Sensory qualities and hydration kinetics of instant-extruded cereals with flaxseed and amaranth

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Abstract
Purpose – The purpose of this study was to evaluate the effects of the addition of flaxseed and amaranth at different proportions on the hydration kinetics, colour and sensory qualities of instant-extruded cereals, important aspects related to the functionality and acceptability of food products.

Design/methodology/approach – Instant-extruded cereals were made with different proportions of flaxseed (6.6–9.3%), amaranth (18.7–33.1%), and maize grits (63.8–67.3%); and characteristics such as hydration kinetics, colour parameters and sensory properties were evaluated.

Findings – The kinetics of milk absorption showed that the extruded cereals maintained their texture and crispness for a sufficiently long time (≤20 min). The \( L^* \), \( a^* \) and \( chroma^* \) values of the extruded cereals were significantly affected (\( p < 0.05 \)) by the flaxseed content. Sensory evaluation showed that all the extrudates had good acceptance in terms of flavour, texture, and colour attributes in relation to high-fibre commercial cereals; according to the preference test, they were as acceptable as commercial extruded cereals when consumed with milk. The addition of high-fibre and protein-containing grains such as flaxseed (8.6–9.3%) and amaranth (18.7–22.9%) in instant-extruded cereals allowed the production of products with acceptable physical and sensory characteristics.

Originality/value – In this study a novel instant-extruded cereal with flaxseed and amaranth was developed. The evaluation of the physical and sensory characteristics of instant-extruded cereals is essential to guarantee consumer acceptability, especially if functional ingredients with a high content of dietary fibre and protein are added.

Keywords Instant-extruded cereals, Flaxseed, Amaranth, Colour parameters, Sensory qualities, Hydration kinetics
Paper type Research paper
Introduction
Hectic lifestyles have made a greater number of consumers look for ready-to-eat products, especially those that complement the daily consumption of functional ingredients that contribute to their health and well-being. These types of products have become popular among consumers owing to the ease in their preparation and storage, as well as their attractive sensory characteristics, such as texture and flavour (Brennan et al., 2013). Instant-extruded cereals, one of the most important and highly consumed ready-to-eat products, have become a significant part of the human diet, and can hence influence overall nutrition. Cereal-based foods constitute a substantial part of the global food supply; in many developing countries, they provide up to 75% of food energy (Dolan, 2023; Kalentunç and Breslauer, 2003). Cereals and grains are considered an important source of nutrients, including complex carbohydrates, proteins, vitamins, and minerals, and provide other important compounds with functional potential, such as dietary fibre, phytochemicals, antioxidants, and phenolic compounds (Barros et al., 2022; Li et al., 2022; Liu, 2007).

Another current priority is the reduction of the environmental impact, in the field of the food industry, a more sustainable diet is sought by reducing the consumption of foods that generate a high ecological footprint, such as the consumption of meats that can be replaced by foods based on plants that are a good source of essential amino acids, such as amaranth and flaxseed that contain methionine and lysine (Sattar et al., 2024; Proserpio et al., 2020; Kajla et al., 2015). The option of this combination of ingredients can also be used by people who practice veganism, helping to reduce their deficiency of essential amino acids. They are also a versatile option for people who have gluten intolerance problems since their choice of extruded cereals on the market is very limited.

Extrusion cooking is a technological and versatile method for cereal processing which is increasingly being used to generate a wide range of ready-to-eat snack foods and breakfast cereals (Stojeska et al., 2010). Extrusion has become a well-established industrial technology with beneficial effects on the nutritional properties and texture of the final product (Ciudad-Mulero et al., 2020; García-Baños et al., 2004). During the extrusion process, solid raw materials are transformed into pastes owing to the effect of shear stresses and high temperatures, causing structural and chemical changes, including the gelatinisation of starch molecules, denaturation and texturing of proteins, release and breakdown of complex carbohydrates, and degradation and formation of bioactive compounds. These transformations affect the physical, chemical, and sensory properties of the extruded products (Cotacallapa-Sucapuca et al., 2021; Singh et al., 2007).

Many existing instant-extruded cereals contain significant caloric value and are high in sugar; therefore, they are regarded as calorie-dense but nutritionally poor foods. However, the nutritional status of extruded cereals can be manipulated by incorporating ingredients high in protein and bioactive components such as dietary fibre. Several investigations have focused on the use of dietary fibre in the formulation of extruded products, and how it can alter their nutritional, physicochemical, and sensory qualities (Brennan et al., 2013; Tobias-Espinoza et al., 2019). In a study where milled flaxseed was added to bean and corn mixtures to obtain extruded products, an increase in the content of omega-3 fatty acids was observed; the addition of 5 and 10% flaxseed resulted in good quality and stable shelf life, and acceptable results were obtained for physicochemical properties and sensory attributes. Similar results in the development of flaxseed and corn-based extrudates were reported by Wu et al. (2007, 2015). In another study, healthy extruded snacks with maize grits and amaranth seeds exhibited good results for sensory attributes, especially appearance and texture (Peksa et al., 2016a). Brennan et al. (2012) developed extruded breakfast cereals with amaranth, millet, and buckwheat, obtaining products with acceptable physicochemical properties; the inclusion of these pseudo-cereals resulted in a reduction in readily digestible
carbohydrates and a low degree of hydration, which reduced sogginess and disintegration of
the product during bowl life.

