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Sensory evaluation and characterization of breakfast cereal formulated with yam flour (*Dioscorea Cayanensis* Lam.)

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Abstract

The present study aimed to develop and characterize a breakfast cereal incorporating yam pulp flour (*Dioscorea cayannensis* Lam.) to create a product that combines sensory and nutritional quality. Four formulations were developed: F1 (standard, 100% corn), F2 (10% yam flour), F3 (20% yam flour) and F4 (30% yam flour). The samples were processed by extrusion, dried, and coated with cocoa syrup before undergoing sensory and physicochemical evaluation. A market research involving 103 consumers was conducted, and it indicated that 77.7% expressed interest in purchasing a product containing yam flour. Among the interviewees, 73.8% indicated the chocolate flavor as their preference for breakfast cereals. Sensory acceptance was assessed with 110 untrained judges using a 9-point hedonic scale for appearance, aroma, flavor, texture, color, and overall acceptance. All formulations achieved an acceptability index above 70%, indicating a good product acceptance. Physicochemical analyses showed that incorporating yam flour significantly increased protein and lipid content, while the carbohydrate content showed a slight reduction. The water activity of the samples remained stable, ensuring good product conservation. Instrumental color analysis revealed expected variations due to the addition of cocoa in the formulation. In conclusion, yam flour is a promising ingredient for the formulation of more nutritious and functional breakfast cereals.

Keywords: extrusion; food technology; functional foods.

Practical Application: Breakfast cereals with yam flour offer nutritious options for nutritionally balanced diets.

1 INTRODUCTION

Extrusion technology is a widely adopted and rapidly growing food processing method used to develop many food products from various ingredients (Yağci et al., 2020). Its popularity stems from its ability to produce foods with desirable taste, texture, size, and shape at an economically viable cost (Singh et al., 2019). The extrusion process involves mixing, cooking, and shearing diverse food ingredients under high pressure and temperature. The technology is very effective due to its high-temperature, short-time (HTST) cooking method, making it the preferred choice in the food industry for producing snacks (Nidhi & Mohan, 2019).

Food extrusion is a processing technique that produces a variety of products by forcing material through a die under controlled conditions, combining simultaneous mechanical and heat treatments at a predetermined rate. This process integrates multiple unit operations (compression, blending, shearing, kneading, and high-temperature heating) to transform food into a molten state. The molten material is then extruded through a narrow die, yielding semi-cooked or fully cooked products with minimal nutritional loss (Leonard et al., 2020).

Corn is typically the main raw material in extrusion. However, exploring alternative food matrices is interesting for improving the nutritional profile of extruded products. From this perspective, yam (*Dioscorea cayennensis* Lam.), also known as *cará-da-costa*, is generally cultivated in sandy soils with low organic matter content (Nascimento et al., 2021). The yam crop (*Dioscorea* ssp.) is grown in various tropical regions worldwide, with most cultivated species originating from Asia and West Africa. Yam is a monocotyledonous, herbaceous plant with elongated, light brown tuberous roots. Its tubers have high levels of carbohydrates (23.2 g/100 g), proteins (2.1 g/100 g), lipids (0.2 g/100 g), dietary fiber (1.7 g/100 g) and vitamin C (5.8 mg/100 g) (Universidade Estadual de Campinas [UNICAMP], 2011).

Breakfast cereals are a key component of the dietary routines of children and adults, who frequently consume them due to convenience, busy schedules and the ability to provide morning satiety. These products are made mainly from starchy materials, such as wheat, corn, barley, rice and oats, with extrusion being a widely used production method (Ferreira et al., 2021). When produced from whole grains, such as millet, amaranth and barley, breakfast cereals are rich in macronutrients (carbohydrates, proteins and dietary fiber), micronutrients (minerals and vitamins), and essential bioactive compounds, including phytochemicals. These nutrients and compounds are essential for maintaining health and managing diet-related conditions, such as overweight, obesity, and

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hypercholesterolemia (Narwal et al., 2020; Olagunju et al., 2021). However, consumer acceptance is closely related to factors such as appearance, nutritional profile, texture and convenience (Ferreira et al., 2021).

Developing new food products, such as breakfast cereals made with fruit and vegetable flours, is a promising strategy for formulating foods that are more nutritionally suitable for the population. Incorporating unconventional ingredients into food products has been shown to improve or maintain their sensory, physicochemical, and nutritional properties (Chima et al., 2022). These products, widely consumed by adults due to their convenience given the lack of time to prepare full meals, often have nutritional limitations, including high energy content and low micronutrient density.

