Food Technology Research Journal, Vol. 9, issue 2, 89-104, 2025

FTRJ

Nutritional and Sensory Evaluation of Extruded Snacks Fortified with Dairy By-Products

[1]Nahed, A.A. Elwahsh, [2]Sahar, S. El-Gohery, [*1]Amany, M. El-Deeb & [3]Mehanna, N.M.

[1]Dairy Research Department, Food Technology Research Institute, Agricultural Research Center, Giza, Egypt.

[2]Bread and Pastry Research Department, Food Technology Research Institute, Agricultural Research Center, Giza, Egypt

[3] Dairy Department, Faculty of Agriculture, Kafr elsheikh University, Egypt

Original Article

Article information
Received 22/08/2025
Revised 25/09/2025
Accepted 27/09/2025
Published 29/09/2025
Available online
30/09/2025

Keywords:
Extruded snacks, dairy by-products, butter milk powder, sweet whey powder

ABSTRACT

This study evaluated the incorporation of buttermilk powder (BMP) and sweet whey powder (SWP) into corn rice extruded snacks, focusing on nutritional, physical, and sensory properties. Fortification significantly increased protein, fat, ash, and essential minerals, with BMP enhancing calcium levels and SWP improving magnesium and phosphorus contents. Amino acid analysis revealed higher essential and non-essential amino acids, particularly glutamic acid and leucine, in fortified samples. Physical quality was maintained at 5–10% substitution, whereas 15% led to reduced expansion and increased hardness. Sensory evaluation confirmed that moderate BMP or SWP inclusion produced snacks with acceptability comparable to the control. Overall, dairy by-product incorporation at 5–10% effectively improves the nutritional profile of extruded snacks without compromising consumer preference, offering a sustainable approach to value-added product development.

1. Introduction

Extruded snacks are a category of ready-to-eat (RTE) food products made from starchy materials such as cereals and legumes. They are typically consumed between meals due to their convenience, affordability, long shelf life, and sensory appeal (Singh et al., 2007; Brennan et al., 2011; Mironeasa et al., 2023). The global snack food market has experienced remarkable growth in recent decades, particularly among children and young adults who prefer portable, flavorful, and crispy options (Popkin & Duffey, 2010). However, the nutritional quality of many commercial extruded snacks remains suboptimal, as they are often high in refined carbohydrates, fats, and salt, while being deficient in essential nutrients such as protein, fiber, vitamins, and minerals (Soni et al., 2020). Extrusion cooking is a versatile high-temperature, short-time (HTST) processing technique that simultaneously applies heat, pressure, and shear. This process leads to starch gelatinization, protein denaturation, and complex structural transformations, resulting in expanded, crispy textures (Guy, 2001; Singh et al., 2007). Moreover, it enables the incorporation of novel and underutilized ingredients, creating opportunities to develop nutritionally enhanced functional snacks with improved bioavailability and desirable sensory characteristics (Yadav et al., 2020a). In response to increasing consumer awareness and the growing demand for health-oriented products, the food industry is actively exploring the incorporation of functional ingredients and nutrient-rich by-products to enhance the nutritional profile of extruded snacks. Dairy by-products, particularly sweet whey powder (SWP) and buttermilk powder (BMP), represent promising options for value addition due to their high levels of quality proteins, bioactive compounds, and functional properties (Onwulata et al., 2001; Sodini et al., 2006).

Journal website: https://ftrj.journals.ekb.eg/
Published by Food Technology Research Institute, ARC
https://10.21608/ftrj.2025.457873

*Corresponding Author
Email: amanyeldrini@gmail.com

Whey proteins are an excellent source of essential amino acids and biologically active peptides, including β-lactoglobulin, α-lactalbumin, and lactoferrin. These proteins not only enrich the nutritional profile of food products but also play a vital role in maintaining textural integrity, expansion, and emulsification during extrusion (Gong et al., 2021; Onwulata, 2010). Moreover, whey-derived peptides have been linked to a variety of health benefits, such as antioxidant, antihypertensive, and immunomodulatory effects (Korhonen & Pihlanto, 2006). On the other hand, buttermilk powder (BMP) is a valuable dairy ingredient rich in milk fat globule membrane (MFGM) components, including phospholipids, sphingolipids, and membrane-associated proteins. These constituents contribute to flavor development, improve creaminess, and promote the formation of stable emulsions (Zanabria Eyzaguirre & Corredig, 2011; Guyomarc'h et al., 2015). In addition, BMP enhances water-binding capacity and supports Maillard-induced color formation, thereby improving the overall sensory appeal of extruded snacks. Several studies have demonstrated the feasibility and benefits of incorporating dairy by-products in extrusion. For example, Onwulata et al. (2001) developed protein-enriched extrudates using whey proteins, which enhanced product expansion and crunchiness. In Egypt, Abd El-Gahany et al. (2013) incorporated whey protein concentrate into puffed corn snacks, achieving favorable textural and nutritional outcomes. Similarly, Makowska et al. (2016a) reported increased protein content and improved consumer acceptability when nanofiltered whey powder was used in corn-based extrudates. The type and level of milk proteins used in extrusion play a critical role in determining rheological and functional properties, including nitrogen solubility index, water-holding capacity, and product hardness (Allen et al., 2007). Moreover, interactions between dairy proteins and starch during extrusion strengthen the matrix structure, enhance crispiness, and reduce undesirable oil uptake during frying or post-processing (Soni et al., 2020; Brennan et al., 2011). In line with sustainable development goals and global efforts to minimize food processing waste, the valorization of dairy by-products represents an environmentally and economically viable approach. This strategy not only converts residual streams into value-added ingredients but also promotes resource efficiency, supports the circular economy, and fosters clean-label food innovation (Toldrá et al., 2021). Therefore, the present study aims to formulate and evaluate extruded snacks by incorporating buttermilk powder (BMP) and sweet whey powder (SWP) into cereal-based matrices. The objectives are to enhance nutritional content, improve textural and sensory properties, and promot sustainability in food manufacturing.

2. Materials and Methods

Materials

Raw Materials

Buttermilk powder (BMP) and sweet whey powder (SWP) were sourced from Germany and Turkey, respectively, and supplied by Froneri Company, 6th of October City, Giza, Egypt. Yellow corn grits (Corn 108 variety) were obtained from El-Suez Company, Sadat City, Minoufia Governorate, Egypt. Rice flour (particle size: 180 μm) and corn oil were purchased from a local market in Shibin El-Kom, Egypt.

Preparation of extruded snacks

Seven formulations, including a control, were developed using the above-mentioned raw materials. The detailed ingredient compositions are provided in Table 1. A base blend consisting of 0.800kg of corn grits and 0.200kg of rice flour was prepared and thoroughly mixed. Portions of this blend were then partially substituted with BMP and SWP at replacement levels of 5%, 10%, and 15%, respectively. For each formulation, 15g of corn oil and sufficient water were added to achieve a final feed moisture content of 14%. The mixtures were homogenized and allowed to rest for one hour for pre-conditioning. Extrusion was performed using a single-screw extruder (model AEV300), equipped with a feeding device, speed control, and temperature regulators for the three main zones: feeding, cooking, and die. The process was carried out at Al-Rowad Food Industries Company, Shobra-Khalfon, Shibin El-Kom, Minoufia, Egypt. The operational parameters employed during extrusion are presented in Table 2. The resulting extrudates were dried in an electric air oven at 105°C for 5 mechanically packaged in polyethylene bags. Samples were stored at ambient temperature (25±2°C) until further analysis.

