributes. The aim was to cover a spectrum that included formulations with no supplementation (T1), different levels of apple pomace enrichment (T2 and T3), various concentrations of mung bean (T4 and T5), and combinations of both supplements (T6, T7, and T8). This comprehensive approach allows for a nuanced understanding of how these specific ingredients and their concentrations contribute to the overall characteristics of the extrudates, providing valuable insights for potential applications in the development of nutritious and appealing snack products.

Laboratory Methods

Apples were purchased from the market in August and September 2020 when they were firm, mature, and fully grown and stored at 4 ℃ until processed. Mung bean and corn grits were stored at room temperature in a clean environment. Mung bean and Corn grits were cleaned to remove dust, straws, small stones, and any other contaminated materials. After cleaning Mung bean and corn grits were ground to obtain fine flour and packed in sealed polythene bags (Figure 1)for further analysis. Apples were placed in the stainless-steel plates after washing and rested for 30 minutes for surface drying. The simple knife was used to cut each apple into six equal pieces, then processed in a lab juicer to collect apple pomace as described below (Figure 2). A hot air oven was used for drying apple pomace at 70 ℃ for 940 minutes until complete drying. The powder was prepared by crushing and mixing the mung beans (Figure 3) and dry matter of apple pomace. To get uniform size, powder was passed through a sieve of 80 mesh sizes. The rationale behind the drying temperature and duration, as well as the grinding parameters, lies in preserving the nutritional content of the raw commodities. The selected parameters were optimized to achieve thorough drying without compromising the quality of the apple pomace and to attain a fine and uniform powder from mung beans and corn grits. Standardized procedures, including sieving, further contributed to the homogeneity of the final powder product.

Figure 1 Packing of corn grits, apple pomace, and mung bean powders respectively.

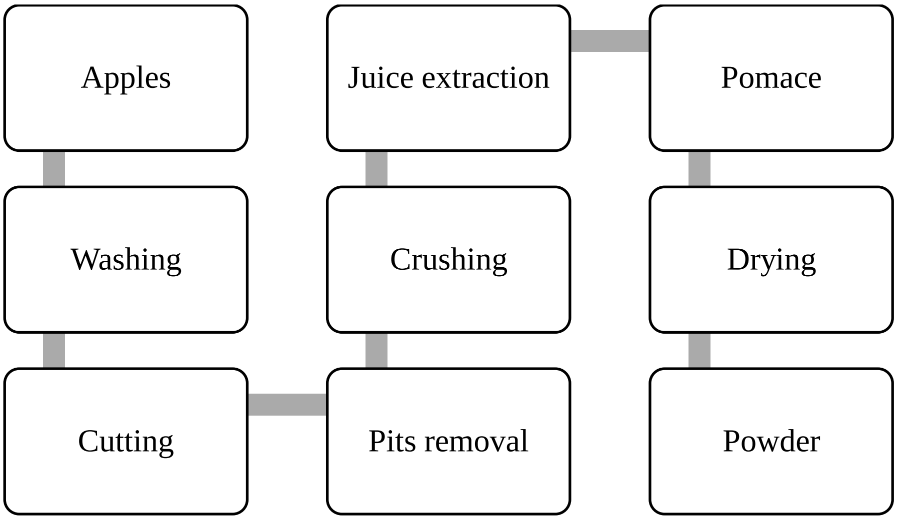

Figure 2 Process flow chart for extracting powder from apples.

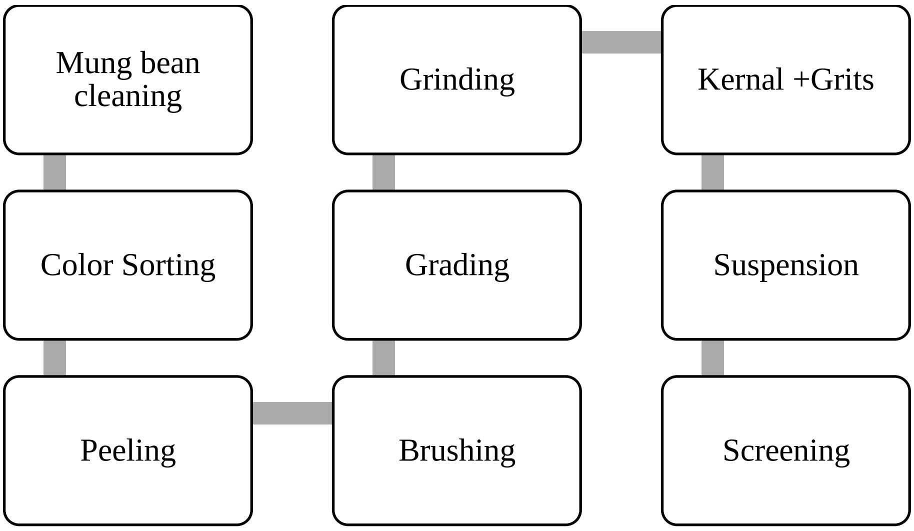

Figure 3 Process flow chart for extracting powder from mung beans.

Description of the Experiment

Sample preparation: A mixed sample with a specific mixing ratio (Table 1) was placed into an extruder hopper which passed to the barrel that cooked the raw material under pressure and shear at high temperature, then mass was forced through a die, and cut into individual pieces of particular shapes and collected into food grade stainless steel bin. After extrusion processing, extrudates were cooled at 20 to 22 °C (room temperature) and sealed into bags for further analysis.

Number of samples analyzed: 8.

Number of repeated analyses: 3.

Number of experiment replication: 3.

Design of the experiment:

Table 1 Mixing ratios of mung bean, apple pomace, and corn grits.

Treatment	Mung bean (%)	Apple pomace (%)	Corn grits (%)
T_1	0	0	100
T_2	0	10	90
T_3	0	20	80
T_4	10	0	90
T_5	20	0	80
T_6	15	5	80
T_7	5	15	80
T_8	10	10	80

Color: The color results were determined in accordance with the methodology mentioned by Lara. et al., (2011) with a colorimeter (Color Test-II Neuhaus Neotec). Tone principles as "L*" (lightness), "a*" (–a greenness; +a inflammation), and "b*" (–b blueness; +b yellowness) were recorded by puffed treats. The outcome results were used to determine hue directions and chroma **[48]**. The white tile control was used under constant light conditions to tape record the specifications i.e., (L* 97.46, a* 0.02, b* 1.72).

Bulk Density: The volumetric displacement methodology outlined by **[49]** was used to determine the bulk density (g/cm^3) of extrudates. Glass beans were utilized as displacement moderators through a diameter of 1 mm. Extrudate density was calculated as (1):

$$\text{Bulk density} = \frac{W_{ex}(\mathrm{g})}{\mathrm{Vc}\ (cm^3)\times(1-\frac{W_{gbd}(g)}{W_{gb}(g)})} \tag{1}$$

Rehydration Ratio: RR (rehydration ratio) was determined following a treatment explained by **[50]**. The extrudate was sliced into 30-mm lengths (M1) with an average weight of 18g and placed in 500 ml of liquid at 30 °C for 10 to 15 minutes. The water was evaporated, and the hydrated trials were weighed (M2). RR was defined as follows (2):

$$\text{Rehydration ratio } = \frac{M2-M1}{M1}\times 100 \tag{2}$$

Porosity: Bulk and apparent volume are used to calculate the porosity of extrudates using the methodology defined by **[51]** by the following equation (3):

$$\text{Porosity } = \frac{\text{Bulk volume} - \text{Apparent volume}}{\text{Bulk volume}} \tag{3}$$

Where:
B.V. = (1/ρb) and A.V. = (1/ρs).

Texture: Extrudate texture was determined by the method outlined by **[52]** the structure analyzer (Mod. TA-XT2 steady Microsystems, Surrey, UK). Extrudates were tested using the Texture Expert Program Version 1.21. A three-aim fold ridge is used to make texture assessments. Extrudates were twisted to determine textural characteristics. For curve examination, products were positioned in the center of a heavy-weight dish design. Before each test, the cellular strain and probe were both calibrated. Fold analysis was used to describe items' hardness and fracture potential by displaying energy (grams) vs range (mm). The weight (grams) was used for flex examination to test firmness and fracture ability. A texture analyzer was used to measure hardness and crispiness (TA-XT Plus, Stable Microsystems, UK) through the method described by **[28]**.

Water Solubility Index: Extrudate powder was sieved to ensure a uniform size distribution of 1.5 g and suspended in 10 ml of water for 15 minutes at room temperature with constant stirring, then centrifuged for 15 minutes at 3000 rpm. For uniform size distribution, extrudates were crushed to powder and sieved using a 60-mesh size. Crushed powder (2.5 g) was suspended in 25 ml water for 30 minutes at room temperature, with intermediate stirring, and then centrifuged for 15 minutes at 3000 rpm. To obtain dry solids, the supernatant was poured into a vanishing dish and water was dissipated until a steady weight was achieved. The WSI measured the amount of dry solids in the supernatant and expressed it as a percentage.

Sensory Evaluation: The method of sensory evaluation of extrudates was used as described by **[53]**. In a sensory evaluation laboratory of food engineering, a group of ten judges (students and faculty) evaluated the extrudates for color, crispiness, taste, texture, and overall acceptability on a 9-point hedonic scale **[54]** ranging from 1 to 9. Panelists washed their mouths with water before testing each sample. The faculty members are well trained and have certifications regarding quality and sensory evaluation from the Government of Pakistan under the organization Punjab Food Authority. The students selected in the panel are particular alumnus of the very institute and working in FMCG industries. The use of a 9-point hedonic scale is a well-established method in sensory science, allowing for a nuanced and detailed assessment of consumer preferences. The 9-point scale offers a higher resolution compared to scales with fewer response points, enabling more precise discrimination between product attributes and facilitating a more comprehensive understanding of consumer preferences.

Statistical Analysis

The obtained triplicate data was subjected to the Tukey test **[55]** to get variance analysis of mean values for each parameter to check the level of significance among different treatments, statistical analysis was performed using Statistics 8.1 (USA). The choice of the Tukey test for statistical analysis in this study was driven by its suitability for multiple comparisons, specifically designed to identify significant differences between treatment means efficiently. Given that the study involves multiple treatments with various concentrations of apple pomace, mung bean, and corn grits, the Tukey test provides a robust approach to compare the means of all treatments while controlling the experiment-wise error rate. Its ability to handle multiple pairwise comparisons without inflating the overall Type I error rate makes it well-suited for exploring differences in physical and sensory attributes across the diverse set of treatments. The assurance of normality and homoscedasticity in the data, crucial assumptions for the application of parametric statistical tests like Tukey, typically involves preliminary analyses.

