Physicochemical and technological properties of water-soluble extracts from germinated yellow corn

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Abstract
Lactose intolerance affects approximately 70% of the global population, leading to increased demand for alternative raw materials and technologies that enhance plant-based beverages' nutritional and functional properties. In this context, the present study investigates the development of water-soluble extracts from germinated yellow corn, aiming to improve their physicochemical and technological properties for a possible use as a plant-based beverage. The effects of germination time and temperature on the physical and physicochemical characteristics of yellow corn grains and their corresponding water-soluble extracts were evaluated. The results demonstrated significant variations in soluble solids content, particularly in assays with prolonged germination times and elevated temperatures (32°C for Assays 2 and 5), which are attributed to increased endogenous enzymatic activity. The rise in soluble solids suggests an increase in reducing carbohydrates due to starch hydrolysis, contributing to enhanced colloidal stability. Furthermore, modifications in color parameters (L^*, a^*, b^*) were observed in both germinated corn flours and their water-soluble extracts, influenced by enzymatic activity and processing conditions. These findings indicate that water-soluble extracts from germinated yellow corn could serve as viable alternatives to plant-based products, thereby reducing the need for added sucrose and chemical additives.
Keywords: Alpha-amylase; endogenous enzymes; starch; temperature.

Propriedades fisico-químicas e tecnológicas de extratos hidrossoluveis de milho amarelo germinado

Resumo
A intolerância à lactose afeta aproximadamente 70% da população global, levando ao aumento da demanda por matérias-primas e tecnologias alternativas que melhorem as propriedades nutricionais e funcionais das bebidas vegetais. Neste contexto, o presente estudo investiga o desenvolvimento de extratos solúveis em água de milho amarelo germinado, visando melhorar suas propriedades físico-químicas e tecnológicas para uma possível utilização como bebida plant-based. Os efeitos do tempo de germinação e da temperatura nas características físicas e físico-químicas dos grãos de milho amarelo e seus correspondentes extratos solúveis em água foram avaliados. Os resultados demonstraram variações significativas no teor de sólidos solúveis, particularmente em ensaios com tempos de germinação prolongados e temperaturas elevadas (32 °C para os Ensaios 2 e 5), que são atribuídos ao aumento da atividade enzimática endógena. O aumento de sólidos solúveis sugere um aumento na redução de carboidratos devido à hidrólise do amido, contribuindo para o aumento da estabilidade coloidal. Além disso, modificações nos parâmetros de cor (L, a*, b*) foram observadas tanto em farinhas de milho germinadas quanto em seus extratos solúveis em água, influenciados pela atividade enzimática e condições de processamento. Essas descobertas indicam que extratos solúveis em água de milho amarelo germinado têm como alternativas viáveis a produtos a base de plantas , reduzindo assim a necessidade de sacarose e aditivos químicos adicionados.*
Palavras-chaves: *Alfa-amilase; amido; enzimas endógenas; temperatura.*

1 Introduction

The demand for non-dairy foods has increased significantly in recent years, primarily due to the growing prevalence of lactose intolerance, a condition that affects approximately 70% of the global population. Lactose, the main carbohydrate in milk, is poorly digested by individuals with this condition. Additionally, allergies to bovine milk proteins, the most widely consumed milk worldwide, further restrict dairy product consumption (Paiva; Costa; Pereira, 2024; Tariq et al., 2004). Beyond health concerns, lifestyle choices, as well as social, environmental, cultural, and economic factors, contribute to the reduced consumption of dairy foods (Andressa *et al*., 2024a).

Plant-based beverages have emerged as key substitutes for milk, typically produced through aqueous extraction from nuts, cereals, pseudocereals, legumes, oilseeds, vegetables, or seeds. Despite the increasing variety of plant-based milk alternatives, many face technological challenges related to processing and preservation. Furthermore, while these alternatives contain functionally active compounds, they often lack the nutritional balance found in bovine milk. As a result, cereals with high nutritional value and health benefits have been explored as raw materials for the development of new food products (Bueno *et al*., 2020; Sharma *et al*., 2024).

Corn (*Zea mays* L.) is one of the world's most important staple foods and contains bioactive compounds that provide significant health benefits (Sheng; Li; Liu, 2018). All corn varieties are rich in dietary fiber, vitamins (A, B, E, and K), minerals (magnesium, potassium, and phosphorus), phenolic acids, flavonoids, sterols, and other phytochemicals such as lignins and complex compounds. However, variations in phytochemical profiles are observed among different corn types, particularly regarding flavonoid and carotenoid content. Yellow corn, the variety used in this study, is a rich source of carotenoids, including lutein, zeaxanthin, β-cryptoxanthin, β-carotene, and α-carotene (Sheng; Li; Liu, 2018).

Certain plant-derived antinutritional compounds can inhibit the bioavailability of vitamins and minerals. However, these limitations can be mitigated through fermentation, germination, and conventional or unconventional thermal processing (Mäkinen *et al*., 2015). Technological processes that increase the solubility of proteins, phenolic compounds, and other bioactive molecules facilitate the production of water-soluble extracts with improved protein and bioactive compound yields. In this context, the grain germination process represents a viable strategy for enhancing the composition of plant-based raw materials intended for water-soluble extracts (Sethi; Tyagi; Anurag, 2016).