Table 1. Composition of snack formulations with buttermilk and sweet whey powder replacements

Blends	Raw materials (g)			
	Mixture of Corn grits and rice flour	Butter milk Powder (BMP)	Sweet Whey powder (SWP)	Corn oil
Control	1000	---------	----------	15
Snack with 5% BMP (B1)	0.950	50	----------	15
Snack with 10% BMP (B2)	0.900	100	----------	15
Snack with 15% BMP (B3)	0.850	150	----------	15
Snack with 5% SWP (W1)	0.950	---------	50	15
Snack with 10% SWP (W2)	0.900	---------	100	15
Snack with 15% SWP (W3)	0.850	----------	150	15

Table 2. Operating parameters of the extrusion process used for snack production

Temperature of feeding zone	100ºC
Temperature of cooking zone	160ºC
Temperature of die zone	180ºC
Feeding screw speed	160 rpm
Barrel screw speed	250 rpm
Screw compression	4:1
Die diameter	2.5mm

Methods

Chemical Analysis

The chemical composition of the raw materials and extruded snack samples was determined for moisture, crude fat, total protein (TP), and ash content using standard AOAC (2012) procedures. Total carbohydrate content was calculated by difference according to AOAC (2012).

Mineral contents, including calcium (Ca), phosphorus (P), magnesium (Mg), and zinc (Zn), were analyzed using atomic absorption spectrophotometry (Varian SpectrAA Models 100 and 200), following AOAC (2000) methods.

Amino acid composition was determined according to AOAC (2016) using an Amino Acids Analyzer (Eppendorf LC 3000 EZChrom).

Sensory evaluation of extruded snacks

Sensory evaluation of the extruded snack samples was carried out by a panel of twenty trained and experienced scientists from the Food Technology Research Institute, Agricultural Research Center, Giza, Egypt. Panelists were trained to assess sensory attributes including color, flavor, texture, taste, and overall acceptability. A nine-point hedonic scale was employed, where 1 = dislike extremely and 9 = like extremely (Predieri et al., 2021).

Physical Properties

Expansion ratio (ER): The expansion ratio was calculated by dividing the average diameter of extrudates (d1) by the diameter of the die (d2), according to Brennan et al. (2008). Five replicates of each sample were measured using a vernier caliper :

$$ER\ (\%) = d1 / d2$$

Where, d1 is the diameter of extruded sample (mm) and d2 is the diameter of the die (mm).

Bulk density (ρ_b) Bulk density was calculated by measuring the actual dimensions (diameter and length) of five randomly selected extrudate samples. Their weights were determined using an electronic balance (accuracy ±0.001g). Bulk density was calculated assuming cylindrical shape (Alvarez-Martinez et al., 1988):

$$\rho b\ (g/cm^3) = 4m / \pi d^2 L$$

Where, m is the weight (g), d is the diameter (cm) and L is the length of the extrudate (cm).

Apparent density (ρ_s) was estimated according to Onyango et al. (2004). Extruded samples were milled and sieved.

A 10ml graduated measuring cylinder was used, gently filled with ground sample, and then weighed. The apparent density (ρs) of the extruded samples was calculated as mass per unit volume (g⁄cm^3). Five measurements were performed to calculate the average.

$$\rho s\left({}^{g}/_{cm^3} \right) = \frac{weight\ of\ extruded\ sample}{volume\ of\ extruded\ sample}$$

Porosity of extruded samples was determined from the bulk volume and apparent volumes (Ali et al, 1996). Porosity was calculated using the equation:

$$Porosity = \frac{Bulk\ volume - Apparent\ volume}{Bulk\ volume}$$

Where, Bulk volume= 1⁄ρ_b and

Apparent volume= 1⁄ ρ_s

Water absorption (WAI) and solubility indices (WSI)

Water absorption were measured as described by Dias-Martins et al., (2024). The extrudates samples were milled to a mean particle size of approximately 180-250 µm. 0.5 g of the ground sample was dispersed in 10 ml of distilled water in a tared centrifuge tube using a rod to break up any lumps. After stirring for 30 minutes with intermittent shaking every 5 minutes. It was centrifuged (Model: PRO-ANALYTICAL.C400, UNITED KINGDOM) at 4000 rpm for 15 minutes. The supernatant was decanted into a petri dish and dried at 105ºC until it reached a constant weight. The weight of the gel remaining in the centrifuge tube was noted. The results were expressed as the average of three measurements.

WAI (g/g) = weight of gel/Dry weight of sample

WSI (%) = Weight of dry solid in supernatant/Dry weight of original sample × 100

Colour measurement

Colour attributes of snack samples after grinding were performed using the CIE L*a*b* system by a Chroma-meter (Minolta, Tokyo, Japan) with a D65 illuminant. The L* value (lightness index scale) ranges from 0 (black) to 100 (white) while, the a* value indicates the redness (+a) or greenness (−a*) and the b* value refers to the yellowness (+b) or blueness (−b*) measurements obtained directly from the instrument. Every measurement was taken three times (Lee et al., 2013).

where, in respect to parameters at time zero, the variations of the a* coordinate are denoted by Δa*, b* by Δb*, and L* by ΔL*

$$\Delta E = \sqrt{(\Delta L*)^2 + (\Delta a*)^2 + (\Delta b*)^2}$$

Water Activity (a_w) was measured using the Rotronic Hygrolab 3CH 8303, (Switzerland) at 25±2°C (Shahidi et al., 2008).

Texture Analysis

The texture analysis of extruded samples was conducted using a texture analyzer set (Ct3 Texture Analyzer Version 2.1, 10000 Gram unit, Brookfield, Engineering Laboratories, Inc. MA 02346-1031, USA) according to the method outlined in the AACC (2010). Measurements were conducted in triplicate.

Statistical Analysis

Data were analyzed using one-way ANOVA within the General Linear Model (GLM) framework, following the method of Snedecor and Cochran (1980). Significant differences among means ($p < 0.05$) were determined using Duncan's multiple range test via SPSS software (version 26.0, IBM Corp., Armonk, NY). Results are presented as mean ± standard deviation (SD) based on three replicates.

3. Results and Discussion

Chemical composition of raw materials and snacks study

The proximate chemical compositions of the raw materials utilized in this study are detailed in Table 3. The results show that buttermilk powder (BMP) contains a high percentage of protein (32.8%) while the lowest protein content is found in corn grits (6.54%). Additionally, the highest value of moisture content is found in rice flour (9.87%), while the lowest moisture content is recorded in sweet whey milk powder (4.03%). The highest content of fat is found in buttermilk powder (6.40%), but the lowest content is in rice flour (0.53%). The highest value of ash content is noticed in sweet whey powder (7.61%), while the lowest is found in corn grits (0.31%). The type and level of milk proteins used in extrusion significantly affect rheological and functional characteristics, such as nitrogen solubility index, water holding capacity, and hardness of the final product (Allen et al., 2007a).