The reported studies mention the addition of flaxseed or amaranth separately, in the
present study the combination of these two ingredients is proposed in the generation of an
instant extruded cereal. This combination is interesting owing to its high protein (essential
amino acids), healthy fat, gluten free, high dietary fibre contents; but several factors related to
the mixture composition and extrusion process, such as appearance, taste, texture, and
flavour, affect the preference towards and acceptability of such foods (Deliza et al., 1996). An
excellent strategy to improve consumer acceptance of newly developed products is to
conduct analytical and sensory evaluation and determine the effects of incorporation of
ingredients, optimal formulations, or conditions of suitable extrusion processes (Dansby and
Bovell-Benjamin, 2003).

Among the considerations for the sensory evaluation of extruded products with high
fibre, and protein contents, are the characteristics of the groups of panellists who participate,
and their behaviour when evaluating the products (Shah et al., 2017). In a study carried out by
Proserpio et al. (2020), sustainable extruded snacks were made by adding flour and legume
bran, evaluating texture, food neophobia and neophobia of food technology and sensory
attributes taking into account the gender and age of the judges. The product with 100% rice
flour was the least accepted sensorially and the most preferred were those made with 100%
chickpea flour, 100% green pea flour, 15% chickpea bran – 85% rice flour, and 15% green
pea bran – 85% rice flour. A significant difference was observed in responses by gender, with
men providing higher scores compared to women. Regarding age, younger people gave
higher scores.

The influence of the characteristics of the panellists during the evaluation of different
types of extruded rice was evaluated by observing notable differences between ethnic groups
(Hof, 2007). A similar study for the sensory evaluation of fish and peanut extruded snacks
was conducted by Suknark et al. (1998). It has also been reported that the preference for
products such as extruded corn snacks seasoned with a mixture of protein and fish oil is not
affected by gender or age (Shaviklo et al., 2014). In a study, extruded crispy snacks made from
cereals and pulses were evaluated by a group of adolescents, and a profile was prepared,
considering gender, age, educational level, father’s occupation, type of family, and monthly
income (Selvi, 2015).

The results show that the addition of ingredients with high fibre and protein contents
modifies the functional properties of the extruded products and affects consumer
acceptability. The incorporation of flaxseed and amaranth as functional ingredients to
obtain healthy extruded products is beneficial owing to the consequent increase in fibre and
protein contents, being a novel, sustainable option with high nutritional quality for people
with gluten intolerance and/or who practice a diet such as veganism where the content of
proteins and essential amino acids is deficient. However, it affects the functional
characteristics (colour, water absorption, viscosity, etc.) and sensory attributes of the
extrudate; hence, it is important to establish the best combination of both ingredients to
obtain quality extrudates with good acceptability. Therefore, the aim of this study was to
evaluate the effects of the addition of flaxseed and amaranth at different proportions on the
hydration kinetics, colour and sensory qualities of instant-extruded cereals, considering the
characteristics of the judges.

**Materials and methods**

**Materials**

Raw materials used were: grains of amaranth (*Amaranthus hypochondriacus*), flaxseed
(*Linum usitatissimum*), maize grits no. 4 (GPC, Muscatine, IA, USA) and minor ingredients
such as sucralose, cocoa and cinnamon were obtained from a local seed distribution store (Monterrey, Nuevo León, Mexico). Amaranth and flaxseed were ground in a roller mill (Zhengzhou Chengli Grain and Oil Machinery Co., Ltd., model 6F-2240, Zhengzhou, China), and sieved at 0.5 mm (model RX-24, Tyler industrial products, Mentor, OH, USA), and stored in polyethylene bags at room temperature until the use. Proximal analysis were analysed on raw materials; moisture, protein, fat, crude fibre, and ash content according to the analysis of official methods (AOAC, 1998), 950.02, 960.52, 920.39, 962.09, and 923.03 respectively: amaranth (1.4 ± 0.01%, 17.4 ± 0.2%, 7.1 ± 0.18%, 3.2 ± 0.05%, and 3.0 ± 0.03%); flaxseed (5.3 ± 0.01%, 22.4 ± 0.2%, 37.2 ± 0.18%, 16.3 ± 0.05%, and 3.3 ± 0.03%).