Brazilian legislation, such as Resolution RDC No. 263/2005 (Brasil, 2005), permits the addition of yam and establishes guidelines for the use of ingredients in food products. Yam flour is rich in dietary fiber, complex carbohydrates and essential nutrients, which can enhance the nutritional value of cereals while providing functional benefits. Thus, this study aims not only to comply with technical and regulatory requirements but also to offer an innovative market alternative with the potential to promote a balanced and accessible diet for the population.

This study seeks to develop and characterize an innovative breakfast cereal incorporating yam pulp flour, aiming to deliver a product that combines sensory appeal and nutritional quality, addressing the growing demand for healthier food alternatives.

1.1 Relevance of the work

The relevance of this study is directly associated with the innovation of using yam flour (*Dioscorea cayanensis* Lam.) as an alternative ingredient in breakfast cereals, a product widely consumed across different age groups. The results demonstrated that the addition of yam flour improved the nutritional profile, with a significant increase in protein, lipid, and mineral contents, along with a reduction in carbohydrates, making the product more balanced and functional. From a sensory perspective, all formulations achieved acceptability indices above 70%, confirming that the incorporation of up to 30% yam flour does not compromise essential attributes such as flavor, texture, and appearance. These findings, combined with the high purchase intention (88.3%) identified in the market research, highlight the feasibility of introducing this product into the healthy and functional food sector. Furthermore, the use of yam, a regional crop often underutilized, promotes the valorization of local raw materials, strengthens the sustainability of the food production chain, and contributes to diversifying the population's diet. Thus, this study integrates scientific, nutritional, economic, and social aspects, reinforcing its contribution to the development of innovative foods with potential positive impact on public health and the consumer market.

2 MATERIAL AND METHODS

2.1 Material

All reagents used in the analyses were of analytical grade; the ingredients for the syrup were purchased from specific food stores. For the cereal formulations, 4 kg of yam (*Dioscorea cayannensis* Lam.) from the same batch was used. The tubers, purchased from a supermarket in the northwest region of Paraná, had light brown skin, a globose shape, a rough cylindrical skin texture, and an average weight of 310 g. The pulps were selected, washed in potable water, sanitized in a sodium hypochlorite solution (150 ppm) for 10 minutes, and rinsed again in potable water. The skin was removed using an industrial peeler (Skymsen ®, Brazil), yielding 2.800 kg of pulp.

The pulps were then sliced (5 mm) using an industrial food processor (Robot Coupe ®, Brazil) and dried in an oven with air circulation (Tecnal ®, Brazil) at 65 °C for 24 hours (Amedor et al., 2024). After dehydration, the slices were cooled to room temperature (25 °C). To prepare the flour designated as F1, the dried slices were ground in a four-blade Wiley mill and sieved through a 0.5 mm mesh sieve (Bertel ®, Brazil). The flour was stored under refrigeration (8 °C) until used for the preparation of the extruded products.

2.2 Cereal processing

Extrusion was performed according to Monteiro et al. (2016) using a single screw equipment IMBRA RX50 (Inbramaq, Ribeirão Preto, SP, Brazil) with a 50 mm diameter and 200 mm in length. The die had two 3 mm diameter holes, and the extrusion parameters included a motor amperage of 20 A, a feed rate of 12 g s^{-1}, and a screw speed of 120 rpm. Subsequently, the samples were subjected to a tumbling process for syrup spraying at 60 °C in a rotating drum. Four breakfast cereal formulations were prepared: standard F1 (100% corn), F2 (10% yam flour), F3 (20% yam flour), and F4 (30% yam flour). These addition levels were determined based on preliminary sensory tests conducted with the product. The other ingredients are listed in Table 1. White corn grits (*Zea mays*) were used as the base ingredient for the extruded products and supplied by Nutrimilho (Maringá, PR, Brazil). The mixtures were prepared by combining yam flour in different proportions, resulting in four formulations. The flours were mixed using a domestic mixing system and stored in polyethylene bags prior to extrusion.

Product evaluation

2.3.1 Market research with consumers

Market research was conducted online from May to June 2023 with 103 consumers. A consumer characterization questionnaire, comprising 15 questions (e.g., gender, age group, education level, breakfast cereal consumption, intention to purchase the product, most attractive attributes, and willingness to pay for 210 g of the product), was validated and distributed to a random sample of participants.

2.3.2 Sensory acceptance

The study involved 110 panelists, including students, staff, and professors from a university center in the central-northern region of Paraná, Brazil, of both genders, between 18 and 59 years old, and regular consumers of breakfast cereal. The tests were conducted in individual booths with white lighting. The

Table 1. Coded samples.