Table 3. Composition of raw materials (g/100g) used in snack preparation *

Ingredient	Moisture (%)	Fat (%)	Protein (%)	Ash (%)	Carbohydrate (%)
Buttermilk powder (BMP)	4.08 ± 0.40	6.40 ± 0.19	32.8± 0.26	6.06 ± 0.21	50.07±0.07
Sweet milk powder (SWP)	4.03 ± 0.33	1.41± 0.1	12.49 ± 0.69	7.61± 0.12	72.28±0.22
Corn grits	9.54± 0.10	1.67± 0.31	6.54± 0.3	0.31± 0.07	80.74±0.34
Rice flour	9.87± 0.13	0.53± 0.35	7.18± 0.24	0.56 ± 0.06	81.15±0.16

*Means ± SD of five determinations

Table 4 shows the gross chemical composition of all snack samples as affected by adding butter- milk powder (BMP) and sweet whey powder (SWP). The extrusion control (mixture of corn grits and rice flour) recorded a moisture content of extruded snacks prepared ranging between (4.89 to 5.54%). These results are in agreement with Ziena and Ziena (2022), who reported a decrease in moisture content from 7.38% (control) to 6.79% in the extrudate samples. It is evident that there was a significant decrease in moisture content as a direct result of the extrusion process, especially due to the heat and pressure factors generated inside the extruder. The data showed that all values are within the allowed limits mentioned in the Egyptian standard specifications (EES 1525/2005), which recommend that the moisture content should not exceed 5% because food with low moisture content would limit microbial growth and extend the storage period, as recorded by Okiki et al. (2015). Snacks with butter milk powder (BMP) had higher values in this respect, which could be due to the functional properties of milk proteins. The use of BMP or SWP significant ($p \leq 0.05$) increased fat, protein and ash contents compared to the control. However, the higher was the replacement level of BMP and SWP, the higher the recorded values. The protein content of the produced snacks ranged from 13.53% for B3 to 10.76 % for W1, while the control samples had 7.91%, which is lower than the recommendation of FAO (2001), of at least 12% crude protein in snacks. Extrudates from corn flour enriched with whey protein concentrate represent a high quality source of proteins and fats (Brncic et al.,2010). Incorporation of milk proteins into maize composite extrudates improved the nutritional value, increasing the protein content of the wholesome product (Ponbhagavathi et al.,2018).The extrusion process does not influence the overall protein content even under severe extrusion conditions as reported by (Onwulata et al.,2003). The increase in protein content is due to the 15% incorporation of buttermilk powder and sweet whey powder and the developed extrudates can improve protein digestibility through the inactivation of enzyme inhibitors and denaturation of proteins in the raw material, making them more susceptible to enzyme attack and enhancing the bioavailability of protein in agreement with Beigh et al., (2020). Onwulata et al., (2003) mentioned that the extrusion process does not influence the overall protein content even under severe extrusion conditions. On the other hand, the control had higher carbohydrate content than all treated samples and this decrease was proportional to the amount of BMP and SWP applied. These results are in agreement with the findings of Abd El-Ghany et al.(2013) who observed a similar effect when different milk protein preparations were used in making crispy puff snacks. In all cases, the impacts of BMP and SWP are mainly due to their richness in protein and fat while corn grits and rice flour had more carbohydrate content as shown in Table 3. The use of whey powder contributes to nutrient integrity and balance, as well as having optimal rheology (Gong et al., 2021a), when mixed with rice, corn, and chickpeas to make extruded products.

Amino acids composition of snacks samples

The amino acids composition was determined for the best samples (B2 and W2) after sensory evaluation compared to the control, as shown in Table 5. Snack foods based on cereals and grains are low in some essential amino acids like threonine, tryptophan, and lysine (Ahmad et al., 2017). The nutritive quality of protein depends on its content of essential amino acids. Nine amino acids are strictly essential for humans: phenylalanine, isoleucine, leucine, lysine, methionine, threonine, tryptophan, valine, and histidine (essential in childhood) (WHO, 2007).

The addition of butter milk powder (BMP) or sweet whey powder(SWP) increased the concentration of most essential and non-essential amino acids, compared to the control. When butter milk powder (BMP) was added to corn-based snacks, (B2) showed higher levels of total amino acids (8.68g/100g) than sweet whey powder (W2- 8.04g/100g) and when corn was used alone (control- 6.68g/100g).

Table 4. Chemical composition (%) of extruded snacks samples

Parameter	Moisture	Fat	Protein	Ash	Carbohydrate
Control	5.54±0.04[a]	1.02±0.03[e]	7.91±0.12[f]	1.43±0.03[f]	83.94±0.36[a]
B1	5.13±0.12[bc]	1.23±0.10[c]	11.20±0.25[d]	1.61±0.02[e]	80.60±0.18[c]
B2	5.22±0.11[b]	1.42±0.03[b]	12.31±0.37[cd]	1.85±0.02[d]	79.01±0.19[d]
B3	4.89±0.01[d]	1.53±0.02[a]	13.53±0.33[a]	2.64±0.02[b]	77.33±0.02[f]
W1	5.05±0.11[cd]	1.13±0.10[d]	10.76±0.20[e]	1.44±0.02[f]	81.54±0.52[b]
W2	5.19±0.25[c]	1.36±0.042[b]	12..67±0.24[c]	1.96±0.02[c]	78.75±0.23[e]
W3	5.25±0.12[b]	1.53±0.03[a]	13.30±0.15[b]	2.72±0 .02[a]	77.06±0.11[g]

Means ± SD followed by different letters in the same column are significantly different at P < 0.05 C: control
B1: snacks with 5% BMP W1: snacks with 5% SWP
B2: snacks with 10% BMP W2: snacks with 10% SWP
B3: snacks with 15% BMP W3: snacks with 15% SWP

Table 5. Amino acid profile (g/100gm) of snacks samples

Amino acids	Control	B2	W2
	Essential amino acids		
Histidine	0.19	0.25	0.23
Isoleucine	0.23	0.35	0.33
Leucine	0.81	0.98	0.95
Lysine	0.13	0.23	0.19
Methionine	0.18	0.18	0.16
Phenylealanine	0.38	0.43	0.45
Therionine	0.23	0.34	0.31
Valine	0.30	0.43	0.40
Total E.A.A	2.45	3.19	3.02
Non-Essential amino acids			
Alanine	0.44	0.53	0.51
Argnine	0.30	0.33	0.32
Aspartic acid	0.43	0.65	0.59
Cystine	0.15	0.28	0.19
Glycine	0.34	0.36	0.31
Glutamic	1.41	1.93	1.74
Proline	0.51	0.71	0.62
Serine	0.30	0.39	0.36
Tyrosine	0.35	0.31	0.38
Total non-E.A.A	4.23	5.49	5.02
Total amino acids	6.68	8.68	8.04

B2: snacks with 10% BMP W2: snacks with 10% SWP

Results agree with Ziena and Ziena (2022) who reported that the total essential amino acids increased significantly ($P \leq 0.05$) in snacks samples compared to the control. Data showed higher content in essential amino acids were leucine (0.98g/100g) and phenylealanine (0.43g/100gm protein) in B2 extruded samples. Treatments B2 and W2 showed higher Glutamic content (1.93 and 1.74g/100g protein, respectively), followed by proline levels, recording 0.71 and 0.62 g/100g as non- essential amino acids compared to the control. These results agree with Natsir et al. (2019), who showed that glutamic acid was an amino acid with the highest concentration in snacks samples. When whey protein was added to corn-based snacks, data reported a higher levels of essential and non-essential amino acids than when corn was used alone. Moreover, the conditions utilized throughout the extrusion process had no significant impact on the amino acid content (Bayomy et al.,2024). On the other hand, extrusion could provide positive impact on the

On the other hand, extrusion could provide positive impact on the amino acid profile (Nadeesha Dilrukshi et al., 2022; Saadat et al., 2020). One of the primary goals of adding whey protein to both rice based on resistant starch and corn, was to increase the amount and quality of protein in the extruded product. To improve the nutritional values of the extruded foods, protein from natural sources is recommended to be combined with other foods or grains (Saadat et al., 2020). The essential amino acids are necessary for tissue maintenance and are also required for the growth of child. The daily protein requirement for infancy is between 1.6 to 2.5 grams per kilogram of body weight/ per day. Approximately 40% of the total protein intake should come from essential amino acids (FAO, 1991).