Mixture formulation and extrusion process
Amaranth and flaxseed flours were mixed in different proportions, using maize grits and minor ingredients (2.5% cocoa, 1.6% sucralose, and 0.6% cinnamon) as the food matrix, to produce six different mixtures (Table 1). The ingredients were mixed in an industrial mixer (Bathammex, Mexico City, Mexico) for 5 min.

Mixture processing. The different mixtures were processed in duplicate in a twin-screw co-rotating extruder (BCTM-30, Bühler, AG, Uzwil, Switzerland) with a length of 600 mm, L/D ratio of 20, and die of 4 mm hole size. The mixtures were fed at 7.5 kg h⁻¹ and processed at a screw speed of 272 rpm. A moisture content of 0.22 kg H₂O kg⁻¹ dry matter, adjusted within the extruder at 150 °C, was controlled at the final stage of the extruding chamber using a TT-137N water heater (Tool-temp, Sulgen, Switzerland). The extrudates were dried at 120 °C for 15 min using an air convection oven (Electrolux 10 GN/1, Stockholm, Sweden) at an air cross-flow velocity of 1.5 m s⁻¹ until their moisture contents ranged from 0.017 to 0.031 kg H₂O kg⁻¹. The colour properties, milk absorption kinetics, and sensory qualities of the extrudates were evaluated. They were then packed and stored at room temperature (25 °C) until further analyses.

Colour parameters
The colour parameters of the different extruded cereals, previously milled and sieved at 0.5 mm (Model RX-24, Tyler Industrial Products, Mentor, OH, USA), were measured by reflectance using a Konica Minolta CR-400/410 colorimeter (Minolta Co., Osaka, Japan), which was calibrated with a reference tile (X = 94.9, y = 0.3185, x = 0.3124). The values of L* [luminosity (0–100)], a* [green (−), red (+)], and b* [blue (−), yellow (+)] were recorded based on 30 measurements for each sample. Chroma* value and Hue angle (h*), which are intensity and pure colour were calculated using the following equations:

\[ Chroma^* = \left( a^{*2} + b^{*2} \right)^{1/2} \]  

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Flaxseed (%)</th>
<th>Amaranth (%)</th>
<th>Maize grits (%)</th>
<th>Minor ingredients (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extrudate 1</td>
<td>8.2</td>
<td>24.7</td>
<td>62.4</td>
<td>4.7</td>
</tr>
<tr>
<td>Extrudate 2</td>
<td>7.3</td>
<td>29.3</td>
<td>58.7</td>
<td>4.7</td>
</tr>
<tr>
<td>Extrudate 3</td>
<td>6.6</td>
<td>33.1</td>
<td>55.6</td>
<td>4.7</td>
</tr>
<tr>
<td>Extrudate 4</td>
<td>9.3</td>
<td>18.7</td>
<td>67.3</td>
<td>4.7</td>
</tr>
<tr>
<td>Extrudate 5</td>
<td>8.6</td>
<td>22.9</td>
<td>63.8</td>
<td>4.7</td>
</tr>
<tr>
<td>Extrudate 6</td>
<td>7.9</td>
<td>26.4</td>
<td>61</td>
<td>4.7</td>
</tr>
</tbody>
</table>

Table 1.
Proportions of ingredients in different instant-extruded cereals*

*Minor ingredients: sucralose (1.6%), cocoa (2.5%), cinnamon (0.6%)
Source(s): Authors’ elaboration
Milk absorption kinetics

The milk absorption kinetics were determined according to the method described by Machado et al. (1999). The initial weight of the extruded cereals was registered; they were then immersed in milk at 4 °C and the weight gained was recorded at 2, 5, 10, and 20 min. The measurements were made in duplicate. Using the data obtained, the milk absorption curves of the extruded samples were plotted.

Sensory evaluation

Participants. For the sensory tests, 40 consumer judges (77.5% female and 22.5% male) were recruited, including undergraduate (85%) and graduated (15%) students. The consumers were young people aged between 20 and 28 years (60% aged >22 years and 40% aged <22 years). The sample size was determined based on the non-probabilistic or convenience sampling technique since the individuals were chosen from the Chemical Sciences Department of the Autonomous University of Chihuahua and had to have the conditions to adequately carry out sensory tests as: not have the habit of smoking, not have any respiratory condition that compromises their sensory perception, the risk of intolerance or allergy to any of the ingredients of the food products or were under a treatment that could alter their sensory perception. The tests were carried out at the Sensory Evaluation Laboratory of the Chemical Sciences Department of the Autonomous University of Chihuahua. In each test, an evaluation format was delivered to each judge with the instructions indicated for its administration, and it was determined that the environmental conditions were adequate: good lighting, privacy, furniture (Delgado-Nieblas, 2021; Poliszko et al., 2019; Mkandawire et al., 2015).