Ingredients (%)	F1	F2	F3	F4
White cornmeal	100	60	60	60
Yam flour	0	10	20	30
Still mineral water	4	4	4	4
Syrup (%)				
Still mineral water (Safira®)	133.3			
Inverted liquid sugar (Diottoni®)	13.33			
Cocoa powder (Nestlé®)	10			
Brown food coloring (Mago®)	0.2			
Natural sweetener steviol glycosides (Stevita®)	0.1			

attributes of appearance, aroma, flavor, texture, color, and overall acceptance were evaluated using a 9-point hedonic scale (1 = "Like extremally" to 9 = "Dislike extremally"). Purchase intention was assessed using a 5-point scale (1 - "would not buy" to 5 - "would definitely buy") (Meilgaard et al., 2006).

Each panelist received approximately 10 g of each sample in white disposable plastic cups (50 mL), coded with three-digit numbers, in a randomized and balanced order (Macfie et al., 1989), accompanied by a glass of water for palate cleansing. The formulations were presented in a sequential monadic manner. The acceptability index (AI) was calculated using the formula: AI (%) = A x 100/B (A = average score obtained for the product; B = maximum score possible) (Macfie et al., 1989).

Participants received a prior invitation and an explanation of the study's stages and objectives. Exclusion criteria included: allergies to cereal, diabetes *mellitus*, pregnancy, not being a student, staff or professor at UNINGÁ, being under 18 or over 59 years old.

2.3.3 Physicochemical and instrumental evaluation

The following evaluations were performed, with results expressed on a wet basis: water activity (Aw), measured using an Aw analyzer (Meter®, Aqualab 4TE, Malaysia) at 25 °C; and color, analyzed using the Commission Internationale de l'Éclairage (CIE) system (L* = lightness, a* = red-green, b* = yellow-blue), with a colorimeter (Konica Minolta®, model Chroma Meter CR 4400, Japan) using illuminant D65 and a 10º angle (Bible & Singha, 1993).

Nutritional composition was analyzed in triplicate, determining the following: moisture (g 100 g^{-1}) (Association of Official Analytical Chemists [AOAC], 2011); ash (g 100 g^{-1}) (AOAC, 2011); protein (g 100 g^{-1}) (AOAC, 2011); lipids (g 100 g^{-1}) (Bligh & Dyer, 1959); and carbohydrates (g 100 g^{-1}), calculated by difference (*% Carbohydrate = 100 - (% moisture + % protein + % lipid + % ash)*).

The daily reference value (VD) was calculated based on a 30 g sample, using average recommended values for adults aged 18 to 59 (Institute of Medicine, 2005), resulting in 2,127.5 kcal/day, 305.55 g/day of carbohydrates, 89.38 g/day of protein, 60.87 g/day of lipids, and 28.02 g/day of dietary fiber.

2.4 Statistical analysis

Results were analyzed using analysis of variance (ANOVA), with means compared using *Tukey's test at* $p \leq .05$. Statistical calculations were performed using the software Statistical Package for the Social Sciences 19.0 (SPSS, Chicago, IL, USA).

3 RESULTS AND DISCUSSION

3.1 Market research

Responses were collected from 103 participants, and the following aspects were analyzed: gender, age group, education level, breakfast cereal consumption, intention to purchase the product, most attractive attributes, and willingness to pay for 210 g of the product. The group of participants was mainly composed of females (79.6%). This predominance is often observed in studies on healthy foods, as women tend to be more engaged in healthy eating habits (Lombardo et al., 2023). Regarding age, 61.2% of the respondents were between 18 and 32 years old, indicating a young audience that is potentially more receptive to new food products. Additionally, 35% have completed higher education, and 21.4% had completed postgraduate studies, suggesting an audience with a relatively high level of education, which may influence their appreciation of nutritional aspects of the product.

When asked about the consumption of products containing yam flour, 94.2% of respondents indicated that they do not consume such products, possibly due to the limited availability of these items on the market. However, research has shown that yam starch has various applications in industrial food production, including edible film formulations and composite flour formulations. Moreover, 77.7% of respondents stated that they would be willing to purchase a product containing yam as an ingredient, suggesting potential market acceptance.

Regarding the flavor preferences for such product, 73.8% of respondents chose chocolate as their favorite, followed by vanilla (24.3%) and strawberry (1.9%). Figure 1 presents the responses regarding factors people consider when buying breakfast cereal, while Figure 2 highlights the most notable impressions of the product.