RESULTS AND DISCUSSION

The objective of the current research work was to prepare fiber- and protein-enriched extrudates using the physical properties of commodities, their quality, and nutritional assessment. To increase the protein contents, mung beans were used, while apple pomace was used as a dietary fiber-rich source. Prepared extrudates were analyzed for color, rehydration ratio, and porosity. These extrudates were also analyzed for bulk density, water solubility index, texture, and sensory assessment. The results are presented and discussed as under.

Physical properties analysis of extruded snacks

The physical properties of fortified snacks were evaluated, including color, bulk density, rehydration ratio, porosity, texture (hardness), and water solubility index. As shown in the tables, the mean results of the treatments indicated significant differences among treatments.

The eight treatments comprise the following ratios in grams. T1 extrudate was prepared with no supplementation, T2 has 10g/100g apple pomace, T3 has 20g/100g, T4 has 10g/100g mung beans, T5 has 20g/100g mung beans, T6 has 5g/100g apple pomace and 15g/100g mung beans, T7 has 15g/100g apple pomace and 5g/100g mung beans, T8 has 10g/100g apple pomace and 10g/100 mung beans.

Bulk density: Table 2 shows the mean values for bulk density of extruded snacks enriched with apple pomace and mung bean. The results for bulk density revealed that extruded snacks with treatment T1 recorded the lowest value of bulk density i.e., 0.033. At the same time, T3 showed the highest bulk density value at 0.143. The fortified snacks T2, T4, T5, T6, T7, and T8 were observed with bulk density values of 0.063, 0.053, 0.043, 0.073, 0.083, and 0.093 respectively. The statistical analysis showed a significant difference among treatments. The bulk density of extrudates increased significantly due to adding apple pomace. The observations are supported by the findings of **[56]** those who reported that the bulk density of extrudates increases with the addition of grape pomace **[32]** suggesting no change in bulk density with the addition of supplement whereas the addition of two supplements shows significance in treatment 3. An increase in bulk density is an indicator of an increase in weight which directly enhances the texture and nutrition of snacks.

Figure 4 Extruded snacks with all eight treatments.

Water solubility index of extrudates: Table 2 shows the mean values for the water solubility index (WSI) of extruded snacks enriched with apple pomace and mung bean. The results for WSI revealed that extruded snacks with treatment T1 were recorded with a maximum value of 48. Meanwhile, the snacks with treatment T7 showed a minimum value of 37 for WSI. The fortified snacks T2, T3, T4, T5, T6, and T8 were observed with water solubility indexes of 46, 47, 46, 42, 47, and 46 respectively. The statistical analysis showed the T3, T6 and T4, T8 are non-significant. The water solubility index drops as apple pomace and mung bean concentrations rise. The Stickiness of extruded items is proportional to the water solubility index. Therefore, snacks without any supplements have a high stickiness. As a result, T1 has the highest water solubility index. These observations were also found by **[57]**.

Texture of snacks (Hardness): Table 2 shows the mean values for extruded snacks enriched with apple pomace and mung bean texture. The results revealed that extruded snacks with treatment T2 had a minimum hardness value of 2.4. Meanwhile, the snacks with treatment T5 recorded the maximum hardness value, which is 5.87. The fortified snacks having treatments T1, T3, T4, T6, T7, and T8 were recorded with hardness values of 2.87, 3.68, 3.83, 4.13, 2.84, and 3.26 respectively. The statistical analysis showed that T2, T5, and T6 are significant. These findings revealed that when the percentage of mung bean in a snack increased, the hardness of the snack increased. The addition of supplements is directly proportional to the texture of snacks. These results correspond to that of **[58]**, who reported that as the percentage of grape pomace in snacks increased, the hardness of the snacks increased.

Porosity: Table 2 shows the mean values for porosity of extruded snacks enriched with apple pomace and mung bean. The results revealed that extruded snacks with treatment T3 were observed to have the highest porosity value of 0.80. Meanwhile, the snacks that were treated with T1 showed the lowest porosity value, 0.56. The fortified snacks T2, T4, T5, T6, T7, and T8 were observed with porosity values of 0.76, 0.58, 0.6, 0.70, 0.66, and 0.72 respectively. The statistical analysis showed that T1 and T3 are significant. Porosity increased as the percentage of apple pomace increased. By the addition of supplements, porosity increased which is inversely proportional to the water solubility index, which was decreased by the addition of a supplement. Hence, the decrease of water solubility index and increase in porosity help children easily digest the snacks. These results follow the findings of **[59]**, who stated that porosity increases as grapes pomace increases, whereas **[32]** suggested no change in porosity by increasing supplement.

Rehydration Ratio: Table 2 shows the mean values for extruded snacks enriched with apple pomace and mung bean rehydration ratio. The results revealed that extruded snacks T1 was observed with the lowest value of rehydration ratio of 57.81. Meanwhile, the snacks T2 showed the highest rehydration ratio value, 77.82. The fortified snacks T2, T4, T5, T6, T7, and T8 were observed with rehydration values of 68.04, 62.05, 70.76, 62.11, 65.23, and 63.39, respectively. The statistical analysis showed a significant difference among treatments, $p < 0.05$.

Color analysis of extruded snack: Color is a key factor in determining whether or not a product will be accepted by consumers. The table revealed the results of a variance of color analysis of snacks, which indicated that color attributes for extruded snacks had a significant impact on the treatments.

L* value: The mean for L* value of extruded snacks as in Table 2 showed the lowest value of 39.81 for the snacks T2. Corn snacks T1 showed the highest value of 62.26. Snacks with treatment T2, T4, T5, T6, T7 and T8 showed 47.79, 56.79, 55.93, 55.97, 46.21 and 48.61 values respectively. As the amount of apple pomace is added, the L* value of extruded snacks decreases.

a* value: The mean for a* value of all treatments is in Table 2. The results showed the lowest value for the snacks prepared without supplementation T1 i.e., 4.01. Corn snacks T3 showed the highest value of 13.69. Snacks T2, T4, T5, T6, T7, and T8 had 13.17, 5.38, 6.39, 10.6, 12.97, and 11.86 values respectively. The statistical analysis showed that T2, T3, and T7 are non-significant. The addition of apple pomace and mung bean increased the a* value of extruded snacks.

b* value: The mean for b* value of all treatments is in Table 2. The results showed the lowest value for the snacks prepared without supplementation T1 i.e., 19.26. Corn snacks T2, T4, T5, T6, T7, and T8 had 22.82, 19.66, 20.06, 21.93, 24.76 and 23.68 values respectively. Snacks with treatment T2 showed the highest value of 28.24. The statistical analysis showed the T3, T8, and T4, T5 are non-significant to each other. The b* value of extruded snacks gradually increased as apple pomace and mung bean were added. The findings of **[56]**, determined that as the amount of grape pomace increased, the L* value decreased and the a* and b* values increased.

Sensory evaluation

For extruded snacks, a nine-point hedonic scale **[54]** was used for evaluating the sensory characteristics i.e. color, texture, crispiness, taste, and overall acceptability.

Color: The color of a product is the first impression that a customer has while deciding whether to acquire it. Mean values for the color of extruded snacks fortified with apple pomace and mung bean are presented in Table 3 which describes how the supplementation of apple pomace and mung bean in extruded snacks has significantly changed the color score of snacks. Corn snacks T1 were liked more as compared to the other snacks with a score of 8 because of their good appearance and similarities with corn snacks commercially available. The color score of other treatments T2, T3, T5, T6, T7, and T8 were 5.5, 5, 7, 6.5, 5.25, and 6 respectively. As the amount of apple pomace increased, the color score decreased. The statistical analysis showed the significance among treatments. This was due to the color of corn snacks fading as the degree of supplementation was increased. A study showed that muffin color decreased with supplementation of apple pomace **[60]**.

Texture: The hardness and softness of extruded snacks are described by the texture parameter. The mean value for the texture of extruded snacks is presented in Table 3 which describes the supplementation of apple pomace and mung bean in extruded snacks has significantly changed the texture score of snacks. The results revealed that snacks T5 were most liked with a score of 8. However, snacks T3 were less liked by the panelists with the lowest value 5. Snack scores of other T1, T2, T4, T6, T7, and T8 were 6.75, 5.53, 7.5, 7, 6, and 6.5 respectively. A study showed that texture likeness decreases in snacks by increasing the apple pomace **[61]**.

Crispiness: Crispiness is described as the crunchiness sensation of snacks. The mean value for the texture of extruded snacks is presented in Table 3 which describes the supplementation of apple pomace and mung bean in extruded snacks has significantly changed the texture score of snacks. The results revealed that snacks T3 were most liked with a score of 8. The lowest value 5 was observed in snacks T1. The mean value of all other treatments T2, T4, T5, T6, T7, T8, are 7.5, 5.5, 6, 5.75, 7, and 6.5 respectively.

Taste: Snack quality and acceptance are strongly influenced by taste. Mean values for taste of extruded snacks are presented in Table 3 which described the supplementation of apple pomace and mung bean in extruded snacks has significantly changed the taste score of snacks. The results revealed that snacks T5 were most liked with a score of 8. Snacks T3 were observed with the lowest value 5. The mean values of all other treatments T1, T2, T4, T6, T7, and T8 were 7, 5.5, 7.5, 6.75, 6, and 6.5 respectively. Increased mung bean supplementation increased the taste of extruded snacks. This could be due to the taste of mung bean, which is popular in Asia.

Overall acceptability: Mean values for taste of extruded snacks are presented in Table 3 which describes the significant relationship between them. The results showed that with treatment T5 was most liked with a score of 8. The lowest value 5 was observed in snack T3. The mean values of all other treatments T1, T2, T4, T6, T7, and T8 are 6.5, 5.5, 7.5, 7, 7.25, and 7.75 respectively **[33]** suggested not to incorporate supplement i.e., spelled flour while extrusion whereas in current study two supplement added to enhance physical as well as nutritional attributes of snacks.

The graphical illustration of the physical properties of snacks (Table 2) and sensory evaluation (Table 3) is shown in Figure 5 and Figure 6 respectively.

Table 2 Effects of treatments on different parameters of physical properties of extruded snacks.