Testing procedures. To evaluate the quality and acceptance of different extruded cereals, the satisfaction degree for the sensory attributes of texture, colour and flavour was evaluated using a five-point hedonic rating scale: 1 = dislike very much, 2 = dislike moderately, 3 = neither like nor dislike, 4 = like moderately, and 5 = like very much. The scale was presented graphically using faces that expressed each description. In addition, the judges were asked to order the extruded cereals according to their preference, from 1 = most preferred to 3 = least preferred; for this test, the extruded cereals were presented in two forms, as cereal without and with milk, because that is how they are consumed. Three sensory tests were performed. An early assessment was carried out with Extrudates 3, 4, and 5 because, in a previous study, these mixtures presented the best physicochemical and functional properties (Tobias-Espinoza et al., 2019) to choose the extrudate that exhibited the best results, which, in this case, was Extrudate 5 (8.6% flaxseed, 22.9% amaranth, and 63.8% maize grits) (Figure 1). Then, it was evaluated against commercial breakfast extruded cereals (second sensory test) and high-fibre commercial breakfast cereals (third sensory test).

Ethics statement. The necessary precautions were taken to protect the confidentiality of the personal information of the participants in the study. For this purpose, an informed consent form was developed that included the justification, the objective of the study, the procedure to be performed, the risk of intolerance or allergy to any of the ingredients of the food products, and the freedom to stop participating in the study at any time.

Statistical methods

The collected data were analysed using analysis of variance (ANOVA), and means comparisons were assessed using Tukey’s test at a 95% significance level for colour.

\[ h^o = \arctan \left( \frac{a^o}{b^o} \right) \]
parameters \((L^*, a^*, b^*, \text{chroma}^*, \text{and hue angle}, h^*)\) and the degree of satisfaction for sensory attributes of texture, colour and flavour. Sensory preference data were analysed using Friedman’s test \((\alpha = 0.05)\). To compare the consumer groups for sensory tests, the chi-squared test (at a 95% confidence level) was carried out to determine if there were significant differences between gender, age, and scholarship. For the kinetics of milk absorption, the significant differences between the different treatments for the weight gained over time \((\alpha = 0.05)\) were evaluated using a general linear model and Tukey’s test (Montgomery, 2009). All experimental data were analysed using the Minitab 17 software.

Results and discussion

Colour parameters

The physical and sensory characteristic of colour of extruded cereals is a very important parameter for assessing consumer acceptability of the final product and depends largely on the type of raw material, ingredients, and additives used (Pełka et al., 2016a). Table 2 shows that the colour parameters of the extruded cereals produced in this study were significantly affected \((p < 0.05)\) by the ingredients (flaxseed and amaranth) and their proportions. Luminosity, which had values of 61.03–61.86, was affected by the content of flaxseed, which

<table>
<thead>
<tr>
<th>Colour parameters</th>
<th>Extrudate 1</th>
<th>Extrudate 2</th>
<th>Extrudate 3</th>
<th>Extrudate 4</th>
<th>Extrudate 5</th>
<th>Extrudate 6</th>
<th>SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>(L^*)</td>
<td>61.71(^{a1})</td>
<td>61.85(^a)</td>
<td>61.86(^a)</td>
<td>61.49(^a)</td>
<td>61.03(^b)</td>
<td>61.43(^{ab})</td>
<td>0.11</td>
</tr>
<tr>
<td>(a^*)</td>
<td>5.56(^{cd})</td>
<td>5.51(^{de})</td>
<td>5.44(^e)</td>
<td>5.71(^a)</td>
<td>5.70(^{ab})</td>
<td>5.62(^{bc})</td>
<td>0.02</td>
</tr>
<tr>
<td>(b^*)</td>
<td>21.03(^d)</td>
<td>21.27(^{bc})</td>
<td>21.19(^{cd})</td>
<td>21.44(^{ab})</td>
<td>21.41(^{ab})</td>
<td>21.59(^a)</td>
<td>0.05</td>
</tr>
<tr>
<td>(\text{Chroma}^*)</td>
<td>21.75(^\text{a})</td>
<td>21.9(^{bc})</td>
<td>21.87(^\text{a})</td>
<td>22.19(^{ab})</td>
<td>22.16(^{ab})</td>
<td>22.31(^a)</td>
<td>0.06</td>
</tr>
<tr>
<td>(h^\circ)</td>
<td>75.20(^\text{a})</td>
<td>75.46(^{ab})</td>
<td>75.59(^\text{a})</td>
<td>75.09(^\text{a})</td>
<td>75.10(^\text{a})</td>
<td>75.40(^b)</td>
<td>0.04</td>
</tr>
</tbody>
</table>

Note(s): \(^{(1)}\) Mean ± standard error (SE). Means with different letters are significantly different based on Tukey’s test \((p < 0.05)\).