Mineral contents of snacks samples

Elements such as calcium (Ca), magnesium (Mg), sodium (Na), potassium (K), iron (Fe), and zinc (Zn) are essential for human health (Jomova et al., 2022). Minerals are heat stable and are unlikely to be lost in the extrusion process. The major health benefits of buttermilk arise from its high content of minerals and vitamins (Ali, 2019). Minerals like calcium, phosphorus, potassium, sodium and magnesium are available as constituents of whey, which are required for normal health and supplementation in case of gastro intestinal disorders (Lifrah et al., 2000). Table 6 shows the concentrations of four elements (Ca, Mg, P and Zn) as affected in snacks samples with the addition of butter milk powder (BMP) and sweet whey powder (SWP). The calcium content of control snacks was 48.42mg/100g, and it increased to 110.46, 171.61 and 231.10mg/100g when BMP was used in concentrations of 5% (B1), 10% (B2) and 15% (B3). Asimilar increase was recorded with SWP (5%, 10% and 15%) in Ca content (87.12, 123.45 and 158.24mg/100g) in snacks, respectively. Significant differences in the concentrations of Ca values were observed between snacks samples fortified with BMP compared to SWP. Whey-based products are an excellent and cost efficient source of calcium (500-2,000mg/100g) (DiRienzo, 2001). Additionally, similar increase was recorded with respect to Mg, P and Zn in snacks samples compared to the control, but mean levels for Mg and P in snacks with the addition of sweet whey powder (SWP) were significantly higher than snacks fortified with butter milk powder (BMP). Similarly, the control extruded product exhibited the lowest elemental content compared to treated extruded products fortified with whey protein (Bayomy et al.,2024). The different formula of snacks samples caused a significant increase in the content of mineral elements compared to the control (Ziena and Ziena, 2022). The intake of calcium, magnesium, and phosphorusis required for bone and teeth development and fortification. In addition, these elements are also needed along with sodium and potassium for metabolic processes, such as of proteins and DNA synthesis, nerve impulses, muscle contraction and relaxation and osmotic balance, among other (NA SEM, 2016).

Table 6. Minerals content (mg/100gm) of snacks samples

Minerals (mg/100gm)	Calcium (Ca)	Magnesium (Mg)	Phosphorus (P)	Zinc (Zn)
Control	48.42±2.36^{g}	37.15±3.07^{e}	225.59±2.16^{f}	1.48±0.02^{f}
B1	110.46±3.15^{e}	44.29±2.52^{de}	254.69±2.98^{e}	2.04±0.03^{d}
B2	171.61±2.46^{b}	45.61±3.07^{cd}	283.98±2.99^{c}	2.63±0.22^{b}
B3	231.10±3.14^{a}	51.36±4.19^{c}	304.65±2.68^{b}	3.21±0.15^{a}
W1	87.12±3.79^{f}	48.86±2.14^{cd}	261.25±3.08^{d}	1.82±0.08^{e}
W2	123.45±4.24^{d}	56.92±2.16^{b}	300.06±2.70^{b}	2.16±0.15^{cd}
W3	158.24±3.20^{c}	65.05±2.16^{a}	328.71±3.31^{a}	2.40±0.06^{c}

Means ± SD followed by different letters in the same column are significantly different at P < 0.05

Physical properties of extruded snacks

The data presented in Table 7 illustrate the impact of different treatments involving the addition of buttermilk powder (BMP) and sweet whey powder (SWP) on the physical properties of extruded snacks. These properties include expansion ratio, bulk density, apparent density, and porosity, which serve as key indicators for evaluating the quality of the final product. Among these, the expansion ratio is a crucial parameter for assessing the quality of extruded cereal products. It is closely linked to bulk density and serves as a fundamental measure of the degree of puffing in extrudates (Abd El-Ghany et al., 2013). The results demonstrate the effect of varying levels of buttermilk powder (B1, B2, B3) and sweet whey powder (W1, W2, W3) on the expansion ratio compared to the control sample. A slight reduction in the expansion ratio was observed in B1 (4.16) and B2 (4.08) compared to the control (4.40). However, a significant reduction was recorded in B3 (2.00), which may be attributed to the high substitution level. Increased replacement rates likely decreased starch content while increasing protein content, thereby compromising expansion (Gomes et al., 2023). In contrast, the addition of sweet whey powder did not negatively affect expansion to the same extent. Samples W1 and W2 exhibited expansion ratios comparable to the control, whereas an increase in W3 led to a reduction, though not as pronounced as in B3. Previous studies suggest that protein content influences the expansion ratio, as the molecular structure and conformation of proteins affect water distribution within the matrix, thereby impacting the stretching properties of the material during extrusion cooking (Moraru & Kokini, 2003). Furthermore, Korkerd et al. (2016) reported that the addition of milk proteins in the formulation may have facilitated interactions between corn flour constituents particularly proteins and lipids with milk proteins. This interaction could have reduced starch swelling and, consequently, expansion. A similar trend was observed by Yadav et al. (2020b), where increasing levels of WPC-70 reduced snack expansion. Likewise, Allen et al. (2007a) reported reduced expansion with increasing whey protein concentrations due to starch–protein interactions. The data also show the values of bulk and apparent density. Bulk density ranged between 0.08 and 0.12g/cm³, with the highest value observed in sample W3 (0.12g/cm³), suggesting that increasing sweet whey powder content may result in denser products. Conversely, sample B3 recorded the lowest bulk density (0.01 g/cm³), which could be attributed to the structural effect of buttermilk powder at high levels. These findings align with those of HewaNadungodage et al. (2022), who reported that the bulk density of extrudates shows a significant positive correlation with protein and fiber content and a negative correlation with starch content. This phenomenon can be explained by the incorporation of protein-rich raw materials. In this context, Hagenimana et al. (2005) reported that caseinate exhibited lower bulk density values. Similarly, according to HewaNadungodage et al. (2022), increasing protein levels alter the granular structure of the product, leading to higher apparent density but lower bulk density. Porosity is another crucial factor in determining texture, as it reflects the formation of air pockets during extrusion. The control sample had a porosity of 0.60, comparable to B1 and W1, indicating that low levels of dairy substitution do not significantly affect porosity. The highest porosity (B3: 0.98) was significantly ($p < 0.05$) different from the other samples, suggesting that higher levels of buttermilk powder cause substantial structural changes. The W3 sample (0.73) also showed a notable increase, though its porosity remained lower than that of B3. Based on these results, it can be concluded that incorporating buttermilk powder or sweet whey powder at moderate levels (B1, B2, W1, and W2) improves certain physical properties without significantly affecting expansion. However, higher levels may increase density and reduce expansion. Specifically, the use of buttermilk powder at high levels (B3) may not be suitable for extruded snacks, as it reduces expansion and increases porosity. During the extrusion process, starch granules are disrupted by shear forces, allowing water molecules to penetrate. Higher Water Solubility Index (WSI) indicate extensive dextrinization of starch molecules, whereas large gelatinized starch fragments contribute to higher Water Absorption Index (WAI) values (Cuj-Laines et al., 2018). Results in Table 8 show that the control sample had the highest WSI value (21.23%), reflecting a greater extent of starch breakdown due to processing conditions. Among the formulated samples, B1 (19.59%) and W1 (18.10%)

