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Breakfast cereals enriched with whey protein: Sensory and nutritional impacts

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Abstract

In recent decades, the prevalence of common diseases such as obesity, diabetes, and cardiovascular disease has increased, making the need for a healthy diet increasingly important to prevent the development of these diseases. The food industry has been working to offer healthier options to consumers by developing a range of foods with nutritious ingredients, such as protein. The extrusion process is a technique used in the food industry to produce breakfast cereals with a high cereal content, high in carbohydrates and low in protein. Whey protein concentrate, a high-biological-value protein, is a popular choice. Whey protein is a valuable source of protein and minerals and is one of the highest-quality components for potential extruded enrichment. The objective of this research was to evaluate the effect of adding whey protein to corn flour in breakfast cereals on the sensory characteristics and physicochemical aspects. Four breakfast cereal formulations were prepared with different levels of whey protein addition: 0% (F1), 11% (F2), 15% (F3), 18% (F4), and corn grits: 100% (F1), 89% (F2), 85% (F3), and 82% (F4). The samples were evaluated for sensory acceptability and physicochemical characteristics, color, moisture content, protein, lipids, ash, and carbohydrates, and for sensory attributes of appearance, aroma, flavor, texture, and color, as well as overall acceptance. The average nutritional composition of the extruded breakfast cereal F4 (18% whey protein) presented the lowest contents of moisture (8.44%), ash (0.83%), protein (22.03%), fat (2.95%), carbohydrate (65.74%), and gross energy (377.63 kcal 100 g^{-1}). Sample F1 had a higher moisture content ($p < .05$) than the other formulations. The ash content of formulation F1 was lower than that of the other formulations, but the lipid content of the breakfast cereals showed no significant differences. The absolute difference between the formulations was slight, but carbohydrates were reduced by 10% in formulation F4 compared to F1. Regarding protein, there was an increase in the protein content of formulations F2 (6.11%), F3 (6.34%), and F4 (9.19%) compared to F1. Higher whey protein contents in cereals increased the parameters of lightness (L*), yellowness (b*), and redness (a*). In general, breakfast cereals with whey protein added are dark in color, with all L* values below 50%, a yellow tone (b*), and a red undertone. Regarding the sensory analysis, there was no significant difference ($p > .05$) between the formulations for the attributes of appearance, flavor, texture, color, overall acceptance, and purchase intention. However, the aroma attributes of F2 and F3 showed differences ($p < .05$) when compared to F1 and F4. Lower scores for all attributes were found in F1. The addition of whey protein at concentrations up to 18% to corn flour is an alternative for the production of extruded breakfast cereal, with moderate sensory acceptance and improved nutritional quality.

Keywords: breakfast cereal; extrusion; whey protein.

Practical Application: Enriching breakfast cereals with whey protein can improve the nutritional profile of a product highly consumed by the population.

1 INTRODUCTION

In recent decades, the prevalence of common diseases such as obesity, diabetes, and cardiovascular disease has increased; therefore, the need for a healthy diet is becoming increasingly important in order to prevent the development of these diseases and improve quality of life (Blüher, 2019; Galmiche et al., 2019). Due to rising healthcare costs and the prevalence of chronic non-communicable diseases, the food industry has been seeking to offer healthier options to consumers by developing various types of functional foods (Duttaroy, 2019).

Increasing protein intake is beneficial for increasing muscle synthesis, aiding fat loss, and reducing the risk of cardiovascular disease, so its consumption should be encouraged (Morales et al., 2017). Whey protein, being a protein of high biological

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value, acts on human health, as an anticancer, antimicrobial, blood pressure-lowering, appetite-suppressing, hypocholesterolemia-lowering, and plaque- and caries-inhibiting properties. The contribution of protein content to the recommended dietary allowance (RDA) is determined by consuming one serving (40 g) of different combinations of extruded snacks. The RDA for protein is 0.8 g/kg/day for the entire adult population, including young and old, men and women (Brazil, 2005).