		Treatment 1	Treatment 2	Treatment 3	Treatment 4	Treatment 5	Treatment 6	Treatment 7	Treatment 8
Bulk Density		0.03^{h}	0.06^{e}	0.14^{a}	0.05^{f}	0.04^{g}	0.07^{d}	0.08^{c}	0.09^{b}
Water Solubility Index		48.0^{a}	46.0^{c}	47.0^{b}	46.0^{c}	42.0^{d}	47.0^{b}	37.0^{e}	46.0^{c}
Texture		2.87^{de}	2.40^{e}	3.68^{bcd}	3.83^{bc}	5.87^{a}	4.13^{b}	2.84^{de}	3.26^{cde}
Porosity		0.56^{e}	0.76^{ab}	0.80^{a}	0.58^{de}	0.60^{de}	0.70^{bc}	0.66^{cd}	0.72^{abc}
Rehydration Ratio		57.8^{e}	77.8^{a}	68.0^{c}	70.7^{b}	62.0^{d}	62.1^{d}	61.9^{d}	58.3^{e}
Color	**L* Value**	62.2^{a}	47.7^{d}	39.8^{f}	56.7^{b}	55.9^{c}	55.9^{bc}	46.2^{e}	48.6^{d}
	a* Value	4.01^{f}	13.1^{a}	13.6^{a}	5.38^{e}	6.39^{d}	10.6^{c}	12.9^{a}	11.8^{b}
	b* Value	19.26^{e}	28.2^{a}	22.8^{c}	19.6^{e}	20.0^{e}	21.9^{d}	24.7^{b}	23.6^{c}

Note: Mean values having the same alphabetic letters are statistically non-significant ($p > 0.05$).

Table 3 Effects of treatments on different parameters of sensory evaluation.

	Treatment 1	Treatment 2	Treatment 3	Treatment 4	Treatment 5	Treatment 6	Treatment 7	Treatment 8
Color	8.00^{a}	5.50^{f}	5.00^{h}	7.50^{b}	7.00^{c}	6.50^{d}	5.25^{g}	6.00^{e}
Texture	6.75^{d}	5.53^{g}	5.00^{h}	7.50^{b}	8.00^{a}	7.00^{c}	6.00^{f}	6.50^{e}
Crispiness	5.00^{h}	7.50^{b}	8.00^{a}	5.50^{g}	6.00^{e}	5.75^{f}	7.00^{c}	6.50^{d}
Taste	7.00^{c}	5.50^{g}	5.00^{h}	7.50^{b}	8.00^{a}	6.75^{d}	6.00^{f}	6.50^{e}
Overall acceptability	6.50^{f}	5.50^{g}	5.00^{h}	7.50^{c}	8.00^{a}	7.00^{e}	7.25^{d}	7.75^{b}

Note: Mean values having the same alphabetic letters are statistically non-significant ($p > 0.05$). T_1 = 100% Corn grits; T_2= 90% corn grits + 10% apple pomace; T_3= 80% corn grits + 20% apple pomace; T_4= 90% corn grits + 10% mung bean; T_5= 80% corn grits + 20% mung bean; T_6= 80% corn grits + 5% apple pomace + 15% mung bean; T_7= 80% corn grits + 15% apple pomace + 5% mung bean; T_8= 80% corn grits + 10% apple pomace + 10% mung bean.

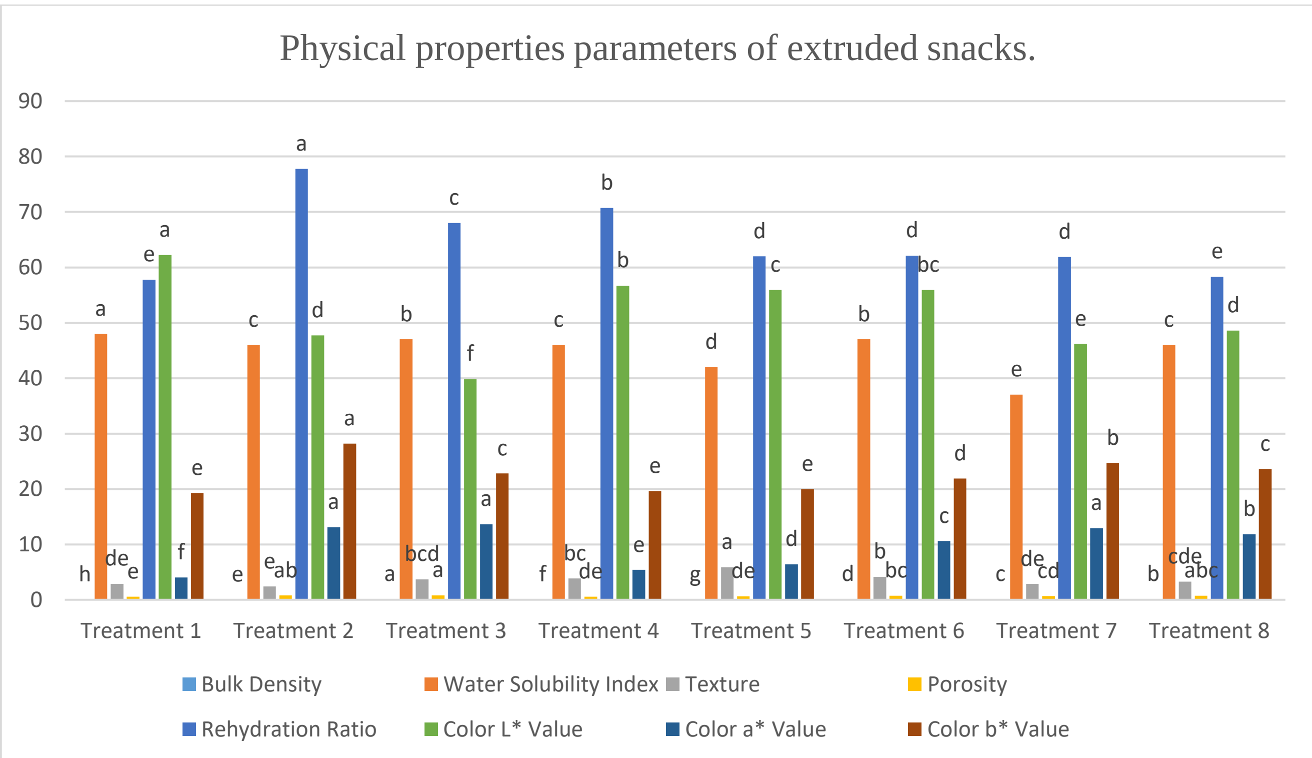

Figure 5 Effects of treatments on different parameters of physical properties of extruded snacks.

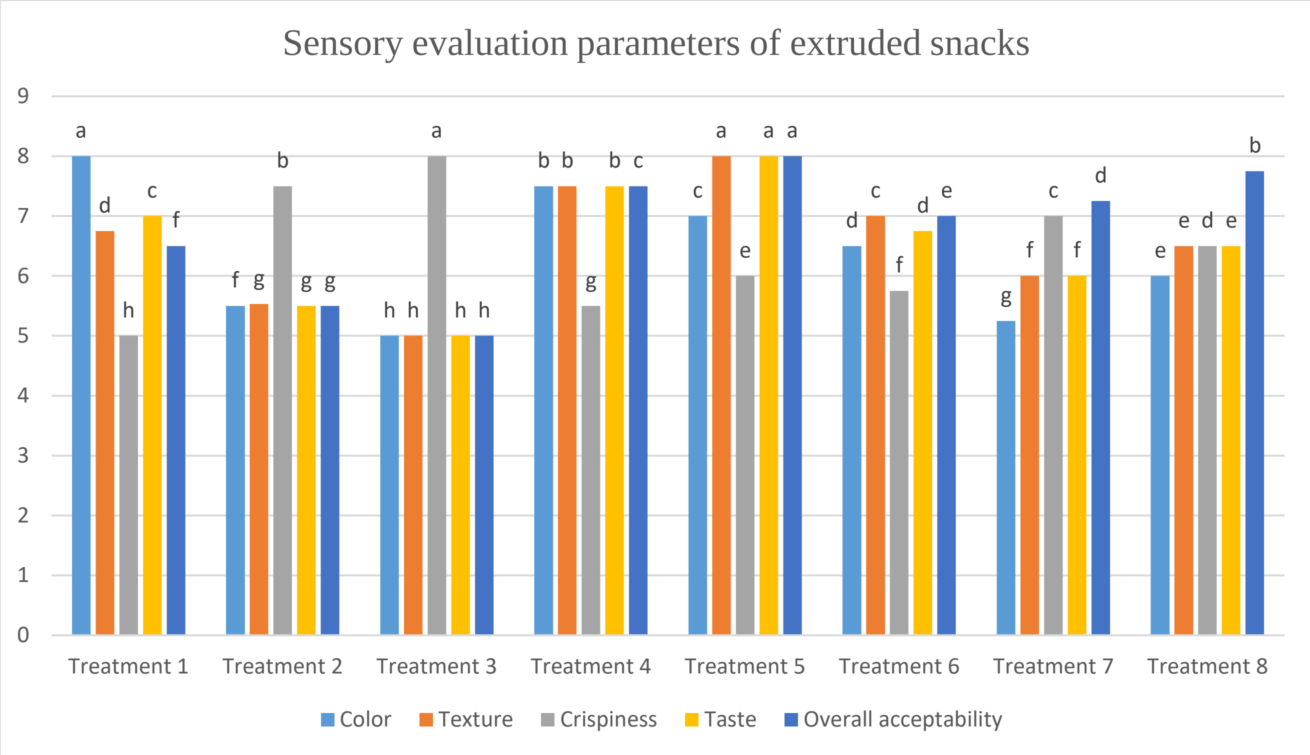

Figure 6 Effects of treatments on different parameters of sensory evaluation.

Energy Content

The energy content was obtained by making food data central as standard (Table 4), provided by United States Department of Agriculture.

Table 4 Energy content of apple pomace, mung bean, and corn grits per 100-gram of protein and carbohydrate as per food data central USA.

	Protein/100g	Carbohydrate/100g	Energy kcal/100g
Apple pomace	0.19	67.72	62.00
Mung Bean	23.90	62.60	347.00
Corn Grits	8.80	79.60	370.00

Note: The eight treatments comprise the following ratios in grams. T_1 extrudate was prepared with no supplementation, T_2 has 10g/100g apple pomace, T_3 has 20g/100g apple pomace, T_4 has 10g/100g mung beans, T_5 has 20g/100g mung beans, T_6 has 5g/100g apple pomace and 15g/100g mung beans, T_7 has 15g/100g apple pomace and 5g/100g mung beans, T_8 has 10g/100g apple pomace and 10g/100 mung beans.