showed relatively high solubility, suggesting moderate dextrinization. Conversely, B3 recorded the lowest WSI value (11.54%), likely due to increased protein content and reduced starch degradation, as previously reported in studies on the effect of protein on extruded product properties (Dewidar & El-Ghandour, 2020; HewaNadungodage et al., 2022). The Water Absorption Index (WAI) measures the ability of food material to absorb and retain water, which is essential in extruded snack production as it influences texture, expansion, and product quality. WAI depends on the availability of hydrophilic groups that bind water molecules and on the gel-forming capacity of macromolecules (Abd El-Ghany et al., 2013). According to the data, the highest WAI value was recorded in B3 (4.95g gel/g sample), likely due to its higher porosity (0.98), which increases surface area for water retention. W2 (4.81g gel/g sample) and W3 (4.49g gel/g sample) also showed relatively high WAI values, whereas the control had the lowest (3.51g gel/g sample). A non-linear relationship was observed with increasing SWP levels, as in W3, where protein aggregation reduced water interaction and absorption (Zhou et al., 2008). Protein aggregation in whey protein isolate-based systems is influenced by concentration and environmental conditions, which affect solubility and water interaction (Maticorena et al., 2018). Overall, the addition of buttermilk powder (BMP) or sweet whey powder (SWP) lowered WSI and increased WAI in all extruded samples compared with the control, consistent with the findings of Brnčić et al. (2011). Hardness is a key sensory attribute of extruded products, reflecting expansion and internal cell structure. It is quantitatively defined as the average force required for a probe to penetrate the extrudate, indicating textural properties and structural integrity (Ponbhagavathi et al., 2020). Hardness values (Table 8) for BMP-based samples ranked as: 15% BMP>control>5% BMP>10% BMP. For SWP-based samples, the ranking was: control> 10% SWP>5% SWP> 15% SWP. Generally, all samples except B3 were less hard than the control. Samples with higher WAI, such as B3 and W2, also showed greater hardness. Despite its high hardness, B3's elevated porosity (0.98) indicates a brittle structure rather than a compact one, leading to an undesirable crumbly texture instead of a crisp bite. This was supported by its low sensory texture score (5.80). The sensory evaluation (Table 9) confirmed that BMP or SWP incorporation influences hardness. Several factors may contribute to the reduction in hardness: both BMP and SWP have water-binding capacity, which alters moisture distribution within the extrudate. Anton & Luciano (2007) noted that hardness also depends on raw material composition, feed moisture, and extrusion conditions. Higher protein levels may also affect extrusion temperature and pressure, thereby influencing expansion and texture (Sumargo et al., 2016). Water activity (a_w) is another important indicator of quality and stability in extruded products. It reflects the extent to which water is available for chemical reactions and microbial growth (Makowska et al., 2014). Data in Table 8 show that aw ranged from 0.21 in the control sample to 0.41 in B3. Low aw values prolong shelf life by reducing microbial activity and chemical degradation, whereas higher values increase spoilage risk. At 25°C, foods with $a_w \leq 0.85$ are classified as low-moisture foods (LMFs), while those with $a_w > 0.85$ are considered high moisture (Liu et al., 2019). The observed association between hardness, aw, and WAI suggests that higher hardness is linked to greater water activity and absorption, likely due to starch–protein structural changes during extrusion. Color is also a critical quality attribute influencing consumer preference. The parameters L* (lightness), a* (red–green), and b* (yellow–blue) indicate how ingredient modifications affect product appearance. Incorporation of BMP or SWP significantly decreased lightness (L*) ($p \leq 0.05$) in all samples except W1 compared to the control, while redness (a*) increased significantly. This suggests protein-rich ingredients darken extrudates due to Maillard reactions during extrusion. Yellowness (b*) also increased with BMP or SWP addition, with the highest values in W2 (26.58) and W3 (26.30), indicating that SWP contributes more strongly to yellowness. These effects align with previous reports linking protein-rich formulations to enhanced yellowness due to amino acid degradation, caramelization, and pigment breakdown (Abd El-Ghany et al., 2013;

Makowska et al., 2016b; HewaNadungodage et al., 2022). The total color change (ΔE) compared to the control was highest in W1 (52.62), followed by W2 (50.21) and W3 (50.11), reflecting substantial changes with SWP incorporation. BMP samples showed lower ΔE values (B1: 46.99, B2: 46.24, B3: 47.19), indicating a milder effect on color. These findings are consistent with Yadav et al. (2020b), who reported that milk protein type and level significantly affected hardness, expansion index, and color of extruded snacks. Similarly, Abd El-Ghany et al. (2013) observed that higher dairy ingredient levels resulted in darker, more brownish extrudates, primarily due to Maillard reactions between reducing sugars (such as lactose) and proteins.

Table 7. Physical characteristics of extruded snacks

Sample	Expansion ratio	Bulk density (g/cm3)	Apparent density (g/cm3)	Porosity
Control	4.40±0.01[a]	0.08±0.02[b]	0.20±0.02[c]	0.60±0.05[b]
B1	4.16±0.21[ab]	0.09±0.01[b]	0.22±0.05[c]	0.59± 0.14[b]
B2	4.08±0.17[ab]	0.09±0.01[ab]	0.30±0.06[b]	0.70±0.08[b]
B3	2.00±0.28[d]	0.01±0.04[c]	0.42±0.04[a]	0.98±0.02[a]
W1	4.24±0.21[ab]	0.09±0.01[ab]	0.22±0.01[c]	0.59±0.05[b]
W2	4.00±0.18[b]	0.09±0.02[ab]	0.33±0.02[b]	0.73±0.05[b]
W3	3.60±0.28[c]	0.12±0.04a	0.35±0.02[b]	0.66±0.14[b]

Means ± SD followed by different letters in the same column are significantly different at P < 0.05
C: control, B1: snacks with 5% BMP, W1: snacks with 5% SWP, B2: snacks with 10% BMP, W2: snacks with 10% SWP, B3: snacks with 15% BMP, W3: snacks with 15% SW

Sensory Evaluation of Extruded Snacks samples

Sensory attributes are key factors determining consumer acceptability of extruded snacks, particularly color, flavor, texture, taste, and overall acceptability. In this study, the effects of incorporating different levels of buttermilk powder (BMP) and sweet whey powder (SWP) were evaluated in comparison with the control sample (C), and the results are presented in Table 9. The control sample achieved the highest scores across all sensory parameters, followed closely by W1 (5% SWP) and B1 (5% BMP). These treatments were not significantly different from the control, indicating that 5% substitution maintained a favorable sensory profile. A gradual decline in color scores was observed with increasing BMP or SWP levels (Fig. 1), with B3 (15% BMP) recording the lowest value (6.50). This reduction is mainly attributed to Maillard browning between lactose and free amino groups during high-temperature extrusion (Abd El-Ghany et al., 2013; Yadav et al., 2020b). For flavor, B1 and W1 recorded high acceptability scores (8.60–8.65), comparable to the control. In contrast, higher substitution levels (B3 and W3) showed reduced flavor scores (6.90 and 7.65, respectively), likely due to off-flavors or excessive browning. A similar trend was observed for texture and taste: moderate incorporation (B1, B2, W1, W2) maintained good consumer perception, while excessive addition (B3, W3) negatively affected crispness and mouthfeel. Although significant differences ($p < 0.05$) were observed among treatments, particularly at 15% substitution, all samples remained within the acceptable sensory range. Notably, B2 (10% BMP) and W2 (10% SWP) achieved scores comparable to the control in most parameters, confirming that moderate addition of dairy by-products can enhance nutritional quality without compromising sensory appeal. These results are consistent with previous studies (Makowska et al., 2016a; Ziena & Ziena, 2022), which emphasized the influence of milk derived proteins on the sensory characteristics of extrudates. Similarly, Gong et al. (2021a) reported that incorporating whey powder with cereals improves nutrient balance and supports favorable textural and rheological properties during extrusion, thereby enhancing consumer acceptance.