Whey protein concentrate (WPC) is a valuable source of protein and minerals and is one of the highest-quality components for potential extrudate enrichment (Brnčić et al., 2011). In addition to these nutritional aspects, whey proteins have rheological and functional properties ideal for the extrusion process, as they exhibit high solubility and high gel- and foam-forming capacity (Gong et al., 2021; Kristensen et al., 2021). The high temperatures employed in extrusion processing can reduce amino acid retention. The Maillard reaction is the main reason for the reduction of amino acids in extruded breakfast cereals based on high-protein cereals. However, amino acid retention rates depend on feed moisture, temperature, and other extrusion parameters (Philipp et al., 2017). Extrusion processing increased protein and starch digestibility and the amino acid profile of extrudates compared to non-extruded blends. In one study, the authors developed snacks fortified with cowpea and whey protein, thereby increasing dietary fiber, antioxidant properties, and the amino acid profile. They observed that, upon in vitro digestion, extruded products showed a reduced glycemic response (Dilrukshi et al., 2022).

The extrusion process is a technique used in the food industry to produce processed foods such as breakfast cereals, cookies, and pasta, as well as pet food (Monteiro et al., 2016). One of the most commonly found extruded products on the market is breakfast cereal, which is a food source rich in energy, sodium, sugar, and fat but low in protein and dietary fiber (Mireault et al., 2023; Philipp et al., 2017). The process typically involves high temperature, high pressure, and high shear rates, which induce chemical and physical changes in food materials (Masatcioglu et al., 2014). This can improve characteristics such as digestibility, texture, flavor, and nutrient availability (Salvador-Reyes et al., 2023). However, high temperatures can cause nutrient loss and the breakdown of heat-sensitive antioxidant compounds. However, extrusion can enhance food safety by extending product shelf life (Egal & Oldewage-Theron, 2020; Santos et al., 2022).

The quality of extruded breakfast cereals has been primarily influenced by their expansion rate, bulk density, microstructure, and textural properties such as bursting force and crispness (Philipp et al., 2017; Tas & Shah, 2021). Therefore, texture and physical characteristics are critical parameters for consumer acceptability. However, the addition of protein- and fiber-rich ingredients to starch-containing extrudates negatively influences these textural and physical characteristics. Some authors have observed that increasing protein and fiber content decreases the expansion rate and increases bulk density (Basilio-Atencio et al., 2020; Beck et al., 2018; Philipp et al., 2017; Téllez-Morales et al., 2020). Some authors have shown that screw speed is the process parameter that exerts the most significant influence on the physical and textural properties of extruded products; therefore, production conditions can also influence these characteristics (Neder-Suárez et al., 2021). Increasing the screw speed has a positive effect, that is, increasing expansion and decreasing snack hardness (Félix-Medina et al., 2020; Neder-Suárez et al., 2021; Philipp et al., 2018). Therefore, the industry faces a challenge in developing a protein-enriched product that maintains physicochemical properties and good consumer acceptability.

Therefore, the objective of the research was to identify the extrusion capacity of flours supplemented with WPC for the production of breakfast cereal and to characterize the physical–chemical, nutritional, and sensory composition, aiming to improve food quality.

1.1 Relevance of the work

Due to the high demand for protein-rich foods and the convenience of consuming breakfast cereals, this work can contribute by demonstrating a viable alternative with high sensory acceptance of a product enriched with whey protein. The study showed that it is possible to significantly enrich the protein content while maintaining good sensory acceptance.

2 MATERIALS AND METHODS

The project was approved by the Research Ethics Committee of Ingá University Centre (UNINGÁ), under opinion No. 4,948,519/2021. To carry out the sensory analysis, participants will receive a prior invitation and an explanation of all stages and objectives. The exclusion criteria will be having an allergy to the ingredients used in the preparation of the breakfast cereal; being pregnant; not being a student, professor, or employee of UNINGÁ; being under 18 or over 59 years of age; and not submitting the signed Free and Informed Consent Form.