Table 5 Protein and carbohydrate energy content for all treatments.

	Treatment 1	Treatment 2	Treatment 3	Treatment 4	Treatment 5	Treatment 6	Treatment 7	Treatment 8
Protein	0	0.019	0.038	2.3	4.6	3.589	1.218	2.40
Carbohydrate	0	6.77	13.54	6.26	12.52	12.77	13.28	13.03
Energy (kcal) /100g	1548	1418.46	1238.27	1538.24	1528.35	1467.95	1349.35	1409.3

The calculated energy content for all treatments is presented in Table 5. The treatment T_1 comprises 1548 kcal/100g of extruded snacks. The energy content of all other treatments T_2, T_3, T_4, T_5, T_6, T_7, & T_8 are 1418.46, 1238.27, 1538.24, 1528.35, 1467.95, 1349.35, 1409.3 kcal/100g respectively.

The discussion section of the analysis on the physical properties of extruded snacks enriched with apple pomace and mung bean offers a nuanced exploration of the findings, their implications, and the broader context within the existing scientific literature. Bulk density is a critical parameter influencing extruded snacks' texture and nutritional aspects. The observed increase in bulk density with the addition of apple pomace aligns with previous studies **[62]**, **[63]**, **[64]**, **[65]**, **[66]**, **[67]**, **[68]**. Some other researchers found an experiment conducted on the enrichment of apple pomace (AP) in the dough and cookies, as AP contains high fiber content which increases the attributes of cookies like color, texture, and rheological properties **[69]**. Kaur and colleagues suggested that to check the effect of apple pomace on the rheology, microstructure, and texture of yogurt, the gelation pH increased, and the fermentation time decreased of yogurt by adding apple pomace powder **[70]**. In another study, researchers found Sample must ferment till the drying process is completed in other applications of apple pomace **[71]**. Others found dried out and powdered fruit pomace is passed through 30, 50, and 60 interlock sieves to get pomace of differing particle proportions **[72]**. Hossain Brishti suggested that along with dietary fiber, apple pomace has a rich amount of phenolics **[73]**. Nguyen et al. found professional apple pomace as a result of a contemporary fruit juice creation herbal can be viewed as a natural product for immediate planning of nutritional fiber, as it has above 50% TDF **[74]**. Akharume and colleagues found pomace will be the biggest result from fruit juices and cider part. The enhancement in bulk density suggests an increase in weight, directly impacting the texture and nutritional content of the snacks **[75]**. This finding underscores the potential of utilizing fruit pomace, such as apple pomace, as a supplementary ingredient to modify the physical properties of extruded snacks, catering to both sensory preferences and nutritional demands. The water solubility index (WSI) serves as a crucial indicator of stickiness in extruded snacks. The negative correlation between WSI and the concentrations of apple pomace and mung beans is a notable observation. As the supplements increase, the stickiness decreases, highlighting the potential of these supplements to influence the texture and overall quality of extruded snacks. The relationship between stickiness and WSI has practical implications for snack manufacturing, as it allows for the customization of texture based on consumer preferences. Texture, specifically hardness, is a key attribute in determining the overall sensory experience of snacks. The positive correlation between hardness and the percentage of mung beans emphasizes the direct impact of supplements on the textural qualities of extruded snacks. This aligns with similar studies on mung bean pomace **[76]**, **[77]**, **[78]**, **[79]**, **[80]**, **[81]**. Hou and colleagues found mung bean (*Vigna radiata* L.) is a vital heartbeat drink all over the globe, particularly in parts of Asia, and contains an extended reputation of practices as an old-fashioned drug. Delić and researchers found enrichment with pomegranate strips increasing the width, angle, and WVP associated with the mung bean healthy protein movies but reduced her MC and WS **[82]**. Şahin et al. found mung bean seeds had been developed an assortment of times to dissect the effect of germination on the design and physicochemical properties of starch. Understanding the influence of specific supplements on texture is essential for optimizing formulations to meet consumer preferences and nutritional requirements. Porosity, a parameter influencing the digestibility of snacks, showed an increase in the percentage of apple pomace **[83]**.

This is a noteworthy finding, as increased porosity is inversely proportional to WSI. The combination of decreased stickiness (lower WSI) and increased porosity suggests potential benefits for the digestibility of these snacks, particularly for children. The correlation observed supports findings in the literature **[84]**, **[85]**, **[86]**, **[87]**, **[88]**, **[89]**, **[90]** and adds to the growing body of knowledge on the interplay between porosity, WSI, and digestibility in extruded snacks. The rehydration ratio, a critical quality parameter, exhibited significant variations among treatments. The highest rehydration ratio observed in snacks with 10% apple pomace suggests a positive impact of this supplement on the rehydration properties of extruded snacks. This finding has implications for the overall quality of the snacks, particularly in terms of moisture retention during processing and storage. Color analysis is crucial for consumer acceptance, and the L*, a*, and b* values provide insights into the color attributes of the snacks. The decrease in L* value with the addition of apple pomace indicates a fading color. The increase in a* and b* values, on the other hand, suggests changes in hue and intensity. These color changes, though influenced by the supplements, need to be balanced to ensure consumer appeal. The findings align with a study on muffins that reported a decrease in color with apple pomace supplementation **[91]**, **[92]**, **[93]**, **[94]**, **[95]**. Yadav et al. found that fiber-enriched chicken nuggets are manufactured by including grain bran (WB) and dried-out fruit pomace (DAP) each at 3, 6, and 9% **[96]**. Other researchers suggested the role of dietary fiber in providing suffered wellness is learned for a number of many years along with adults there, clearly close research that food diets abundant with high-fiber food items lessen the likelihood of long-term conditions, like CVD and cancers **[97]**. Ötles et al. suggested dietary fiber is a set of food elements and is resilient to digestive minerals and discovered generally in grains, vegetables, and fruits **[98]**. Dahl et al. found fiber is helpful to health insurance and, if eaten in enough amounts **[99]**. Lin et al. found protein is a vital constituent of the system and takes on a broad spectral range of functionality in a system **[100]**. Rodríguez-Miranda et al. suggested the extrusion of combinations of taro flour with nixtamalized flour or with non-nixtamalized flour on a single-screw extruder triggered the creation of food of varied traits **[101]**. In another study, a researcher found after a total examination of the many features for real variables like mass thickness, development proportion, drinking water intake list, and liquid solubility **[102]**. Korkerd et al. unearthed that wealthy sourced elements of healthy protein and fiber from dinners handled by way of merchandise, defatted soybean food, germinated rice that will be brown, and mango strip dietary fiber, happened to be put into corn determination at 20% (w/w) to give fortified extruded food **[103]**. Sriwattana et al. propose a three-element aggregate test that was utilized to improve the strategy of damaged-rice-based treatment fortified with proteins and dietary fiber. Inside their patent discovered that system for manufacturing fiber-fortified nutrition that features creating prepared the foodstuff and then externally implementing dietary fiber **[104]**. Sharma et al. learned the impact of the mixing stage (zero, 5, 10, 15. and 20%) of corn wheat, defatted germ, and gluten with grain flour in the physical substance **[105]**. Researchers discovered that extruded food comprised cooked from flour combinations created using grain flour, corn flour, and egg albumin powder inside an amount of 35-50: 35-50: 5-30 correspondingly, and dampness changed into modified to 17-20 **[106]**. In another study, researchers recommend fortification of extrusion feed preparations with protein. The sensory evaluation conducted using a nine-point hedonic scale sheds light on the overall acceptability of the extruded snacks. The significant changes in color, texture, crispiness, taste, and overall acceptability across treatments underscore the multifaceted impact of supplementation on the sensory characteristics of snacks. These findings provide valuable information for product development, helping manufacturers tailor formulations to meet consumer expectations. The comprehensive analysis of physical properties and sensory evaluation in this study contributes to the evolving understanding of the impact of apple pomace and mung bean supplementation on extruded snacks. The observed relationships between supplements and various parameters offer practical insights for the food industry, guiding the development of snacks that not only meet nutritional demands but also align with consumer preferences. As the demand for nutritious and appealing snack options continues to rise, research in this domain remains critical for advancing both scientific knowledge and product innovation **[107]**.

Challenges and Future Directions

The comprehensive study on the physical properties, sensory evaluation, and nutritional aspects of extruded snacks enriched with apple pomace and mung bean has provided valuable insights. However, challenges and future directions in this research domain still exist. One challenge lies in further optimizing the formulations to achieve an ideal balance between sensory attributes and nutritional content. Understanding the molecular interactions during the extrusion process, especially with the addition of apple pomace and mung bean, could unveil opportunities for fine-tuning the snack formulations. Additionally, investigating the long-term effects of these fortified snacks on consumer health and understanding the bioavailability of nutrients in the human digestive system could enhance the practical application of the findings. Further studies could focus on the bioactive compounds present in apple pomace and mung bean and their potential health benefits, contributing to the broader understanding of functional foods. Collaborating with experts in food engineering and nutritional science, exploring novel ingredients for fortification, considering sustainability aspects, and developing innovative processing techniques are crucial for addressing malnutrition on a broader scale **[108]**, **[109]**, **[110]**, **[111]**, **[112]**, **[113]**, **[114]**. Moreover, studying the economic feasibility and scalability of the developed snacks for potential commercialization is essential. As technology advances, incorporating data-driven approaches and artificial intelligence in food research may open new avenues for optimizing formulations and predicting consumer preferences. Ultimately, the journey towards addressing malnutrition through fortified snacks requires a multidisciplinary approach, integrating insights from food science, nutrition, and technology to create impactful and sustainable solutions.