Table 8. Evaluation of water solubility, water absorption, hardness, water activity and color of extruded snacks

samples	Water solubility index WSI) %	Water absorption index (WAIG)g gel/g sample	Hardness	Water activity (αw)	Color measurement			
					L*	a*	b*	ΔE
Control	21.23 ± 0.31^{a}	3.51 ± 0.23^{e}	7.85 ± 0.4^{b}	$0.208\pm.01^{f}$	71.15 ± 0.15^{a}	-2.52 ± 0.23^{e}	21.40 ± 0.32^{d}	51.82 ± 0.53^{b}
B1	19.59 ± 0.19^{b}	3.69 ± 0.06^{dc}	7.03 ± 0.5^{bc}	$0.262\pm.01^{c}$	65.55 ± 0.95^{b}	2.97 ± 0.06^{d}	21.64 ± 0.25^{d}	46.99 ± 0.54^{d}
B2	$17.04\pm.09^{cd}$	3.99 ± 0.20^{cd}	4.86 ± 0.26^{de}	$0.220\pm.02^{e}$	63.76 ± 0.77^{c}	5.32 ± 0.24^{c}	22.81 ± 0.72^{c}	46.24 ± 0.26^{e}
B3	11.54 ± 0.15^{e}	4.95 ± 0.0^{3a}	10.28 ± 0.59^{a}	$0.414\pm.01^{a}$	62.66 ± 0.43^{c}	7.01 ± 0.45^{a}	25.83 ± 0.32^{a}	47.19 ± 0.23^{d}
W1	18.09 ± 0.37^{c}	4.08 ± 0.36^{c}	6.06 ± 0.35^{cd}	$0.234\pm.03^{d}$	70.24 ± 0.50^{a}	3.11 ± 0.23^{d}	24.81 ± 0.63^{b}	52.62 ± 0.34^{a}
W2	17.61 ± 0.33^{c}	4.81 ± 0.08^{ab}	7.51 ± 0.69^{bc}	$0.279\pm.01^{b}$	65.94 ± 0.13^{b}	6.43 ± 0.34^{b}	26.58 ± 0.15^{a}	50.21 ± 0.39^{c}
W3	16.12 ± 0.24^{d}	4.49 ± 0.19^{b}	4.24 ± 0.22^{e}	$0.241\pm.01^{d}$	66.10 ± 0.51^{b}	5.73 ± 0.44^{c}	26.30 ± 0.32^{a}	50.11 ± 0.19^{c}

Means ± SD followed by different letters in the same column are significantly different at $P < 0.05$ **C:** control B1: snacks with 5% BMP
W1: snacks with 5% SWP
B2: snacks with 10% BMP W2: snacks with 10% SWP
B3: snacks with 15% BMP W3: snacks with 15% SW

Table 9. Sensory Evaluation of Extruded Snacks

Sample	Color (9)	Flavor (9)	Texture (9)	Taste (9)	Overall acceptability (9)
Control	8.85±0.33^{a}	8.70±0.67^{a}	8.85±0.33^{a}	8.75±0.42^{a}	8.95±0.15a
B1	8.55±0.49^{a}	8.60±0.51^{a}	8.85±0.33^{a}	8.55±0.49^{a}	8.75±0.42^{ab}
B2	7.65±0.74^{b}	8.35±0.47^{ab}	8.65±0.47^{ab}	8.20±0.75^{a}	8.15±0.33^{bc}
B3	6.50±0.84^{c}	6.90±1.19^{c}	5.80±1.39^{d}	6.25±1.62^{c}	5.95±1.30^{e}
W1	8.70±0.42^{a}	8.65±0.66^{a}	8.68±0.33^{ab}	8.55±0.49^{a}	8.45±0.68^{abc}
W2	7.55±0.59^{b}	8.10±0.87^{ab}	7.94±0.81^{bc}	7.90±0.84^{a}	7.75±0.85^{cd}
W3	7.20±0.78^{b}	7.65±0.81^{b}	7.55±1.21^{c}	7.25±1.08^{b}	7.30±1.15^{d}

Means ± SD followed by different letters in the same column are significantly different at $P < 0.05$

C: control B1: snacks with 5% BMP W1: snacks with 5% SWP
B2: snacks with 10% BMP W2: snacks with 10% SWP
B3: snacks with 15% BMP W3: snacks with 15% SW

In conclusion the addition of BMP and SWP at levels up to 10% can be considered technologically and sensorially acceptable in extruded snack formulations. However, exceeding this level (15%) may result in undesirable changes in color, flavor, and texture, likely due to intensified Maillard browning and protein-lactose interactions under thermal stress.

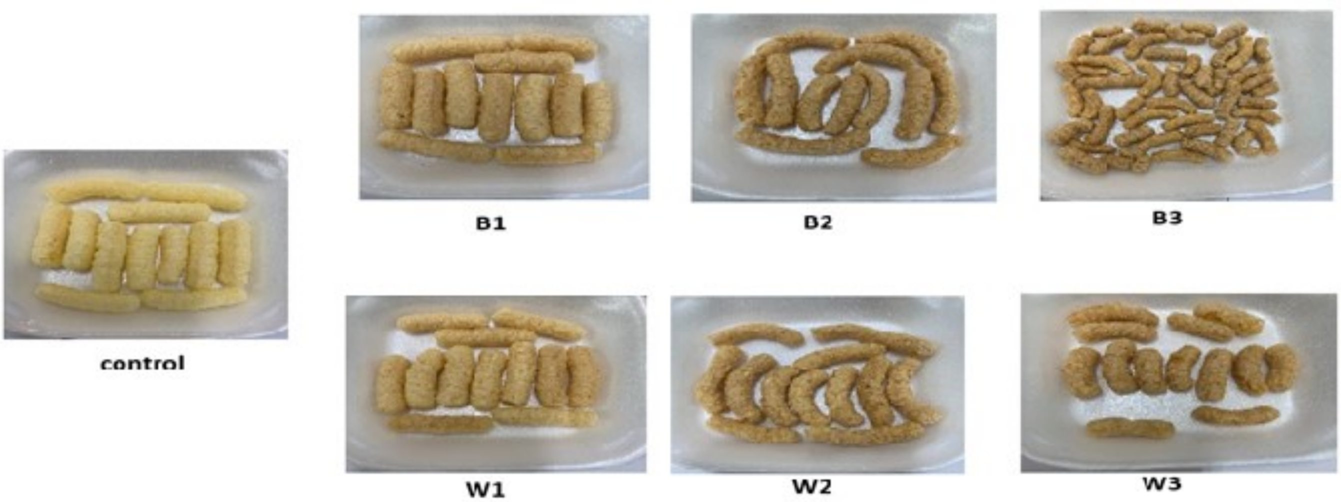

Figure 1. Snacks extrudates are prepared by incorporating corn grits with different level of butter milk powder and sweet whey powder

4. Conclusion

This study demonstrates that incorporating buttermilk powder (BMP) and sweet whey powder (SWP) into extruded cereal-based snacks at levels of 5–10% is both technologically feasible and nutritionally beneficial. Fortification significantly enhanced protein, amino acid, and mineral content without compromising sensory quality, while higher levels (15%) negatively affected texture and color. From a practical perspective, extrusion is already a widely applied, cost-effective technology, and BMP and SWP are readily available dairy by-products, making large-scale production highly feasible. The resulting products align with growing consumer demand for protein-rich, functional, and sustainable snacks. Furthermore, the use of dairy by-products contributes to waste valorization and circular economy strategies, offering both environmental and economic benefits.

In conclusion, BMP and SWP enriched extruded snacks represent a promising opportunity for the food industry to develop value added, health oriented products that combine improved nutrition, consumer acceptability and sustainability.