The product received high acceptance, with 88.3% of participants expressing willingness to purchase it. This positive response is supported by favorable perceptions of the product's attributes: 42% highlighted its nutritional quality, 34% valued the inclusion of yam flour and 24% appreciated its practicality. The emphasis on nutritional quality aligns with trends in the functional food market, where consumers prioritize health benefits. Most participants (79.6%) indicated they were willing to pay between R$ 10.00 and R$ 15.99 for the product, while 18.4% would accept prices between R$ 16.00 and R$ 21.99. These findings underscore the importance of maintaining affordability, as price sensitivity may be a key factor in expanding the consumer base.

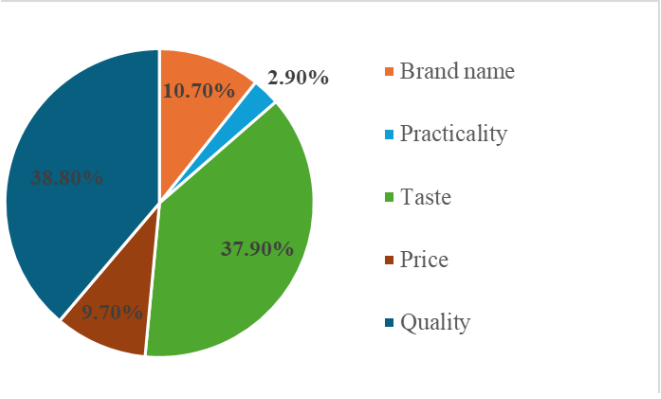

Figure 1. When you buy a breakfast cereal, what do you look for (choose one)?

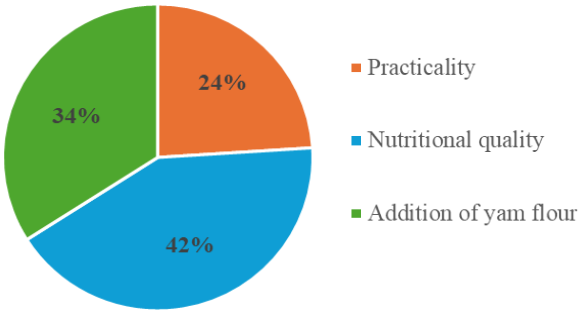

Figure 2. What impressed you most about this product?

3.2 Sensory acceptance

The parameters of appearance, aroma, flavor, texture, color, overall acceptance and purchase intention were evaluated. Results are presented in Table 2.

The incorporation of up to 30% yam flour showed no statistically significant difference ($p < .05$) for any of the evaluated attributes, and all formulations achieved an AI > 70%, indicating good sensory acceptability (Meilgaard et al., 2006). It can be concluded that yam flour is a promising ingredient for developing food products with appealing functional and sensory characteristics, contributing to the diversification of healthy options on the market. According to Shrestha et al. (2024), the incorporation of fruits and vegetables into breakfast cereals is widely recommended due to their increased fiber, bioactive compound, and essential micronutrient content. Studies such as Okoronkwo et al. (2019) have demonstrated that adding sweet potato and yam flour to breakfast cereals significantly enhances sensory attributes, such as texture, flavor and color, while improving nutritional value and achieving higher consumer acceptance (Shrestha et al., 2024).

3.3 Physicochemical and instrumental evaluation

The color parameters L*, a* and b* of breakfast cereals formulated with varying levels of yam flour are presented in Table 3. Generally, these breakfast cereals can be considered dark in color, with all L* values below 52%, exhibiting a yellow tone (b*) and a red undertone (a*) (Konica Minolta, 2007). These results can be attributed to the inclusion of cocoa powder in the syrup. Water activity (aW) values were similar across samples, ranging from 0.3691 (F1) to 0.3879 (F4). It indicates good shelf life stability, which helps preserve nutrients and maintain structural properties, such as texture and crunchiness (Katz & Labuza, 1981).

The centesimal composition of the cereals (Table 4) shows significant changes increasing yam flour content. Moisture content ranged from 5.89 to 6.76%, with no significant differences ($p < .05$). Protein content increased, reaching the highest value in formulations F3 and F4, indicating that yam flour addition enhanced the protein content of the cereal. Ash content was also higher in formulations with greater yam flour content, particularly F3 and F4, which may reflect the elevated mineral

Table 2. Sensory acceptability of breakfast cereal with added yam flour.