CONCLUSION

The research aimed to develop corn-extruded snacks enriched with protein and carbohydrates based on physical properties and quality cum nutritional assessment to overcome malnutrition. To combat malnutrition deficiency mung bean as a protein source was added in extrudates, and apple pomace was used as a dietary fiber source. The quality assessment of snacks was studied deeply, and eight treatments were done on each parameter. Different mixing ratios of ingredients were applied on extrudates, and quality cum sensory parameters were evaluated. The bulk density of the snacks increased with the addition of apple pomace, indicating a higher weight and enhanced texture. The water solubility index decreased as the concentrations of apple pomace and mung bean rose, leading to reduced stickiness in snacks. The hardness of the snacks increased with a higher percentage of mung bean, showing a direct relationship between supplements and texture. Porosity increased with the addition of apple pomace, inversely proportional to the water solubility index, making the snacks easily digestible. The rehydration ratio varied among treatments, with significant differences observed. Additionally, the color analysis highlighted the impact of supplementation on L*, a*, and b* values, influencing the overall acceptance by consumers. The results of the water solubility index showed that extruded snacks prepared without supplementation (T1) were observed with maximum value. The porosity of extruded snacks fortified with apple pomace and mung bean results showed that extruded (T3) was observed with highest value of porosity. Rehydration ratio of extruded snacks fortified with apple pomace and mung bean results showed (T1) was with lowest value of rehydration ratio. In a nutshell, supplementation with apple pomace and mung bean significantly affected all the parameters measured through testing and sensory evaluation. Treatments showed that the mixing ratio comprises 80% corn grits + 15% apple pomace + 5% mung bean i.e T7 was best among all and has best nutrient content that is adequate, balanced, and effective for malnutrition remedy.

REFERENCES

1. Crittenden, A. N., & Schnorr, S. L. (2017). Current views on hunter-gatherer nutrition and the evolution of the human diet. In American Journal of Physical Anthropology (Vol. 162, Issue S63, pp. 84–109). Wiley. https://doi.org/10.1002/ajpa.23148
2. Wattick, R., Hagedorn, R., & Olfert, M. (2018). Relationship between Diet and Mental Health in a Young Adult Appalachian College Population. In Nutrients (Vol. 10, Issue 8, p. 957). MDPI AG. https://doi.org/10.3390/nu10080957
3. Ohlhorst, S. D., Russell, R., Bier, D., Klurfeld, D. M., Li, Z., Mein, J. R., Milner, J., Ross, A. C., Stover, P., & Konopka, E. (2013). Nutrition research to affect food and a healthy life span1,2. In The Journal of Nutrition (Vol. 143, Issue 8, pp. 1349–1354). Elsevier BV. https://doi.org/10.3945/jn.113.180638
4. Greene, J. M., & McAdam, P. A. (1983). Nutritional Requirements and the Appropriate Use of Supplements. In Nutrition in the Middle and Later Years (pp. 17–45). Elsevier. https://doi.org/10.1016/b978-0-7236-7046-9.50008-4
5. Organization W.H.O. (2003). In Diet, nutrition, and the prevention of chronic diseases: report of a joint WHO/FAO expert consultation (Vol. 916). World Health Organization.
6. Mehta, N. M., Corkins, M. R., Lyman, B., Malone, A., Goday, P. S., Carney, L. (Nieman), Monczka, J. L., Plogsted, S. W., & Schwenk, W. F. (2013). Defining Pediatric Malnutrition. In Journal of Parenteral and Enteral Nutrition (Vol. 37, Issue 4, pp. 460–481). Wiley. https://doi.org/10.1177/0148607113479972
7. Hawkes, C., Ruel, M. T., Salm, L., Sinclair, B., & Branca, F. (2020). Double-duty actions: seizing programme and policy opportunities to address malnutrition in all its forms. In The Lancet (Vol. 395, Issue 10218, pp. 142–155). Elsevier BV. https://doi.org/10.1016/s0140-6736(19)32506-1
8. Majekodunmi, A., Ajiboye, E. A., Odaibo, A. (2011). Single cell proteins: as nutritional enhancer. In Adv. Appl. Sci. Res. (Vol. 2, Issue 5, pp. 396–409). Prime Scholars.
9. Vorster, H. H. (2010). The link between poverty and malnutrition: A South African perspective. In Health SA Gesondheid (Vol. 15, Issue 1). AOSIS. https://doi.org/10.4102/hsag.v15i1.435
10. Vorster, H. H. (2010). The link between poverty and malnutrition: A South African perspective. In Health SA Gesondheid (Vol. 15, Issue 1). AOSIS. https://doi.org/10.4102/hsag.v15i1.435
11. Olsen, E. M., Petersen, J., Skovgaard, A. M., Weile, B., Jorgensen, T., & Wright, C. M. (2006). Failure to thrive: the prevalence and concurrence of anthropometric criteria in a general infant population. In Archives of Disease in Childhood (Vol. 92, Issue 2, pp. 109–114). BMJ. https://doi.org/10.1136/adc.2005.080333
12. Vorster, H. H. (2010). The link between poverty and malnutrition: A South African perspective. In Health SA Gesondheid (Vol. 15, Issue 1). AOSIS. https://doi.org/10.4102/hsag.v15i1.435
13. Hengeveld, L. M., Wijnhoven, H. A., Olthof, M. R., Brouwer, I. A., Harris, T. B., Kritchevsky, S. B., Newman, A. B., & Visser, M. (2018). Prospective associations of poor diet quality with long-term incidence of protein-energy malnutrition in community-dwelling older adults: the Health, Aging, and Body Composition (Health ABC) Study. In The American Journal of Clinical Nutrition (Vol. 107, Issue 2, pp. 155–164). Elsevier BV. https://doi.org/10.1093/ajcn/nqx020
14. Koletzko, B., Bhatia, J., Bhutta, Z. A., Cooper, P., Makrides, M., Uauy, R., Wang, W. (2015). Pediatric nutrition in practice. Karger Medical and Scientific Publishers. https://doi.org/10.1159/isbn.978-3-318-02691-7
15. Hudson, J. A., Charron, E., Maple, B., Krom, M., Heavner-Sullivan, S. F., Mayo, R. M., Dickes, L., & Rennert, L. (2020). Baby-Friendly Hospital Initiative Is Associated with Lower Rates of Neonatal Hyperbilirubinemia. In Breastfeeding Medicine (Vol. 15, Issue 3, pp. 176–182). Mary Ann Liebert Inc. https://doi.org/10.1089/bfm.2019.0220
16. Seemer, J., Volkert, D., Fleckenstein-Sußmann, D., Bader-Mittermaier, S., Sieber, C. C., & Kiesswetter, E. (2021). Usual Protein Intake Amount and Sources of Nursing Home Residents with (Risk of) Malnutrition and Effects of an Individualized Nutritional Intervention: An enable Study. In Nutrients (Vol. 13, Issue 7, p. 2168). MDPI AG. https://doi.org/10.3390/nu13072168
17. Trumbo, P., Schlicker, S., Yates, A. A., & Poos, M. (2002). Dietary Reference Intakes for Energy, Carbohydrate, Fiber, Fat, Fatty Acids, Cholesterol, Protein and Amino Acids. In Journal of the American Dietetic Association (Vol. 102, Issue 11, pp. 1621–1630). Elsevier BV. https://doi.org/10.1016/s0002-8223(02)90346-9

18. Oh, R., Gilani, B., & Uppaluri, K. R. (2019). Low carbohydrate diet. In StatPearls. StatPearls Publishing.
19. Thilagavathi, T., Pandiyan, M., Suganyadevi, M., Sivaji, M., Yuvaraj, M., & Sasmitha, R. (2020). Dietary fibre-health benefits. In Biotica Research Today (Vol. 2, Issue 6, pp. 519–522. Society for Biotic and Environmental Research (SBER) & BIOTICA.
20. Mahmood, M. W., Abraham-Nordling, M., Håkansson, N., Wolk, A., & Hjern, F. (2018). High intake of dietary fibre from fruit and vegetables reduces the risk of hospitalisation for diverticular disease. In European Journal of Nutrition (Vol. 58, Issue 6, pp. 2393–2400). Springer Science and Business Media LLC. https://doi.org/10.1007/s00394-018-1792-0
21. Nations, U. (2015). Transforming our world: The 2030 agenda for sustainable development. Department of Economic and Social Affairs.
22. Bressani, R., Harper, J., & Whickstrom, B. (1984). Processed and packaged weading foods: development, manufacture and marketing. In Improving the nutritional status of children during weaning period (pp. 51–64). Moi University.
23. Leonard, W., Zhang, P., Ying, D., & Fang, Z. (2019). Application of extrusion technology in plant food processing byproducts: An overview. In Comprehensive Reviews in Food Science and Food Safety (Vol. 19, Issue 1, pp. 218–246). Wiley. https://doi.org/10.1111/1541-4337.12514
24. Wang, Y.-Y., & Ryu, G.-H. (2013). Physical properties of extruded corn grits with corn fibre by CO2 injection extrusion. In Journal of Food Engineering (Vol. 116, Issue 1, pp. 14–20). Elsevier BV. https://doi.org/10.1016/j.jfoodeng.2012.10.041
25. O’Shea, N., Arendt, E., & Gallagher, E. (2013). Enhancing an Extruded Puffed Snack by Optimising Die Head Temperature, Screw Speed and Apple Pomace Inclusion. In Food and Bioprocess Technology (Vol. 7, Issue 6, pp. 1767–1782). Springer Science and Business Media LLC. https://doi.org/10.1007/s11947-013-1181-x
26. Arêas, J. A. G., Rocha-Olivieri, C. M., & Marques, M. R. (2016). Extrusion Cooking: Chemical and Nutritional Changes. In Encyclopedia of Food and Health (pp. 569–575). Elsevier. https://doi.org/10.1016/b978-0-12-384947-2.00266-x
27. Pathak, N., & Kochhar, A. (2018). Extrusion Technology: Solution to Develop Quality Snacks for Malnourished Generation. In International Journal of Current Microbiology and Applied Sciences (Vol. 7, Issue 1, pp. 1293–1307). Excellent Publishers. https://doi.org/10.20546/ijcmas.2018.701.158
28. de Morais, E. C., Cruz, A. G., & Bolini, H. M. A. (2013). Gluten-free bread: multiple time–intensity analysis, physical characterisation and acceptance test. In International Journal of Food Science & Technology (Vol. 48, Issue 10, pp. 2176–2184). Wiley. https://doi.org/10.1111/ijfs.12202
29. Shah, F., Sharif, M. K., Butt, M. S., & Shahid, M. (2016). Development of protein, dietary fiber, and micronutrient enriched extruded corn snacks. In Journal of Texture Studies (Vol. 48, Issue 3, pp. 221–230). Wiley. https://doi.org/10.1111/jtxs.12231
30. Paula, A. M., & Conti-Silva, A. C. (2014). Texture profile and correlation between sensory and instrumental analyses on extruded snacks. In Journal of Food Engineering (Vol. 121, pp. 9–14). Elsevier BV. https://doi.org/10.1016/j.jfoodeng.2013.08.007
31. Zhang, J., Liu, L., Jiang, Y., Faisal, S., & Wang, Q. (2020). A new insight into the high-moisture extrusion process of peanut protein: From the aspect of the orders and amount of energy input. In Journal of Food Engineering (Vol. 264, p. 109668). Elsevier BV. https://doi.org/10.1016/j.jfoodeng.2019.07.015
32. Cueto, M., Porras-Saavedra, J., Farroni, A., Alamilla-Beltrán, L., Schöenlechner, R., Schleining, G., & Buera, P. (2015). Physical and mechanical properties of maize extrudates as affected by the addition of chia and quinoa seeds and antioxidants. In Journal of Food Engineering (Vol. 167, pp. 139–146). Elsevier BV. https://doi.org/10.1016/j.jfoodeng.2015.07.027
33. Jozinović, A., Šubarić, D., Ačkar, Đ., Babić, J., & Miličević, B. (2016). Influence of spelt flour addition on properties of extruded products based on corn grits. In Journal of Food Engineering (Vol. 172, pp. 31–37). Elsevier BV. https://doi.org/10.1016/j.jfoodeng.2015.04.012
34. Asghar, A., Ali, S. M., & Yasmin, A. (2012). Effect of climate change on apple (Malus domestica var. ambri) production: A case study in Kotli Satian, Rawalpindi, Pakistan. In Pakistan Journal of Botany (Vol. 44, Issue 6, pp. 1913–1918). Pakistan Botanical Soc.
35. Eberhardt, M. V., Lee, C. Y., & Liu, R. H. (2000). Antioxidant activity of fresh apples. In Nature (Vol. 405, Issue 6789, pp. 903–904). Springer Science and Business Media LLC. https://doi.org/10.1038/35016151
36. Li, W., Yang, R., Ying, D., Yu, J., Sanguansri, L., & Augustin, M. A. (2020). Analysis of polyphenols in apple pomace: A comparative study of different extraction and hydrolysis procedures. In Industrial Crops and Products (Vol. 147, p. 112250). Elsevier BV. https://doi.org/10.1016/j.indcrop.2020.112250