References

Abd El-Gahany, S.E., El-Geddawy, M.A. and El-Beltagy, A.E. (2013). Utilization of whey protein concentrate in manufacturing puffed snacks. Egyptian Journal of Dairy Science, 41(1):59–70.

Abd El- Ghany, I.H., El-Asser, M.A., Nagy, K.S. and Abd El-Maksoud, A.A. (2013). Effect of milk proteins on physical and chemical characteristics of crispy puff snacks. Journal of Agricultural Science and Technology A, 3:633–645.

Ahmad, S., Ashraf, K. and Khan, I. (2017). Quality and shelf life of snack food as influenced by incorporation of high protein pulses in multipurpose flour. Journal of Food Science and Nutrition, 3, 19–24.

Ali, A.H. (2019). Current knowledge of buttermilk: Composition, applications in the food industry, nutritional and beneficial health characteristics. International Journal of Dairy Technology, 72(2), 169–182.

Ali, Y., Hanna, M.A. and Chinnaswamy, R. (1996). Expansion characteristics of extruded corn grits. Lebensmittel-Wissenschaft und -Technologie, 29 (8), 702–707.

Allen, K. E., Carpenter, C.E. and Walsh, M.K. (2007) a . Influence of protein level and starch type on an extrusion-expanded whey product. International Journal of Food Science and Technology, 42, 953–960.

Allen, K., Carpenter, C.E. and Cornforth, D.P. (2007) b . Functional properties of milk proteins in extruded snack products. Journal of Food Science, 72(6), E309–E315.

Alvarez-Martinez, L., Kondury, K.P., & Harper, J.M. (1988). A general model for expansion of extruded products. Journal of Food Science, 53, 609–615.

Anton, A.A. and Luciano, F.B. (2007). Instrumental texture evaluation of extruded snack foods: A review. Ciência e Tecnologia de Alimentos, 5:245–251.

AOAC. (2000). Official Methods of Analysis (17th ed.). Washington, DC: Association of Official Analytical Chemists.

A.A.C.C. (2010). Approved methods of Analysis 11th edition, Methods 10-15D, and 44-15. St-, Plau. MN.

AOAC. (2012). Methods of Analysis, Vol. 1: Agricultural Chemicals, Contaminants, Drugs (19th ed.). Washington, DC.

AOAC. (2016). Official Methods of Analysis of AOAC International (20th ed.). Arlington, VA: AOAC International.

Bayomy, H.M., Alamri, E.S., Albalawi, A.N., Alharbi, R., Ozaybi, N.A., Rozan, M.A. and Shamsia, S.M. (2024). Production of extruded functional snacks based on resistant starch using waste rice and whey milk. LWT, 197, 115871.

Beigh, M., Hussain, S.Z., Qadri, T., Naseer, B., Raja, T. and Naik, H.R. (2020). Investigation of process and product parameters for physicochemical properties of low glycemic index water chestnut and barley flour-based extruded snacks. British Food Journal, 122, 227–241.

Brennan, M.A., Derbyshire, E., Tiwari, B.K. and Brennan, C.S. (2011). Ready-to-eat snack products: The role of extrusion technology in developing functional snacks. Trends in Food Science & Technology, 22(11):599–606.

Brennan, M.A., Merts, I., Monro, J., Woolnough, J. and Brennan, C.S. (2008). Impact of guar and wheat bran on the physical and nutritional quality of extruded breakfast cereals. Starch, 60, 248–256.

Brnčić, M., Karlović, S., Rimac Brnčić, S., Bosiljkov, T., Ježek, D. and Tripalo, B. (2010). Textural properties of infrared dried apple slices as affected by high power ultrasound pre-treatment. African Journal of Biotechnology, 9(41):6907–6915.

Cuj-Laines, R., Hernández-Santos, B., Reyes-Jaquez, D., Delgado Licon, E., Juárez-Barrientos, J.M. and Rodríguez-Miranda, J. (2018). Physicochemical properties of ready-to-eat extruded nixtamalized maize-based snacks enriched with grasshopper. International Journal of Food Science and Technology, 53(8):1889–1895.

Dewidar, O.M. and Hanan, M. (2020). Development of extruded snacks and corn flakes using yellow corn and by-product broken beans. Middle East Journal of Applied Science, 10(2):390–406.

Dias-Martins, A.M., Trombete, F.M., Cappato, L.P., Chavez, D.W.H., Santos, M.B. and Carvalho, C. W. P. (2024). Processing, composition, and technological properties of decorticated, sprouted, and extruded pearl millet (Pennisetum glaucum (L.) R. Br.) flours. Journal of Food Process Engineering, 47(2), Article e14561. https://doi.org/ 10.1111/jfpe.1456

FAO. (1991). Protein Quality Evaluation (FAO Food and Nutrition Paper No. 51). Bethesda, MD: Joint FAO/WHO Expert Consultation.

FAO. (2001). The State of Food and Agriculture 2001 (No. 33). Rome: Food and Agriculture Organization.

Gomes, K.S., Berwian, G.F., Tiepo, C.B. and Colla, L.M. (2023). Development and evaluation of extruded protein snacks added lentil and texturized soy protein. Food Science and Technology, Campinas, 43, e1123. https://doi.org/10.5327/fst.1123

Gong, W., Guo, X., Huang, H., Li, X., Xu, Y. and Hu, J.-N. (2021)a. Structural characterization of modified whey protein isolates using cold plasma treatment and its applications in emulsion oleogels. Food Chemistry, 356, Article 129703. https://doi.org/10.1016/j.foodchem.2021.129703

Gong, Z., Zhu, J. and Cheng, Y. (2021)b. Functional and nutritional evaluation of extruded snacks enriched with whey protein and cereal blends. Food Hydrocolloids, 113, 106456.

Guy, R.C.E. (2001). Extrusion cooking: Technologies and applications. Woodhead Publishing.

Guyomarc'h, F., Nono, M. and Lopez, C. (2015). Buttermilk: Composition and potential uses in dairy technology and nutrition. Dairy Science & Technology, 95(4):579–596.

Hagenimana, A., Pu, P. and Ding, X. (2005). Study on thermal and rheological properties of native rice starches and their corresponding mixtures. Food Research International, 38(3):257–266.

HewaNadungodage, N.D., Torrico, D.D., Brennan, M. A. and Brennan, C.S. (2022). Nutritional, physicochemical, and textural properties of gluten-free extruded snacks containing cowpea and whey protein concentrate. International Journal of Food Science and Technology, 57(7):3903–3913.

Jomova, K., Makova, M., Alomar, S.Y., Alwasel, S. H., Nepovimova, E., Kuca, K. and Valko, M. (2022). Essential metals in health and disease. Chemico-biological interactions, 367, 110173.

Korhonen, H. and Pihlanto, A. (2006). Bioactive peptides: Production and functionality. International Dairy Journal, 16(9), 945–960.

Korkerd, S., Wanlapa, S., Puttanlek, C., Uttapap, D. and Rungsardthong, V. (2016). Expansion and functional properties of extruded snacks enriched with nutrition sources from food processing byproducts. Journal of Food Science and Technology, 53(1):561–570.

Lee, K.H., Wu, T.Y. and Siow, L.F. (2013). Spray drying of red (Hylocereus polyrhizus) and white (Hylocereus undatus) dragon fruit juices: Physicochemical and antioxidant properties of the powder. International Journal of Food Science and Technology, 48:2391–2399.

Lifrah, E.V., Hourigan, J.A. and Sleigh, R.W. (2000). New wheys for lactose. Food Australia, 52:120–125.