Source(s): Authors elaboration
is an ingredient with a dark hue. Extrudates 5 and 6, which had higher contents of flaxseed (8.6 and 7.9%, respectively), exhibited the lowest luminosity values (Table 2); flaxseed is high in fibre (Lan et al., 2020; Kajla et al., 2015), and the presence of fibre decreased the luminosity values of the extruded products, as indicated by Santillán-Moreno et al. (2011). In a study conducted by Vadukapuram et al. (2014), who evaluated extruded bean snacks fortified with flaxseed at levels of 5–20%, the luminosity parameter ($L^*$) was significantly affected by the addition of flaxseed, presenting a decrease in value and therefore a darkening of the snacks as the flaxseed percentage increased. Sinaki and Koksel (2024), enriched lentil extrudates with several sources of dietary fibre: namely carrot powder, wheat bran and red lentil hulls, obtaining a significant increase in their dietary fibre content; However, some important physical changes occurred such as the decrease in luminosity in terms of the colour parameter.

On the other hand, Extrudates 2 and 3, which had the lowest contents of flaxseed (7.3 and 6.6%, respectively) and the highest percentages of amaranth (29.3 and 33.1%, respectively), presented the highest luminosity values (61.85 and 61.86, respectively) (Table 2). These values are consistent with those obtained in a study by Pêksa et al. (2016b), in which the luminosity values of corn-based extruded cereals with pumpkin flour, Jerusalem artichoke, and amaranth were higher when more amaranth was added to the mixtures.

The values for the colour parameter $a^*$ (5.44–5.71) indicated positive results marking a colour trend in the extrudates towards red, probably due to the presence of ingredients such as flaxseed, which presents this type of tonality (Lan et al., 2020; Wu et al., 2007). In agreement with this, Extrudates 4 and 5, which had the highest percentages of flaxseed (9.3 and 8.6%, respectively), exhibited the highest values of $a^*$, whereas Extrudates 2 and 3, which had the lowest contents of flaxseed (6.6 and 7.3%, respectively), exhibited the lowest $a^*$ values (Table 2).

The results of the colour parameter $b^*$ (21.03–21.59) showed the tendency of the extruded cereals to become more yellow, owing to the ingredients with this type of tonality that were used (amaranth and maize grits). Extrudates 4, 5, and 6, which had higher percentages of maize grits (61–67.3%), presented the highest $b^*$ values (21.41–21.59). Extrudates 2 and 3, which had lower percentages of maize grits, exhibited lower $b^*$ values.

The parameter $h^\circ$, with values of 75.09–75.59, presented a colour purity with a tendency towards yellow (90°), due to the presence of ingredients such as amaranth and maize grits, which exhibit such colour tones. Maize grits were present in greater amounts in the mixtures of the extruded cereals (55.6–67.3%), whereas the amaranth contents were between 18.7 and 33.1%. Therefore, Extrudates 2 and 3, which had the highest contents of amaranth and maize grits, exhibited the highest $h^\circ$ values (75.46 and 75.59, respectively) (Table 2).

Ingredients with darker colours, such as flaxseed, have a significant impact on colour parameters, especially intensity, represented by the chroma* value, as indicated by Vadukapuram et al. (2014). In their study, an increase in flaxseed concentration in mixtures with bean and corn flours contributed to the darkening of the extrudates, and the same effect was observed when the content of chia seeds in mixtures with corn flour was increased (Byars and Singh, 2015). The chroma* values obtained in this study ranged from 21.75 to 22.31, with the highest being presented by Extrudates 4, 5, and 6, which had the highest contents of flaxseed. Extrudates 2 and 3, which had lower flaxseed contents and high percentages of amaranth, showed lower chroma* values (Table 2). This is consistent with the results of a study by Pêksa et al. (2016b), wherein the extrudate with the highest amaranth content was characterised by the lowest colour intensity.

Similar results were reported by Wu et al. (2007), who evaluated the colour parameters of flaxseed and corn-based extrudates, and found that the values of $L^*$, $a^*$, and $b^*$ were significantly affected by the content of flaxseed meal. The values of $L^*$ (luminosity) and $b^*$ ( yellowness) decreased, whereas those of $a^*$ (redness) increased.
These changes in the colour of the extruded mixtures could also have been due to various reactions that occurred during the extrusion process, including the Maillard reaction, caramelisation, and carbohydrate hydrolysis, as well as non-enzymatic reactions, such as the degradation of pigments (Hu et al., 2020; Camire et al., 1990).

**Milk absorption kinetics**

The analysis of the milk absorption kinetics of the different extruded cereals showed a significant difference \( p < 0.05 \) between the mixtures in terms of the time and the interaction between ingredients, due to the type of ingredients and their proportions in each mixture. The data collected after 20 min of rehydration were analysed using absorption kinetics to compare the behaviour of the different extrudates (Figure 2).