37. Diñeiro García, Y., Valles, B. S., & Picinelli Lobo, A. (2009). Phenolic and antioxidant composition of by-products from the cider industry: Apple pomace. In Food Chemistry (Vol. 117, Issue 4, pp. 731–738). Elsevier BV. https://doi.org/10.1016/j.foodchem.2009.04.049
38. Shalini, R., & Gupta, D. K. (2010). Utilization of pomace from apple processing industries: a review. In Journal of Food Science and Technology (Vol. 47, Issue 4, pp. 365–371). Springer Science and Business Media LLC. https://doi.org/10.1007/s13197-010-0061-x
39. Skinner, R. C., Gigliotti, J. C., Ku, K.-M., & Tou, J. C. (2018). A comprehensive analysis of the composition, health benefits, and safety of apple pomace. In Nutrition Reviews. Oxford University Press (OUP). https://doi.org/10.1093/nutrit/nuy033
40. Rasul, F., Cheema, M., Sattar, A., Saleem, M. F., & Wahid, M. A. (2012). Evaluating the performance of three mungbean varieties grown under varying inter-row spacing. In J. Anim. Plant Sci. (Vol. 22, Issue 4, pp. 1030–1035). Elewa Biosciences Journals.
41. Dahiya, P. K., Linnemann, A. R., Van Boekel, M. A. J. S., Khetarpaul, N., Grewal, R. B., & Nout, M. J. R. (2014). Mung Bean: Technological and Nutritional Potential. In Critical Reviews in Food Science and Nutrition (Vol. 55, Issue 5, pp. 670–688). Informa UK Limited. https://doi.org/10.1080/10408398.2012.671202
42. Du, M., Xie, J., Gong, B., Xu, X., Tang, W., Li, X., Li, C., & Xie, M. (2018). Extraction, physicochemical characteristics and functional properties of Mung bean protein. In Food Hydrocolloids (Vol. 76, pp. 131–140). Elsevier BV. https://doi.org/10.1016/j.foodhyd.2017.01.003
43. Hou, D., Yousaf, L., Xue, Y., Hu, J., Wu, J., Hu, X., Feng, N., & Shen, Q. (2019). Mung Bean (Vigna radiata L.): Bioactive Polyphenols, Polysaccharides, Peptides, and Health Benefits. In Nutrients (Vol. 11, Issue 6, p. 1238). MDPI AG. https://doi.org/10.3390/nu11061238
44. Shahrajabian, M. H., Sun, W., & Cheng, Q. (2019). A short review of health benefits and nutritional values of mung bean in sustainable agriculture. Instytut Uprawy Nawożenia i Gleboznawstwa - Państwowy Instytut Badawczy. https://doi.org/10.26114/PJA.IUNG.381.2019.37.05
45. Serna-Saldivar, S. O., & Perez Carrillo, E. (2019). Food Uses of Whole Corn and Dry-Milled Fractions. In Corn (pp. 435–467). Elsevier. https://doi.org/10.1016/b978-0-12-811971-6.00016-4
46. Serna-Saldivar, S. O. (2004). MAIZE | Foods from Maize. In Encyclopedia of Grain Science (pp. 242–253). Elsevier. https://doi.org/10.1016/b0-12-765490-9/00095-1
47. Loy, D. D., & Lundy, E. L. (2019). Nutritional Properties and Feeding Value of Corn and Its Coproducts. In Corn (pp. 633–659). Elsevier. https://doi.org/10.1016/b978-0-12-811971-6.00023-1
48. Guyot, S., Marnet, N., Sanoner, P., & Drilleau, J.-F. (2003). Variability of the Polyphenolic Composition of Cider Apple (Malus domestica) Fruits and Juices. In Journal of Agricultural and Food Chemistry (Vol. 51, Issue 21, pp. 6240–6247). American Chemical Society (ACS). https://doi.org/10.1021/jf0301798
49. Selani, M. M. (2015). Characterization and application of fruit byproducts in the development of beef burger and corn extruded product. [Doctoral dissertation, Universidade de São Paulo].
50. Yu, J., & Anchordoquy, T. J. (2009). Synergistic effects of surfactants and sugars on lipoplex stability during freeze-drying and rehydration. In Journal of Pharmaceutical Sciences (Vol. 98, Issue 9, pp. 3319–3328). Elsevier BV. https://doi.org/10.1002/jps.21564
51. Rathod, R. P., & Annapure, U. S. (2016). Effect of extrusion process on antinutritional factors and protein and starch digestibility of lentil splits. In LWT - Food Science and Technology (Vol. 66, pp. 114–123). Elsevier BV. https://doi.org/10.1016/j.lwt.2015.10.028
52. Piga, A., Catzeddu, P., Farris, S., Roggio, T., Sanguinetti, A., & Scano, E. (2005). Texture evolution of "Amaretti" cookies during storage. In European Food Research and Technology (Vol. 221, Issues 3–4, pp. 387–391). Springer Science and Business Media LLC. https://doi.org/10.1007/s00217-005-1185-5
53. Meilgaard, M. C., Carr, B. T., & Carr, B. T. (2006). Sensory Evaluation Techniques. CRC Press. https://doi.org/10.1201/b16452
54. Peryam, D. R., & Pilgrim, F. J. (1957). Hedonic scale method of measuring food preferences. In Food technology (Vol. 11, pp. 9–14). IFT.
55. Tukey, J. W. (1977). Exploratory data analysis. 2 [ed]. Addison-Wesley Publishing Company, 688 p.
56. Altan, A., McCarthy, K. L., & Maskan, M. (2008). Twin-screw extrusion of barley–grape pomace blends: Extrudate characteristics and determination of optimum processing conditions. In Journal of Food Engineering (Vol. 89, Issue 1, pp. 24–32). Elsevier BV. https://doi.org/10.1016/j.jfoodeng.2008.03.025
57. Hashimoto, J. M., & Grossmann, M. V. E. (2003). Effects of extrusion conditions on quality of cassava bran/cassava starch extrudates. In International Journal of Food Science & Technology (Vol. 38, Issue 5, pp. 511–517). Wiley. https://doi.org/10.1046/j.1365-2621.2003.00700.x

58. Altan, A., McCarthy, K. L., & Maskan, M. (2009). Effect of extrusion process on antioxidant activity, total phenolics and β-glucan content of extrudates developed from barley-fruit and vegetable by-products. In International Journal of Food Science & Technology (Vol. 44, Issue 6, pp. 1263–1271). Wiley. https://doi.org/10.1111/j.1365-2621.2009.01956.x

59. Yağcı, S., & Göğüş, F. (2008). Response surface methodology for evaluation of physical and functional properties of extruded snack foods developed from food-by-products. In Journal of Food Engineering (Vol. 86, Issue 1, pp. 122–132). Elsevier BV. https://doi.org/10.1016/j.jfoodeng.2007.09.018

60. Younas, M. B., Rakha, A., Sohail, M., Rashid, S., & Ishtiaq, H. (2015). Physicochemical and sensory assessment of apple pomace enriched muffins. In Pakistan Journal of Food Sciences (Vol. 25, Issue 4, pp. 224–234). Pakistan Society of Food Scientists and Technologists.

61. Sudha, M. L., Baskaran, V., & Leelavathi, K. (2007). Apple pomace as a source of dietary fiber and polyphenols and its effect on the rheological characteristics and cake making. In Food Chemistry (Vol. 104, Issue 2, pp. 686–692). Elsevier BV. https://doi.org/10.1016/j.foodchem.2006.12.016

62. Sahu, C., Patel, S., & Tripathi, A. K. (2022). Effect of extrusion parameters on physical and functional quality of soy protein enriched maize based extruded snack. In Applied Food Research (Vol. 2, Issue 1, p. 100072). Elsevier BV. https://doi.org/10.1016/j.afres.2022.100072

63. Sobowale, S. S., Kewuyemi, Y. O., & Olayanju, A. T. (2021). Process optimization of extrusion variables and effects on some quality and sensory characteristics of extruded snacks from whole pearl millet-based flour. In SN Applied Sciences (Vol. 3, Issue 10). Springer Science and Business Media LLC. https://doi.org/10.1007/s42452-021-04808-w

64. Rani, P., Kumar, A., Purohit, S. R., & Rao, P. S. (2020). Extrusion of fermented rice-black gram flour for development of functional snacks: Characterization, optimization and sensory analysis. In Journal of Food Science and Technology (Vol. 58, Issue 2, pp. 494–509). Springer Science and Business Media LLC. https://doi.org/10.1007/s13197-020-04558-4

65. Preethi, P., Mangalassery, S., Shradha, K., Pandiselvam, R., Manikantan, M. R., Reddy, S. V. R., Devi, S. R., & Nayak, M. G. (2021). Cashew apple pomace powder enriched the proximate, mineral, functional and structural properties of cereal based extrudates. In LWT (Vol. 139, p. 110539). Elsevier BV. https://doi.org/10.1016/j.lwt.2020.110539

66. Kloepfer, I. N. (2022). Sensory Characterization and Consumer Acceptance of Corn-Based Extruded Puffed Snacks with Apple or Cranberry Pomace. [Doctoral dissertation, Washington State University].