Liu, S., Xu, J., Xie, L., Zhu, M. and Tang, J. (2019). Dry inoculation methods for nonfat milk powder. Journal of Dairy Science, 102(1):77–86. https://doi.org/10.3168/ jds.2018-14478

Makowska, A., Cais-Sokolińska, D. and Lasik, A. (2014). Effect of technological factors on water activity of extruded corn product with an addition of whey proteins. Acta Scientiarum Polonorum Technologia Alimentaria, 13(3):243–247.

Makowska, A., Polcyn, A. and Chudy, S. (2016)a . Quality and nutritional value of corn snacks enriched with nanofiltered whey powder. Acta Scientiarum Polonorum Technologia Alimentaria, 15(1):79–87.

Makowska, A., Cais-Sokolińska, D., Aśkiewicz, A., Tokarczyk, G. and Paschke, H. (2016)b . Quality and nutritional properties of corn snacks enriched with nanofiltered whey powder. Czech Journal of Food Sciences, 34(2):154–159. https://doi.org/10.17221/313/2015-CJFS

Maticorena, E., Alarcón, C., Troncoso, E. and Zúñiga, R.N. (2018). The degree of protein aggregation in whey protein isolate-based dispersions modifies their surface and rheological properties. CyTA – Journal of Food, 16(1):146–155.

Mironeasa, S. , Cotovanu, I., Mironeasa, C. and Ungureanu-Iuga, M. (2023). AReviewofthe Changes Produced by Extrusion Cooking on the Bioactive Compounds from Vegetal Sources. Antioxidants , 12, 1453. https://doi.org/10.3390/antiox12071453

Moraru, C.I. and Kokini, J.L. (2003). Nucleation and expansion during extrusion and microwave heating of cereal foods. Comprehensive Reviews in Food Science and Food Safety, 2(4):147–165.

Nadeesha Dilrukshi, H.N., Torrico, D.D., Brennan, M. A. and Brennan, C.S. (2022). Effects of extrusion processing on the bioactive constituents, in vitro digestibility, amino acid composition, and antioxidant potential of novel gluten-free extruded snacks fortified with cowpea and whey protein concentrate. Food Chemistry, 389, Article 133107. https://doi.org/10.1016/j.foodchem.2022.133107

National Academies of Sciences, Engineering, and Medicine (NA SEM) (2016). Dietary Reference Intakes. Food and Nutrition Board, Institute of Medicine. https://www.nationalacademies.org/hmd/Activities/Nutrition/SummaryDRIs/DRI-Tables.aspx

Natsir, H., Wahab, A.W., Budi, P., Dali, S. and Arif, A.R. (2019). Amino acid and mineral composition of Moringa oleifera leaves extract and its bioactivity as antioxidant. Journal of Physics: Conference Series, 1317, 120–130.

Okiki, P.A., Osibote, I.A., Balogun, O., Oyinloye, B. E., Idris, O., Asoso, S.O. and Olagbemide, P.T. (2015). Evaluation of proximate, minerals, vitamins and phytochemical composition of Moringa oleifera Lam. cultivated in Ado Ekiti, Nigeria. Advances in Biological Research, 9, 436–443.

Onwulata, C.I. (2010). Incorporation of whey products in extruded snacks. Advances in Food and Nutrition Research, 61, 71–90.

Onwulata, C.I., Konstance, R.P., Cooke, P.H., & Farrell Jr, H. M. (2003). Functionality of extrusion-texturized whey proteins. Journal of Dairy Science, 86(11), 3775–3782.

Onwulata, C.I., Smith, P.W., Hsing, Y.I. and Konstance, R.P. (2001). Incorporation of whey products in extruded corn products. LWT – Food Science and Technology, 34(6):424–429.

Onyango, C., Noetzold, H., Bley, T. and Henle, T. (2004). Proximate composition and digestibility of fermented and extruded uji from maize finger millet blend. Lebensmittel-Wissenschaft und Technologie, 37: 827– 832, https://doi.org/10.1016/j.lwt.2004.03.008

Ponbhagavathi, T.R.T., Singh, A.K., Raju, P.N., Arora, S., Meena, G.S. and Borad, S. (2018). Effect of extrusion processing parameters on hardness and crispiness of milk protein-maize based extrudates. International Journal of Chemical Studies, 6(1):1656–1658.

Ponbhagavathi , T.R.T., Singh, A.K., Raju , P.N. and Upadhyay, N. (2020). Effect of Rennet Casein and Whey Protein Concentrate on Extrusion Behavior of Maize Flour. Current J. of Applied Science and Techn. 39(33):16-27. DOI:10.9734/cjast/2020/

Popkin, B.M. and Duffey, K.J. (2010). Does hunger and satiety drive eating anymore? The American Journal of Clinical Nutrition, 91(5), 1342–1347.

Predieri, S., Magli, M., Gatti, E., Camilli, F., Vignolini, P. and Romani, A. (2021). Chemical composition and sensory evaluation of saffron. Foods, 10, 2604.

Saadat, S., Akhtar, S., Ismail, T., Sharif, M.K., Shabbir, U., Ahmad, N. and Ali, A. (2020). Multilegume bar prepared from extruded legumes flour to address protein energy malnutrition. Italian Journal of Food Science, 32(1).

Shahidi, F., Sedaghat, N., Farhoosh, R. and Mousavi-Nik, H. (2008). Shelf-life determination of saffron stigma: Water activity and temperature studies. World Applied Sciences Journal, 5 (2):132–136.

Saffron stigma: Water activity and temperature studies. World Applied Sciences Journal, 5(2):132–136.

Singh, S., Gamlath, S. and Wakeling, L. (2007). Nutritional aspects of food extrusion: A review. International Journal of Food Science & Technology, 42(8):916–929.

Snedecor, G.W. and Cochran, W.G. (1980). Statistical Methods (7th ed.). Iowa State University Press.

Sodini, I., Morin, P., Olabi, A., & Jiménez-Flores, R. (2006). Compositional and functional properties of buttermilk: A review. Dairy Science & Technology, 86(3), 295–311.

Soni, A., Singh, A., Sharma, V., & Kaur, A. (2020). Nutritional and quality aspects of extruded snack foods. Current Research in Food Science, 3:340–352.

Sumargo, F., Gulati, P., Weier, S.A., Clarke, J. and Rose, D.J. (2016). Effects of processing moisture on the physical properties and in vitro digestibility of starch and protein in extruded brown rice and pinto bean composite flours. Food Chemistry, 211:726–733. https://doi.org/10.1016/j.foodchem.2016.05.097

Toldrá, F., Mora, L., & Reig, M. (2021). New insights into meat by-product utilization. Meat Science, 181, 108608.

WHO. (2007). Protein and amino acid requirements in human nutrition (WHO Technical Report Series, No. 935). Geneva: World Health Organization.

Yadav, D.N., Singh, K.K. and Rehal, J. (2020a). Extruded functional foods: A review. International Journal of Food Science and Technology, 55 (2):347–357.

Yadav, U., Singh, R.R.B., Prakash, K., Arora, S. and Chatterjee, A. (2020b). Suitability studies of different milk proteins for supplementation in functional extruded snack. Indian Journal of Dairy Science, 73(5).

Zanabria Eyzaguirre, F. and Corredig, M. (2011). The role of milk fat globule membrane in buttermilk functionality. Journal of Dairy Science, 94(12): 5921–5932.

Zhou, P., Liu, X. and Labuza, T.P. (2008). Effects of moisture-induced whey protein aggregation on protein conformation, the state of water molecules, and the microstructure and texture of high-protein-containing matrix. Journal of Agricultural and Food Chemistry, 56(12):4534–4540.

Ziena, H.M. and Ziena, A.H.M. (2022). Nutritious novel snacks from some of cereals, legumes and skimmed milk powder. Applied Food Research, 2 (1):100092.