In general, it was observed that the extrudate with the highest content of maize grits (Extrudate 4) absorbed the most milk (Figure 2). Maize grits are an important source of starch, which facilitates milk absorption. On the other hand, Extrudate 3, which had the lowest maize grit content and the highest proportion of ingredients high in fibre (flaxseed and amaranth, 39.7%), showed the least milk absorption (Figure 2). In a study evaluating the effect of “incorporation of dietary fibre from wheat and oat bran in extruded cereals” on the rehydration properties of milk, a loss in hardness and crunchiness was observed after immersion in milk. The addition of fibre resulted in maintenance of hardness when immersed in milk; this was confirmed using magnetic resonance measurements, which showed slower penetration of milk into the granules containing dietary fibre (Chassagne-Berces et al., 2011). The formation of capillaries and a porous structure during the extrusion process can explain an improvement in solvent retention capacity. Therefore, the structure and porosity of cereals are very important factors. The porosity of cereals is strongly related to their milk absorption capacity (Beech et al., 2022; Sharma et al., 2011). Machado et al. (1999) determined the effect of

![Figure 2. Milk absorption kinetics of extruded cereals](image)

**Note(s):** → Extrudate 1\(^b\) (3.96), ← Extrudate 2\(^b\) (4.08), → Extrudate 3\(^b\) (3.89), ← Extrudate 4\(^b\) (4.54), ← Extrudate 5\(^b\) (4.16), and → Extrudate 6\(^b\) (4.13).

Means with different letters are significantly different based on Tukey’s test \( p < 0.05 \), standard error 0.06

**Source(s):** Authors elaboration
whole milk and defatted milk on the absorption kinetics of extruded breakfast cereals, and observed that fat plays an important role in the mechanism of the absorption process. A layer of fat was deposited on the surface of the solid matrix, which repelled water and thus prevented the absorption of solids, enabling the cereal to better retain its cellular structure. Therefore, it was concluded that whole milk better maintains the structure of the cereal during the absorption process in milk, as observed and exploited in the present study. It is notable that the extruded cereals maintained their firmness and crispness for a long time after soaking (\( \leq 20 \) min), which is a characteristic desired by consumers.

In a study, the impact of the addition of oat flour as a source of dietary fibre for the production of instant extruded rice was evaluated. Some structural, physical and sensory properties were analysed, such as texture, hydration properties, rehydration characteristics, digestibility, etc. Extruded instant rice with the addition of 44% oats presented the highest rehydration time, sensory score, adhesiveness, and a resistant starch content of 6.06%. (Wu et al., 2024)

Sensory evaluation

To perform sensory evaluation of commercial breakfast cereals, an early assessment was carried out to select the extrudate with the best characteristics, which, in this case, was the extruded cereal of the mixture 5 (8.6% flaxseed, 22.9% amaranth, and 63.8% maize grits). The results obtained for the comparison of Extrudate 5 with commercial expanded-extruded cereals showed a significant difference in the degree of preference according to the Friedman test \( (p < 0.05) \). It was observed that Extrudate 5 was just as preferable as the commercial cereal, CE2 (Honey Nut Scooters\textsuperscript{®}), but it was significantly different from the commercial cereal, CE1 (Cheerios\textsuperscript{®}), in both the tests of cereal with and without milk (Table 3).

Table 4 shows the characteristics of the consumer group in the preference test for commercial expanded-extruded cereals. In the preference test of extruded cereals with milk, consumers who were male, \(< 22\) years old, and had graduated showed a similar distribution when evaluating cereals, without presenting a significant difference \( (p \geq 0.05) \). Females, those aged \( > 22 \) years, and undergraduates showed a significant difference in their preference \( (p \leq 0.05) \), mostly choosing the commercial extruded cereal, CE1. This means that in the consumer groups of females, those \(< 22 \) years of age, and graduates, there is a significant difference when choosing different types of cereals, unlike consumer groups of males, those \( > 22 \) years of age, and undergraduates. This can be explained by the fact that the consumer

| Preference for extruded cereal (mixture 5) and commercial extruded cereals |
|-----------------------------|----------------|----------------|
| Type of presentation       | Extrudate 5    | CE1            | CE2            |
| Extrudate without milk     | 2.5\textsuperscript{b} | 1.5\textsuperscript{a} | 2.1\textsuperscript{b} |
| Extrudate with milk        | 2.4\textsuperscript{b} | 1.4\textsuperscript{a} | 2.1\textsuperscript{b} |

| Preference of extruded cereal (mixture 5) and commercial high fibre cereals |
|-----------------------------|----------------|----------------|
| Type of presentation       | Extrudate 5    | FC1            | FC2            |
| Extrudate without milk     | 2.5\textsuperscript{a} | 1.6\textsuperscript{b} | 1.9\textsuperscript{a} |
| Extrudate with milk        | 2.3\textsuperscript{b} | 1.9\textsuperscript{a} | 1.9\textsuperscript{a} |

\textbf{Note(s):} Medians with different letters are significantly different based on Friedman’s test \( (\alpha = 0.05) \). Preference score by order: 1 = most preferred, 3 = least preferred. CE1, Cheerios\textsuperscript{®}; CE2, Honey Nut Scooters\textsuperscript{®}; FC1, All-Bran\textsuperscript{®}; FC2, Bran Flakes\textsuperscript{®}

\textbf{Source(s):} Authors elaboration

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Table 3. Preference for extruded cereal (mixture 5) and commercial cereals*
groups of females, those <22 years of age, and graduates have greater numbers, and therefore there is greater variability when choosing.