67. Asif, M., Javaid, T., Razzaq, Z. U., Khan, M. K. I., Maan, A. A., Yousaf, S., Usman, A., & Shahid, S. (2023). Sustainable utilization of apple pomace and its emerging potential for development of functional foods. In Environmental Science and Pollution Research. Springer Science and Business Media LLC. https://doi.org/10.1007/s11356-023-28479-9

68. O'Shea, N., Arendt, E., & Gallagher, E. (2013). Enhancing an Extruded Puffed Snack by Optimising Die Head Temperature, Screw Speed and Apple Pomace Inclusion. In Food and Bioprocess Technology (Vol. 7, Issue 6, pp. 1767–1782). Springer Science and Business Media LLC. https://doi.org/10.1007/s11947-013-1181-x

69. Sharma, C., Singh, B., Hussain, S. Z., & Sharma, S. (2017). Investigation of process and product parameters for physicochemical properties of rice and mung bean (Vigna radiata) flour based extruded snacks. In Journal of Food Science and Technology (Vol. 54, Issue 6, pp. 1711–1720). Springer Science and Business Media LLC. https://doi.org/10.1007/s13197-017-2606-8

70. Kaur, J., Singh, B., & Singh, A. (2023). Sorghum–mung bean combination snacks: Effect of extrusion temperature and moisture on chemical, functional, and nutritional characteristics. In Legume Science (Vol. 5, Issue 3). Wiley. https://doi.org/10.1002/leg3.186

71. Brishti, F. H., Chay, S. Y., Muhammad, K., Ismail-Fitry, M. R., Zarei, M., & Saari, N. (2021). Texturized mung bean protein as a sustainable food source: Effects of extrusion on its physical, textural and protein quality. In Innovative Food Science & Emerging Technologies (Vol. 67, p. 102591). Elsevier BV. https://doi.org/10.1016/j.ifset.2020.102591

72. Hossain Brishti, F., Chay, S. Y., Muhammad, K., Rashedi Ismail-Fitry, M., Zarei, M., Karthikeyan, S., Caballero-Briones, F., & Saari, N. (2021). Structural and rheological changes of texturized mung bean protein induced by feed moisture during extrusion. In Food Chemistry (Vol. 344, p. 128643). Elsevier BV. https://doi.org/10.1016/j.foodchem.2020.128643

73. Hossain Brishti, F., Chay, S. Y., Muhammad, K., Rashedi Ismail-Fitry, M., Zarei, M., Karthikeyan, S., Caballero-Briones, F., & Saari, N. (2021). Structural and rheological changes of texturized mung bean protein induced by feed moisture during extrusion. In Food Chemistry (Vol. 344, p. 128643). Elsevier BV. https://doi.org/10.1016/j.foodchem.2020.128643

74. Nguyen, T. P., Lin, J., & Songsermpong, S. (2023). Influence of feed moisture content on physical and sensory properties of extruded pure mung bean starch vermicelli. In International Journal of Food Science & Technology (Vol. 58, Issue 8, pp. 4205–4214). Wiley. https://doi.org/10.1111/ijfs.16513

75. Akharume, F., Xiong, Y. L., & Adedeji, A. (2019). Effects of Transglutaminase in Product Formulation on Physico-textural Properties of Protein Rich Extruded Snacks. In 2019 Boston, Massachusetts July 7- July 10, 2019. 2019 Boston, Massachusetts July 7- July 10, 2019. American Society of Agricultural and Biological Engineers. https://doi.org/10.13031/aim.201900306

76. Azzollini, D., Derossi, A., Fogliano, V., Lakemond, C. M. M., & Severini, C. (2018). Effects of formulation and process conditions on microstructure, texture and digestibility of extruded insect-riched snacks. In Innovative Food Science & Emerging Technologies (Vol. 45, pp. 344–353). Elsevier BV. https://doi.org/10.1016/j.ifset.2017.11.017

77. Lisiecka, K., Wójtowicz, A., Samborska, K., Mitrus, M., Oniszczuk, T., Combrzyński, M., Soja, J., Lewko, P., Kasprzak Drozd, K., & Oniszczuk, A. (2023). Structure and Texture Characteristics of Novel Snacks Expanded by Various Methods. In Materials (Vol. 16, Issue 4, p. 1541). MDPI AG. https://doi.org/10.3390/ma16041541

78. Gomes, K. S., Berwian, G. F., Tiepo, C. B. V., & Colla, L. M. (2023). Development and evaluation of extruded protein snacks added. In Food Science and Technology (Vol. 43). Zeppelini Editorial e Comunicacao. https://doi.org/10.5327/fst.1123

79. Kaur, J., Singh, B., Singh, A., Sharma, S., & Kidwai, M. K. (2023). Effect of extrusion processing on techno-functional properties, textural properties, antioxidant activities, in vitro nutrient digestibility and glycemic index of sorghum–chickpea-based extruded snacks. In Journal of Texture Studies (Vol. 54, Issue 5, pp. 706–719). Wiley. https://doi.org/10.1111/jtxs.12760

80. Eftekhariyazdi, M., Zenoozian, M. S., Milani, E., Rad, A. H. E., & Armin, M. (2023). Effect of extrusion parameters on physical, microstructural and functional quality of lentil-quinoa extruded snack enriched with pumpkin by stepwise response surface methodology. Research Square Platform LLC. https://doi.org/10.21203/rs.3.rs-2962834/v1

81. Kaur, J., Singh, B., Singh, A., Sharma, S., & Kidwai, M. K. (2023). Effect of extrusion processing on techno-functional properties, textural properties, antioxidant activities, in vitro nutrient digestibility and glycemic index of sorghum–chickpea-based extruded snacks. In Journal of Texture Studies (Vol. 54, Issue 5, pp. 706–719). Wiley. https://doi.org/10.1111/jtxs.12760

82. Delić, J., Ikonić, P., Jokanović, M., Peulić, T., Ikonić, B., Banjac, V., Vidosavljević, S., Stojkov, V., & Hadnađev, M. (2023). Sustainable snack products: Impact of protein- and fiber-rich ingredients addition on nutritive, textural, physical, pasting and color properties of extrudates. In Innovative Food Science & Emerging Technologies (Vol. 87, p. 103419). Elsevier BV. https://doi.org/10.1016/j.ifset.2023.103419

83. Şahin, N., Bilgiçli, N., & Sayaslan, A. (2023). Improvement of Functional and Nutritional Properties of Extruded Snacks with the Utilization of Red Dog Flour. In Brazilian Archives of Biology and Technology (Vol. 66). FapUNIFESP (SciELO). https://doi.org/10.1590/1678-4324-2023220180

84. Kantrong, H., Klongdee, S., Jantapirak, S., Limsangouan, N., & Pengpinit, W. (2021). Effects of extrusion temperature and puffing technique on physical and functional properties of purpled third-generation snack after heat treatment. In Journal of Food Science and Technology (Vol. 59, Issue 6, pp. 2209–2219). Springer Science and Business Media LLC. https://doi.org/10.1007/s13197-021-05234-x

85. Obradović, V., Babić, J., Dragović-Uzelac, V., Jozinović, A., Ačkar, Đ., & Šubarić, D. (2021). Properties of Extruded Snacks Prepared from Corn and Carrot Powder with Ascorbic Acid Addition. In Processes (Vol. 9, Issue 8, p. 1367). MDPI AG. https://doi.org/10.3390/pr9081367

86. Félix-Medina, J. V., Montes-Ávila, J., Reyes-Moreno, C., Perales-Sánchez, J. X. K., Gómez-Favela, M. A., Aguilar-Palazuelos, E., & Gutiérrez-Dorado, R. (2020). Second-generation snacks with high nutritional and antioxidant value produced by an optimized extrusion process from corn/common bean flours mixtures. In LWT (Vol. 124, p. 109172). Elsevier BV. https://doi.org/10.1016/j.lwt.2020.109172

87. Waseem, M., Majeed, Y., Nadeem, T., Naqvi, L. H., Khalid, M. A., Sajjad, M. M., Sultan, M., Khan, M. U., Khayrullin, M., Shariati, M. A., & Lorenzo, J. M. (2023). Conventional and advanced extraction methods of some bioactive compounds with health benefits of food and plant waste: A comprehensive review. In Food Frontiers (Vol. 4, Issue 4, pp. 1681–1701). Wiley. https://doi.org/10.1002/fft2.296

88. Waseem, M., & Majeed, Y. (2023). Cell-based food needs collaborative efforts for safe production and suitable consumption. In Food Safety and Health (Vol. 1, Issue 1, pp. 6–8). Wiley. https://doi.org/10.1002/fsh3.12009