2.1 Raw materials

Neutral-flavored protein (Dux) was purchased from a local health food store (Maringá, PR, Brazil), and corn grits were supplied by Nutrimilho (Maringá, PR, Brazil). The ingredients for the syrup were purchased from specific food stores, namely still mineral water (Safira), 100% cocoa powder (Nestlé), chocolate-flavored WPC (Dux), inverted liquid sugar (Diottoni), and brown food coloring (Mago).

2.2 Formulation

Four breakfast cereal formulations were developed: standard F1 (100% corn) and the others with 11% (F2), 15% (F3), and 18% (F4) of whey protein added. These additional levels were defined through preliminary sensory tests carried out with the product. In addition to whey protein, the following ingredients were used in the formulations: corn grits at 89% (F2), 85% (F3), and 82% (F4); 2% still water; and whey protein mixed with the grits and added to the water.

White cornmeal grits (*Zea mays*) were used as the base ingredient for the extruded products. The mixtures were prepared by combining corn flours with varying proportions of whey protein, yielding four formulations (Table 1). The flours were mixed in a domestic mixing system and stored in polyethylene

Table 1. Formulations of extruded snacks.

	F1	F2	F3	F4
Ingredients (%)				
Corn grits	100	89	85	82
Neutral whey protein concentrate	0	11	15	18
Still mineral water	2	2	2	2
Syrup (%)				
Still mineral water	80	80	80	80
Inverted liquid sugar	8	8	8	8
Whey protein concentrate (chocolate)	8	8	8	8
100% cocoa powder	3	3	3	3
Brown food coloring	1	1	1	1

bags before extrusion. The ingredients for the syrup – still mineral water, 100% cocoa powder, liquid invert sugar, brown food coloring, and chocolate-flavored WPC – were mixed in a container until fully dissolved. They were then sieved to remove any lumps and stored for later spraying.

2.3 Extrusion

Extrusion was performed according to Monteiro et al. (2016) using an IMBRA RX50 single-screw extruder (INBRAMAQ, Ribeirão Preto, SP, Brazil) with a 50 mm diameter and 200 mm length. The die had two 3 mm-diameter orifices, and the extrusion parameters were 20 A of motor amperage, a feed rate of 12 g s^{-1}, and a screw speed of 120 rpm. Subsequently, the samples were subjected to the tumbling process for spraying the syrup at 60 °C in a rotating drum.

2.4 Sensory analysis

One hundred untrained panelists participated in the study. These included students, staff, and faculty of both genders, aged 18–52, and were expected to be regular breakfast cereal consumers. The tests were conducted in individual booths with white lighting. Participants received a prior invitation and an explanation of all the stages and objectives for the sensory analysis. Appearance, aroma, flavor, texture, color, and overall acceptance were assessed using a 9-point mixed hedonic scale, ranging from 1 ("I disliked it very much") to 9 ("I liked it very much") (Meilgaard et al., 2015). Questions were also asked about overall acceptance, using a structured 9-point hedonic scale, and about purchase intention, using a structured 5-point scale (1: "I certainly would not buy," 5: "I certainly would buy"). The panelists received a portion of each sample (approximately 10 g) in white disposable plastic cups (50 mL), coded with three-digit numbers, in a randomized and balanced manner (Macfie et al., 1989), accompanied by a glass of water for palate cleansing. The formulations were presented to the panelists in a monadic and sequential manner. The acceptability index (AI) was calculated according to the formula: AI (%) = A × 100/B (A = average score obtained by the product; B = maximum score attributed to the product) (Macfie et al., 1989).

2.5 Physicochemical analysis

Chemical determinations were performed in triplicate on breakfast cereal supplemented with different levels of whey protein. The following evaluation was performed: moisture was measured as the mass loss of the sample heated in an oven at 105 °C until constant weight.