For the test of extruded cereals with milk, a significant difference was observed at the time of choosing for consumer groups of females, undergraduates, and those >22 and <22 years of age ($p \leq 0.05$). On the other hand, consumers who were male and had graduated ($p \geq 0.05$) showed a similar distribution, that is, they chose different cereals in the same way when these were consumed with milk (Table 4).

In the analysis of the degree of satisfaction, there was a significant difference between the three cereals in terms of the attributes of flavour, texture, and colour ($p < 0.05$). In this case, the extrudate of mixture 5 was different from the other two cereals in terms of flavour, with the lowest score of 3.3, which represents the description *neither like nor dislike to like moderately* according to the hedonic rating scale established for the degree of satisfaction (Figure 2). This may be because the expanded commercial cereals contain added sugar and artificial flavours that make them more attractive to the consumer. With regards to the texture (3.8) and colour (3.5) attributes, extruded mixture 5 was not significantly different ($p > 0.05$) from the CE2, and was equally acceptable, obtaining a favourable score, which indicates that it was moderately preferred according to the hedonic rating scale (Figure 3).

Sensory analysis for the degree of preference of high-fibre commercial cereals showed a significant difference for the cereal test without milk ($p < 0.05$), but did not show a significant difference for the cereal test with milk ($p > 0.05$); therefore, the extruded cereal (mixture 5) was just as preferable as high-fibre commercial cereals, FC1 (All-Bran®) and FC2 (Bran Flakes®) when it was consumed with milk. As for the test without milk, mixture 5 was not significantly different from FC2, but was different from FC1 (Table 3).

According to the characteristics of the consumer group for the preference test without milk (Table 4), consumers who were males, <22 years old, and had graduated showed a similar distribution, without presenting a significant difference ($p > 0.05$). Conversely,

<table>
<thead>
<tr>
<th>Characteristics profile</th>
<th>Extrudate 5</th>
<th>FC1</th>
<th>FC2</th>
<th>$p$-value*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
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<td></td>
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<tr>
<td>Male</td>
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<td>2</td>
<td>5</td>
</tr>
<tr>
<td>Age</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
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<td>2</td>
<td>8</td>
<td>16</td>
</tr>
<tr>
<td>&gt;22 years old</td>
<td>2</td>
<td>3</td>
<td>11</td>
<td>8</td>
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<tr>
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<td>10</td>
</tr>
<tr>
<td>Graduated</td>
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<td>1</td>
<td>3</td>
<td>2</td>
</tr>
</tbody>
</table>

**Note(s):** *$p$-values were calculated using the chi-squared test, $\alpha = 0.05$. CE1, Cheerios®; CE2, Honey Nut Scooters®; FC1, All-Bran®; FC2, Bran Flakes®

**Source(s):** Authors elaboration

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<table>
<thead>
<tr>
<th>Test of high-fibre commercial cereals</th>
<th>Extrudate 5</th>
<th>FC1</th>
<th>FC2</th>
<th>$p$-value*</th>
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</tr>
<tr>
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<td>3</td>
<td>2</td>
<td>5</td>
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</tr>
<tr>
<td>Female</td>
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<tr>
<td>Age</td>
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<td>Graduated</td>
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</tr>
</tbody>
</table>

**Table 4.** Preferences and characteristics of consumer groups
consumer groups of females, those >22 years of age, and undergraduates showed a significant difference in their preference ($p$-value ≤0.05), mostly choosing the commercial high-fibre cereal, FC2. This means that consumer groups of males, those <22 years of age, and graduates do not choose any cereal in a particular way, but the distribution in their choice of cereals is similar. In contrast, consumer groups of females, those >22 years of age, and undergraduates choose differently between cereals.

**Figure 3.** Sensory experience mapping on texture, colour and flavour of extrudate 5 and commercial extruded cereals, and high fibre commercial cereals.
For the test of high-fibre breakfast cereals with milk, consumers who were males, graduates, undergraduates, and >22 years and <22 years of age (\(p \geq 0.05\)) showed a similar distribution when choosing different cereals. Only the female consumer group showed a significant difference (\(p \leq 0.05\)) when choosing cereals (Table 4). This can be explained by the fact that the female group was the largest, and therefore, there was greater variability when choosing.