Parameters	F1	F2	F3	F4
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
Appearance	8.04 ± 0.87[a]	7.89 ± 0.83[a]	8.12 ± 0.81[a]	7.76 ± 1.56[a]
Aroma	8.09 ± 1.25[a]	7.79 ± 1.21[a]	8.09 ± 0.79[a]	7.77 ± 1.14[a]
Flavor	7.91 ± 1.55[a]	7.57 ± 1.50[a]	7.87 ± 0.94[a]	7.74 ± 1.48[a]
Texture	8.04 ± 1.01[a]	7.71 ± 2.20[a]	7.88 ± 1.22[a]	7.78 ± 0.50[a]
Color	8.01 ± 1.17[a]	7.80 ± 0.52[a]	8.09 ± 2.14[a]	8.20 ± 0.473[a]
Global acceptance	8.00 ± 2.00[a]	7.63 ± 1.57[a]	7.94 ± 1.68[a]	7.80 ± 0.52[a]
AI (%)	88.88	84.77	88.22	86.66
Purchase intention	4.19 ± 0.50[a]	4.37 ± 0.50[a]	4.41 ± 0.50[a]	4.16 ± 1.33[a]

Same superscript letters in the same line indicate no statistically significant difference by Tukey's test ($p < .05$) for formulations F1, F2, F3 and F4; SD: standard deviation; AI: acceptability index.

Table 3. Color parameters and water activity of breakfast cereals.

Sample	L	a*	b*	aW
F1	19.12[a] ± 0.80	10.21[a] ± 0.30	7.36[a] ± 0.72	0.3691[a] ± 0.02
F2	17.31 [a] ± 0.22	11.74[a] ± 0.24	8.56[a] ± 0.81	0.4091[a] ± 0.05
F3	21.71[a] ± 0.71	11.03[a] ± 0.36	9.03[a] ± 0.58	0.4055[a] ± 0.21
F4	13.85[a] ± 0.03	12.71[a] ± 0.84	11.02[a] ± 0.75	0.3879[a] ± 0.14

*Same superscript letters in the same column indicate no statistically significant difference ($p < .05$). L: luminosity; a: red-green; b: yellow-blue; aW: water activity.

Table 4. Centesimal composition of breakfast cereals.

Sample	Moisture (g/100g)	Protein (g/100g)	Ash (g/100g)	Lipids (g/100g)	Carbohydrates (g/100g)
F1	5.89[a] ± 0.31	6.20[c] ± 0.73	0.23[b] ± 0.83	7.32[b] ± 0.03	56.29[b] ± 0.24
F2	6.76[a] ± 0.45	7.38[b] ± 0.54	0.58[b] ± 0.98	9.01[a] ± 0.02	76.30[a] ± 0.05
F3	6.38[a] ± 0.03	7.83[ab] ± 0.98	1.36[a] ± 0.02	9.40[a] ± 0.51	74.83[a] ± 0.04
F4	6.04[a] ± 0.23	9.81[a] ± 0.41	1.13[a] ± 0.03	10.57[a] ± 0.41	72.45[a] ± 0.06

*Same superscript letters in the same column indicate no statistically significant difference ($p < .05$).

content in yam (phosphorus: 194 mg/100 g; calcium: 78.0 mg/100 g; magnesium: 74.6 mg/100 g; iron: 10.9 mg/100 g and zinc: 4.3 mg/100 g) (Bekele & Bekele, 2017).

The lipid content increased significantly with yam flour addition, from 7.32 (F1) to 10.57% (F4). Carbohydrate content decreased from 76.30 to 72.45%, due to higher proportions of other components, such as proteins and lipids. These results confirm that yam flour addition directly impacts the nutritional composition of the cereal, providing greater nutritional density, particularly in protein content.

Therefore, breakfast cereals with added yam flour enable consumers to increase their nutrient intake while also reducing the risk of chronic non-communicable diseases (NCDs) (Kwon et al., 2007). According to Shrestha et al. (2024), breakfast cereals enriched with ingredients like yam flour can contribute to preventing NCDs due to their high levels of fiber and antioxidants. Thus, incorporating yam flour into breakfast cereals not only enhances the nutritional profile but also improves functional and sensory appeal, making it a viable option for the healthy food market.

4 CONCLUSIONS

Market research indicated strong consumer acceptance, with 88.3% of respondents showing purchase intention. Additionally, 77.7% stated that they would purchase a product containing yam flour, reflecting a growing demand for healthier and more functional food alternatives.

Sensory tests revealed high acceptance for all formulations, with acceptability indices exceeding 70%. Incorporating up to 30% yam flour did not compromise key attributes such as flavor, texture, or appearance, reinforcing its suitability for breakfast cereal formulations without adversely affecting consumer experience.

The inclusion of yam flour enhanced the nutritional profile of the breakfast cereal, significantly increasing protein and dietary fiber content and probably elevating levels of essential minerals, such as iron, calcium, and magnesium. It also reduced the carbohydrate proportion, resulting in a more balanced nutritional composition. These findings suggest that incorporating yam flour into breakfast cereals is a promising strategy for developing nutritious products while maintaining sensory acceptability and physicochemical stability.

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