Proteins (g 100 g^{-1}) were measured by the Kjeldahl method to determine total nitrogen. Lipid content (g 100 g^{-1}) was measured by the Bligh Dyer method (Bligh & Dyer, 1959); ash content was determined by carbonization followed by complete incineration in a muffle furnace at 550 °C. All methods are recommended by the Association of Official Analytical Chemists (AOAC, 2006). Carbohydrates were calculated by the method of differences, subtracting the moisture, ash, protein, and lipid contents from 100 (% carbohydrate 100 − (% moisture + % protein + % lipid + % ash)). Total energy was estimated as (kcal 100 g−1), using the values recommended by Atwater and Woods (1986) for lipid (9 kcal g), protein (4 kcal g), and carbohydrate (4 kcal g). The results are expressed as g 100 g^{-1}; color will be analyzed using the Commission Internationale de l'Eclairage system: L* (luminosity), a* (red-green), and b* (yellow-blue), with readings taken on a colorimeter.

The Daily Reference Value was calculated in relation to 30 g of the sample, based on the average values recommended for adults aged 18–59 years (Brazil, 2005), resulting in 2,127.5 kcal/day, 305.55 g/day of carbohydrates, 89.38 g/day of proteins, and 60.87 g/day of lipids.

2.6 Statistical analysis

The results were analyzed using analysis of variance. The means of the breakfast cereals supplemented with different levels of whey protein were analyzed using Tukey's test at $p \leq .05$. The Statistical Package for the Social Sciences (SPSS, Chicago, IL, USA) version 19.0 was used to perform the statistical analyses.

3 RESULTS AND DISCUSSION

3.1 Sensory analysis

The results of the test to evaluate the acceptance of the breakfast cereal formulation in the proportions of standard F1 (100% corn) and the others added with 11% (F2), 15% (F3), and 18% (F4) of whey protein are presented in Table 2.

There was no significant difference ($p > .05$) between the formulations for the attributes' appearance, flavor, texture, color, overall acceptance, and purchase intention. However, in the aroma attribute, F2 and F3 differed ($p < .05$) from F1 and F4. Lower scores for all attributes were found in F1. Data that corroborate Santos et al. (2019) in the acceptance of extrudates based on resistant starch from rice residues and whey (10%). Furthermore, the AIs were generally greater than 60%, which, according to Alonso et al. (2016), is considered the average acceptance rate.

3.2 Physicochemical characterization of breakfast cereal

The color parameters L*, a*, and b* of breakfast cereals added with different concentration levels of whey protein are described in Table 3.

Table 2. Sensory scores for the evaluation of breakfast cereals with different whey protein concentrate contents.

Parameters	F1	F2	F3	F4
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
Appearance	5.8 ± 1.78 [a]	6.48 ± 1.68 [a]	6.15 ± 1.75 [a]	6.16 ± 1.80 [a]
AI (%)	67.03	69.62	66,66	70
Aroma	5.45 ± 1.73 [b]	6.21 ± 1.65 [ab]	5.55 ± 1.71 [ab]	6.26 ± 1.74 [a]
AI (%)	65.74	65.37	63.70	66.11
Flavor	5.55 ± 1.77 [a]	6 ± 1.61 [a]	5.75 ± 1.68 [a]	5.8 ± 2.14 [a]
AI (%)	66.29	65.37	62.22	62.77
Texture	6.06 ± 1.92 [b]	6.93 ± 1.60 [a]	6.61 ± 1.85 [ab]	6.33 ± 1.94 [ab]
AI (%)	72.59	73.14	70.18	72.40
Color	5.71 ± 1.94 [ab]	6.65 ± 2.04 [a]	6.15 ± 2.05 [ab]	5.58 ± 2.20 [b]
AI (%)	69.07	66.48	65	67.22
Global acceptance	5.81 ± 1.74 [a]	5.8 ± 1.42 [a]	6 ± 1.45 [a]	5.7 ± 1.90 [a]
AI (%)	65.92	65	65.37	62.77
Purchase intention	3.01 ± 1.26 [a]	3.11 ± 0.91 [a]	2.96 ± 1.06 [a]	2.78 ± 1.31 [a]
AI (%)	62	58.33	59	58.33

Distinct lowercase letters in the line indicate a significant difference by Tukey's test ($p < .05$) for the formulations. SD: standard deviation; AI: acceptability index. Breakfast cereal with 100% corn added with concentrated whey protein and neutral flavor: 0% (F1); 11% (F2); 15% (F3), and 18% (F4): The authors, 2024.