For the analysis of the degree of satisfaction with high-fibre commercial cereals, a significant difference was observed between cereals for the texture and colour attributes (\(p < 0.05\)); however, there was no significant difference for the flavour attribute (\(p > 0.05\)), and hence the extruded cereal (mixture 5) was as acceptable as commercial cereals high in fibre in terms of flavour with an acceptance score (3.3) which represents the description *neither like nor dislike* to *like moderately* according to the hedonic rating scale (Figure 2). For the texture (3.3) and colour (3.3) attributes, it was just as acceptable as the FC1, since there was no significant difference between them, but it was not as acceptable as the FC2, which indicates that it was moderately preferred (Figure 3).

The results of this study, in which a high-fibre extruded cereal had good acceptance by consumers, are consistent with those reported by Altan et al. (2008) who evaluated the acceptability of extruded products made from mixtures of barley and tomato pomace, and found that the lowest score was for the extrudate that had no tomato pomace, whereas the highest score was for the extrudate with 10% tomato pomace. Similarly, Clark and Johnson (2002) performed an acceptance analysis of a cereal and a breakfast bar enriched with wheat fibre, which was very successful. In another study, an extrudate with a mixture of legumes, sorghum, and rice presented a crunchy texture and obtained the best score for sensory acceptance characteristics (Lakshmi et al., 2014). The effect of adding pumpkin flour on the physical and sensory properties of extruded snacks made from corn grits was evaluated. For the sensory evaluation, sociodemographic information of the panellists was provided, such as age and gender. Consumers indicated that the incorporation of pumpkin flour improved the flavour and appearance of the extrudates, increasing general acceptability. The addition of pumpkin flour caused significant changes in the colour of the extrudates, for example a reduction in luminosity and the green/red colour balance shifted towards red (Poliszko et al., 2019). In a study, high-fibre extruded breakfast cereals were developed with the addition of carrot sub-products and based on corn grits and wheat and oat bran, evaluating their physical and sensory characteristics. Extruded cereals added with carrot bagasse had a good percentage of acceptance compared to a commercial product (Delgado-Nieblas et al., 2021). In turn, Proserpio et al. (2020), developed sustainable extruded snacks by adding flour and legume bran and evaluated texture, food neophobia, food technology neophobia, and sensory attributes considering the gender and age of the judges. The best preferred extrudes were those made with 100% chickpea flour, 100% green pea flour, 15% chickpea bran – 85% rice flour, and 15% green pea bran – 85% rice flour. A significant difference was observed in the responses, by gender, with men providing higher scores compared to women; and the young people were the ones who gave the highest marks.

Extruded breakfast cereals made with mixtures of corn bran and oatmeal, with percentages of 30 and 40% corn bran, presented good scores for sensory attributes of colour, flavour and texture (Holguín-Acuña et al., 2008). Moya (2008) used a test to evaluate the sensory profiles of the flavour and texture attributes of extruded products made of oatmeal, bran, and nopal. The results showed that the treatment with the addition of dried prickly pear cactus had better acceptance with respect to a commercial reference cereal. In another study, the impact of combining legumes and pseudocereals on the physical and sensory qualities of extruded snacks was evaluated, where lupine protein-based cereals showed better sensory and textural properties (Martin et al., 2022).
Conclusions
Extruded cereals based on mixtures of flaxseed, amaranth and maize grits were obtained. The different levels of flaxseed and amaranth and their simple and combined effects had a significant impact on the physical and sensory properties of the extruded products, such as the colour parameters, milk absorption kinetics, and degrees of preference and satisfaction. This was due to the characteristics of each ingredient and its proportion in the mixtures formulated to obtain extrudates. The $L^*$, $a^*$, and $\text{chroma}^*$ values of the extruded cereals were affected by the content of flaxseed, which is an ingredient with a dark hue. According to the kinetics of milk absorption, the extruded cereals maintain their texture and crispness for a sufficiently long time ($\leq 20\text{ min}$). It was observed that the extrudate with the highest content of maize grits (Extrudate 4) absorbed the most milk, whereas Extrudate 3, which had the lowest maize grit content and the highest proportion of ingredients high in fibre (flaxseed and amaranth, 39.7%), showed the least milk absorption.

Sensory analysis showed that the extruded cereals had good acceptance in terms of flavour, texture, and colour attributes in relation to high-fibre commercial cereals, and according to the preference test, they were as acceptable as commercial extruded cereals when consumed with milk. According to the characteristics of the consumer groups for the preference test of the different breakfast cereals, it is common that, when evaluating cereals, there will be a significant difference ($p \leq 0.05$) for females, those $>22$ years of age and undergraduates. This is because these consumer groups have greater numbers, and therefore, there is greater variability when choosing.

The addition of high-fibre grains such as flaxseed (8.6–9.3%) and amaranth (18.7–22.9%) in instant-extruded cereals, processed by extrusion cooking, enabled the production of a good-quality product with acceptable physical and sensory properties. Which can be competitive to be marketed or used in social feeding programs.

References


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