89. Waseem, M., Majeed, Y., Nadeem, T., Naqvi, L. H., Khalid, M. A., Shafiq, M., & Sajjad, M. M. (2022). Climate Change, Flood Disaster, and Food Insecurity in Pakistan. Research Square Platform LLC. https://doi.org/10.21203/rs.3.rs-2284023/v1
90. Waseem, M., Tahir, A. U., & Majeed, Y. (2023). Printing the future of food: The physics perspective on 3D food printing. In Food Physics (Vol. 1, p. 100003). Elsevier BV. https://doi.org/10.1016/j.foodp.2023.100003
91. Waseem, M., Khan, M. U., Majeed, Y., Ntsefong, G. N., Kirichenko, I., Klopova, A., Trushov, P., & Lodygin, A. (2023). Seaweed-based films for sustainable food packaging: properties, incorporation of essential oils, applications, and future directions. In Potravinarstvo Slovak Journal of Food Sciences (Vol. 17, pp. 899–917). HACCP Consulting. https://doi.org/10.5219/1908
92. Majeed, Y., & Waseem, M. (2022). Postharvest Handling Systems. In Encyclopedia of Smart Agriculture Technologies (pp. 1–9). Springer International Publishing. https://doi.org/10.1007/978-3-030-89123-7_125-1
93. Majeed, Y., Khan, M. U., Waseem, M., Zahid, U., Mahmood, F., Majeed, F., Sultan, M., & Raza, A. (2023). Renewable energy as an alternative source for energy management in agriculture. In Energy Reports (Vol. 10, pp. 344–359). Elsevier BV. https://doi.org/10.1016/j.egyr.2023.06.032
94. Kantrong, H., Klongdee, S., Jantapirak, S., Limsangouan, N., & Pengpinit, W. (2021). Effects of extrusion temperature and puffing technique on physical and functional properties of purpled third-generation snack after heat treatment. In Journal of Food Science and Technology (Vol. 59, Issue 6, pp. 2209–2219). Springer Science and Business Media LLC. https://doi.org/10.1007/s13197-021-05234-
95. Obradović, V., Babić, J., Dragović-Uzelac, V., Jozinović, A., Ačkar, Đ., & Šubarić, D. (2021). Properties of Extruded Snacks Prepared from Corn and Carrot Powder with Ascorbic Acid Addition. In Processes (Vol. 9, Issue 8, p. 1367). MDPI AG. https://doi.org/10.3390/pr9081367
96. Yadav, U., Singh, R. R. B., & Arora, S. (2018). Evaluation of quality changes in nutritionally enriched extruded snacks during storage. In Journal of Food Science and Technology (Vol. 55, Issue 10, pp. 3939–3948). Springer Science and Business Media LLC. https://doi.org/10.1007/s13197-018-3319-3
97. Edwards, E. J., Edwards, M. S., & Lyvers, M. (2015). Cognitive trait anxiety, situational stress, and mental effort predict shifting efficiency: Implications for attentional control theory. In Emotion (Vol. 15, Issue 3, pp. 350–359). American Psychological Association (APA). https://doi.org/10.1037/emo0000051
98. Ötles, S., & Ozgoz, S. (2014). Health effects of dietary fiber. In Acta Scientiarum Polonorum Technologia Alimentaria (Vol. 13, Issue 2, pp. 191–202). Uniwersytet Przyrodniczy w Poznaniu (Poznan University of Life Sciences). https://doi.org/10.17306/j.afs.2014.2.8
99. Dahl, W. J., & Stewart, M. L. (2015). Position of the Academy of Nutrition and Dietetics: Health Implications of Dietary Fiber. In Journal of the Academy of Nutrition and Dietetics (Vol. 115, Issue 11, pp. 1861–1870). Elsevier BV. https://doi.org/10.1016/j.jand.2015.09.003
100. Lin, D., Long, X., Huang, Y., Yang, Y., Wu, Z., Chen, H., Zhang, Q., Wu, D., Qin, W., & Tu, Z. (2020). Effects of microbial fermentation and microwave treatment on the composition, structural characteristics, and functional properties of modified okara dietary fiber. In LWT (Vol. 123, p. 109059). Elsevier BV. https://doi.org/10.1016/j.lwt.2020.109059
101. Rodríguez-Miranda, J., Ruiz-López, I. I., Herman-Lara, E., Martínez-Sánchez, C. E., Delgado-Licon, E., & Vivar-Vera, M. A. (2011). Development of extruded snacks using taro (Colocasia esculenta) and nixtamalized maize (Zea mays) flour blends. In LWT - Food Science and Technology (Vol. 44, Issue 3, pp. 673–680). Elsevier BV. https://doi.org/10.1016/j.lwt.2010.06.036
102. Seth, D., & Rajamanickam, G. (2012). Development of extruded snacks using soy, sorghum, millet and rice blend – A response surface methodology approach. In International Journal of Food Science & Technology (Vol. 47, Issue 7, pp. 1526–1531). Wiley. https://doi.org/10.1111/j.1365-2621.2012.03001.x
103. Korkerd, S., Wanlapa, S., Puttanlek, C., Uttapap, D., & Rungsardthong, V. (2015). Expansion and functional properties of extruded snacks enriched with nutrition sources from food processing by-products. In Journal of Food Science and Technology (Vol. 53, Issue 1, pp. 561–570). Springer Science and Business Media LLC. https://doi.org/10.1007/s13197-015-2039-1
104. Sriwattana, S., Laokuldilok, N., & Prinyawiwatkul, W. (2008). Sensory Optimization of Broken-Rice Based Snacks Fortified with Protein and Fiber. In Journal of Food Science (Vol. 73, Issue 6). Wiley. https://doi.org/10.1111/j.1750-3841.2008.00853.x
105. Sharma, S., Gupta, J. P., Nagi, H. P. S., & Kumar, R. (2011). Effect of incorporation of corn byproducts on quality of baked and extruded products from wheat flour and semolina. In Journal of Food Science and Technology (Vol. 49, Issue 5, pp. 580–586). Springer Science and Business Media LLC. https://doi.org/10.1007/s13197-011-0304-5

106. Kocherla, P., K. Aparna, K., & Lakshmi, D. N. (2012). Development and evaluation of RTE (Ready to Eat) extruded snack using egg albumin powder and cheese powder. In Agricultural Engineering International: CIGR Journal (Vol. 14, Issue 4, pp. 179–187). International Commission of Agricultural and Biosystems Engineering.

107. Day, L., & Swanson, B. G. (2013). Functionality of Protein-Fortified Extrudates. In Comprehensive Reviews in Food Science and Food Safety (Vol. 12, Issue 5, pp. 546–564). Wiley. https://doi.org/10.1111/1541-4337.12023

108. Waseem, M., Majeed, Y., Nadeem, T., Naqvi, L. H., Khalid, M. A., Sajjad, M. M., Sultan, M., Khan, M. U., Khayrullin, M., Shariati, M. A., & Lorenzo, J. M. (2023). Conventional and advanced extraction methods of some bioactive compounds with health benefits of food and plant waste: A comprehensive review. In Food Frontiers (Vol. 4, Issue 4, pp. 1681–1701). Wiley. https://doi.org/10.1002/fft2.296

109. Waseem, M., & Majeed, Y. (2023). Cell-based food needs collaborative efforts for safe production and suitable consumption. In Food Safety and Health (Vol. 1, Issue 1, pp. 6–8). Wiley. https://doi.org/10.1002/fsh3.12009

110. Waseem, M., Majeed, Y., Nadeem, T., Naqvi, L. H., Khalid, M. A., Shafiq, M., & Sajjad, M. M. (2022). Climate Change, Flood Disaster, and Food Insecurity in Pakistan. Research Square Platform LLC. https://doi.org/10.21203/rs.3.rs-2284023/v1

111. Waseem, M., Tahir, A. U., & Majeed, Y. (2023). Printing the future of food: The physics perspective on 3D food printing. In Food Physics (Vol. 1, p. 100003). Elsevier BV. https://doi.org/10.1016/j.foodp.2023.100003

112. Waseem, M., Khan, M. U., Majeed, Y., Ntsefong, G. N., Kirichenko, I., Klopova, A., Trushov, P., & Lodygin, A. (2023). Seaweed-based films for sustainable food packaging: properties, incorporation of essential oils, applications, and future directions. In Potravinarstvo Slovak Journal of Food Sciences (Vol. 17, pp. 899–917). HACCP Consulting. https://doi.org/10.5219/1908

113. Majeed, Y., & Waseem, M. (2022). Postharvest Handling Systems. In Encyclopedia of Smart Agriculture Technologies (pp. 1–9). Springer International Publishing. https://doi.org/10.1007/978-3-030-89123-7_125-1

114. Majeed, Y., Khan, M. U., Waseem, M., Zahid, U., Mahmood, F., Majeed, F., Sultan, M., & Raza, A. (2023). Renewable energy as an alternative source for energy management in agriculture. In Energy Reports (Vol. 10, pp. 344–359). Elsevier BV. https://doi.org/10.1016/j.egyr.2023.06.032

Funds:

This research received no external funding.

Acknowledgments:

We would like to thank Dr. Abid Aslam Maan for providing the equipment and other necessary sources to conduct our research work at the canning hall, University of Agriculture, Faisalabad.

Conflict of Interest:

The authors declare no conflict of interest.

Ethical Statement:

This article does not contain any studies that would require an ethical statement.

Contact Address:

Muzammal Shafiq, University of Agriculture, Faisalabad, Department of Food Engineering, Pakistan
Tel.: +923474943238
E-mail: muzammalshafiq833@gmail.com
ORCID: https://orcid.org/0000-0003-4052-8857

Muhammad Waseem, University of Agriculture, Faisalabad, Department of Food Engineering, Pakistan
Tel.: +923117002248
E-mail: waseemsofficial@gmail.com
ORCID: https://orcid.org/0000-0002-7387-6201

***Yaqoob Majeed**, University of Agriculture, Faisalabad, Department of Food Engineering, Pakistan
Tel.: +923006815542
E-mail: yaqoob.majeed@uaf.edu.pk
ORCID: https://orcid.org/0000-0003-1782-3436

Muhammad Arslan Khalid, University of Agriculture, Faisalabad, Department of Food Engineering, Pakistan
Tel.: +923136640046
E-mail: chadury.arslan@gmail.com
ORCID: https://orcid.org/0000-0002-4116-2669

Tayyaba Nadeem, Government College Women University Faisalabad, Faisalabad, Department of Food Science and Technology, Pakistan,
Tel.: +923356767248
E-mail: tayyabasofficial@gmail.com
ORCID: https://orcid.org/0000-0001-8089-9885

Maksim Rebezov, V. M. Gorbatov Federal Research Center for Food Systems, Department of Scientific Research, 26 Talalikhin Str., Moscow, 109316, Russia; Ural State Agrarian University, Department of Biotechnology and Food, 42 Karl Liebknecht Str., Yekaterinburg, 620075, Russia,
Tel.: +79999002365
E-mail: rebezov@ya.ru
ORCID: https://orcid.org/0000-0003-0857-5143

Mars Khayrullin, Moscow State University of technologies and management (The First Cossack University), Department of Scientific Research, K.G. Razumovsky, 73 Zemlyanoy Val, Moscow, 109004, Russia,
Tel.: +79049755219
E-mail: 89049755219@ya.ru
ORCID: https://orcid.org/0000-0003-1697-7281

Orynzhamal Sarsembenova, Almaty University of Energy and Communication, Department of Engineering Ecology and Occupational Safety; Gumarbek Daukeev, Almaty, 050000, Kazakhstan,
Email: oryn23@mail.ru
ORCID: https://orcid.org/0000-0001-8089-9885

Corresponding author: *