Table 3. Color parameters L*, a*, and b* (mean ± standard deviation) of breakfast cereals added with different levels of whey protein.

Samples	*L* *	*a* *	*b* *
F1	30.89 ± 0.02 [b]	8.89 ± 0.32 [b]	5.46 ± 0.44 [c]
F2	34.43 ± 2.61 [b]	8.90 ± 0.04 [b]	7.11 ± 0.39 [bc]
F3	37.40 ± 2.66 [b]	9.25 ± 0.56 [b]	7.75 ± 0.03 [b]
F4	47.47 ± 3.32 [a]	11.54 ± 0.59 [a]	10.40 ± 1.34 [a]

Distinct lowercase letters on the line indicate significant differences by Tukey's test ($p < .05$) for breakfast cereals. Corn flour added with concentrated whey protein and neutral flavor: 0% (F1), 11% (F2), 15% (F3), and 18% (F4).

Higher whey protein contents in cereals increased the parameters of lightness (*L**), yellowness (b*), and redness (a*). In general, breakfast cereals added with whey protein can be considered dark in color, since all L * values were less than 50%, with a yellow tone (b*) and red undertone (a*). According to Monteiro et al. (2016), the Maillard and caramelization reactions are the most likely explanations for products produced at high temperatures and low moisture content being redder and having a higher melanoidin content. In the sensory analysis, the panelists noticed a difference in the color of cereals with a higher whey protein content (18%), indicating a preference for the product with brighter and yellower tones. These results corroborate those of Santos et al. (2019) in their formulation of extruded breakfast cereals produced with mixtures of broken rice grain by-products, passion fruit peel, and whey, where the luminosity (L*) of the breakfast cereals varied between 73.16 and 79.95. The chromaticity coordinates a* and b* varied from 5.08 to 9.3 and from 15.53 to 18.36, respectively. The color of breakfast cereals is an important marketing characteristic and is influenced by the raw materials that make up their formulation (Alonso et al., 2016).

Table 4 presents the average nutritional composition of breakfast cereals enriched with whey protein: F1 (0%), F2 (11%), F3 (15%), and F4 (18%). Sample F1 had a higher moisture content ($p < .05$) than the other formulations, suggesting that the presence of proteins reduced moisture. Similar results were reported for snacks extruded with flour blends and fortified with whey by-product, which had a moisture content of 8.13% in formulations containing 10% whey protein (Bayomy et al., 2024). The higher moisture content was also observed by Allai et al. (2022) in their study of extruded cereals composed of different types of flours, where the group composed only of corn, as well as sample F1 in this research, had a moisture content of 9.18%. The extrusion process can enhance food safety by extending product shelf life through reduced moisture during processing (Egal & Oldewage-Theron, 2020; Santos et al., 2022). Generally, foods with high water content are susceptible to microbial action and have reduced shelf life; therefore, reducing moisture levels extends the product's shelf life.

The ash content of formulation F1 was lower than that of the other formulations. The presence of whey protein, a raw material with a high ash content caused this increase (Alonso et al., 2016). The lipid content of the breakfast cereals did not show significant differences, indicating the lowest energy macronutrient content. Another result was that adding whey protein to corn flour reduced the carbohydrate content, although the absolute difference between the formulations was slight: carbohydrates were reduced by 10% in formulation F4. There was an increase in the protein content of formulations F2 (6.11%), F3 (6.34%), and F4 (9.19%) compared to F1. This was due to the addition of whey protein to the breakfast cereal. The F2 18.95% formulation obtained results of 18.95% protein, a value higher than that found in similar studies carried out with the addition of 10% concentrated whey protein in an extruded cassava breakfast cereal with cinnamon flavor, which obtained a concentration of 8.38% protein in the final product (Silva et al., 2011). Bayomy et al. (2024) developed an extruded snack with mixtures of corn and leftover resistant starch based on rice and a chickpea flour fortified with whey by-product (10%) that presented protein levels of 10.46. The differences can be explained by the differences in the raw materials and mixtures of each cereal or, in the case of this work, by the addition of whey protein (chocolate flavor concentrate) in the syrup, further increasing the protein content, in addition

Table 4. Mean nutritional composition (± standard deviation) of breakfast cereals with different levels of whey protein added.

Parameters	F1	RDV	F2	RDV	F3	RDV	F4	RDV
	Mean ± SD	30 g	Mean ± SD	30 g	Mean ± SD	30 g	Mean ± SD	30 g
Humidity (%)	9.27 ± 0.32 [a]		8.28 ± 0.31 [a]		8.64 ± 0.28 [a]		8.44 ± 0.02 [a]	
Ash (%)	0.66 ± 0.28 [a]		0.83 ± 0.28 [a]		0.83 ± 0.29 [a]		0.83 ± 0.29 [a]	
Proteins (%)	12.84 ± 0.29 [a]	4.30%	18.95 ± 0.05 [b]	6.36%	19.18 ± 0.26 [b]	6.43%	22.03 ± 0.22 [c]	7.28%
Lipids (%)	2.88 ± 0.06 [a]	1.41%	2.7 ± 0.06 [a]	1.33%	2.0 ± 0.02 [a]	0.98%	2.95 ± 0.04 [a]	1.45%
Carbohydrates	74.20	7.28%	69.21	6.79%	69.30	6.80%	65.74	6.45%
Energy value (kcal 100 g^{-1})	374.12	5.27%	376.94	5.31%	371.96	5.24%	377.63	5.32%

Distinct lowercase letters on the line indicate a significant difference by Tukey's test ($p < .05$). RDV: recommended daily value; SD: standard deviation; for the formulations: Corn flour added with concentrated whey protein and neutral flavor: 0% (F1), 11% (F2), 15% (F3), and 18% (F4).

to the presence of sweeteners, reducing the need to add higher levels of sugar to the syrup. Therefore, consuming breakfast cereals with whey protein supplements allows the population to increase their protein intake while ensuring a balanced meal with adequate proportions of carbohydrates and high-quality proteins. Furthermore, the extrusion process often improves protein chemistry, making proteins more soluble and digestible (Gulati et al., 2020). This is one of the nutritional indicators for improving the product and providing consumers with better nutritional properties (Dilrukshi et al., 2022). To improve the nutritional values of extruded foods, it is recommended that natural protein sources be combined with other foods, such as grains (Saadat et al., 2020). Therefore, consuming this cereal offers an additional benefit for people with protein digestion difficulties, such as bariatric patients and the elderly, in addition to providing a more balanced diet.

4 CONCLUSIONS

The production of breakfast cereals with an addition level of up to 18% WPC has moderate consumer acceptance, achieving sensory acceptance levels comparable to those of products developed with the same production criteria. Furthermore, it improves the chemical and nutritional profile by increasing protein and ash content while reducing carbohydrate and moisture content. In addition to promoting improvements in food composition without altering energy values, which remained similar at 374.12–377.63 kcal 100 g^{-1}, the physical characteristics were similar to those of products consumed by the general population.

Consuming breakfast cereals with added whey protein should be encouraged, as it helps consumers access healthier foods. The fortification of extruded food formulations with proteins from selected sources and high biological value can improve health and increase the quality of snacks and breakfast cereals.

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