Germinated cereals and other grains generally exhibit superior nutritional profiles compared to non-germinated counterparts. They are richer in compounds that are more easily digestible by the gastrointestinal tract, providing energy and improving the bioavailability of vitamins, minerals, amino acids, proteins, and phytochemicals (Andressa *et al*., 2024b). These bioactive compounds contribute to various health benefits, including reducing the risk of cardiovascular diseases, cancer, and diabetes. Additionally, they function as anti-aging agents and aid in controlling blood pressure, preventing arterial blockages, mitigating obesity, and promoting overall health (Chalorcharoenying *et al*., 2017).

The germination process induces chemical modifications through increased enzymatic activity, involving phytases, glycosidases, amylases, and proteases. This process consists of sequential stages: grain soaking in water, germination, and drying (Pacheco; Cunha; Andressa, 2025).

During germination, endogenous enzymatic activation results in the hydrolysis of proteins, complex carbohydrates, and lipids into simpler compounds such as amino acids, sugars, and free fatty acids. Additionally, new cellular constituents and phytochemicals are synthesized (Kathuria et al., 2024). Notably, germination can enhance the natural carotenoid content in yellow corn, particularly xanthophylls such as lutein and zeaxanthin. Luo et al. (2020) reported that carotenoid concentration in sprouted grains were elevated by 42.5% to 135% compared to unsprouted grains.

Therefore, this study aimed to evaluate the influence of germination time and temperature on the technological (color and sedimentation) and chemical (pH, acidity, soluble solids, and reducing sugar concentration) properties of water-soluble extracts from yellow corn.

2 Material and methods

The yellow corn seeds were sourced from a local market in Diamantina, Minas Gerais (MG), Brazil. Following the sanitization process, the seeds were manually selected and subsequently subjected to germination according to the experimental design.

All chemicals used were of analytical grade, meeting the required purity standards for the applied methodologies.

2.1 Experimental design

The germination process of yellow corn seeds was conducted using a Completely Randomized Design (CRD) (Table 1). The incubation times and temperatures were selected based on preliminary laboratory tests (data not published).

Table 1 – Germination times and temperatures for yellow corn

Assay	Time (hours)	Temperature (ºC)
Control	–	–
Assay 1	48	18
Assay 2	48	32
Assay 3	60	25
Assay 4	72	18
Assay 5	72	32

Source: research data

2.2 Germination process

The germination process followed the methodology described by Andressa *et al*. (2024a), with adjustments. The samples (200 g) were pre-washed with distilled water and then immersed in a 1.25% sodium hypochlorite solution (1:5 w/v, seeds to water) at room temperature for 30 minutes. After sanitization, the samples were rinsed with distilled water to remove residual chlorine from the seed surfaces.

Subsequently, the sanitized seeds were soaked in distilled water (1:5 w/v) for 24 hours at room temperature (20°C). After this period, the soaking liquid was drained, and the seeds were manually arranged in polyethylene trays (0.045 m²) between two layers of cotton (approximately 20 g each), separated by an intermediate layer of paper towel (0.044 m²), ensuring careful placement to prevent overlapping. Each cotton layer was moistened with 100 mL of distilled water. The trays were then placed in a BOD germination chamber TF-33A (Telga, Belo Horizonte, Brazil), ensuring a controlled environment for germination. To maintain adequate humidity, the samples were sprayed with distilled water every 12 hours, and an additional polyethylene tray containing 8 liters of water (0.2 m² surface area) was positioned at the bottom of the chamber.

The relative humidity was maintained at 75-80%, determined using a psychrometric chart based on dry bulb and wet bulb temperatures recorded every 12 hours. The entire process was conducted in the absence of light.

After germination, the samples were dried at 45°C for 12 hours in a forced-air oven (TE 394/1, Tecnal, Piracicaba, Brazil) with an air circulation speed of 1 m/s. Once dried, the samples were cooled to room temperature, packed in high-density polyethylene bags, and stored at 4°C in a DFN41 refrigerator (Electrolux, Curitiba, Brazil) until further analysis.

2.3 Preparation of corn water-soluble extracts

The germinated corn seeds were processed using a Multi Grãos disc mill (Malta, Caxias do Sul, Brazil) and subsequently mashed in a water bath (SL-150, Solab, Piracicaba, Brazil) at 75°C for one hour in a 1:6 ratio (40 g of corn flour per 240 mL of potable water, dry basis). The content of soluble solids was determined following AACCI method 80-51.01 (AACCI, 2010). Readings in °Brix were obtained using a digital refractometer, previously calibrated with distilled water, with small sample portions analyzed every 5 minutes.

After the mashing process, the samples were blended using a PMX-700 mixer (Philco, Curitiba, Brazil) at maximum speed for 2 minutes and then filtered through a 0.88 mm mesh. The final volume was adjusted to 250 mL with potable water in a volumetric flask. The samples were subsequently stored in polypropylene containers and frozen at –18°C in a DFN41 freezer (Electrolux, Curitiba, Brazil) under light-free conditions until analysis.

2.4 Analysis of water-soluble extracts

The determination of total reducing sugars was carried out following method described by AOAC (2019). The analyses were performed in triplicate, and the results were presented as a percentage of glucose.

The pH and total titratable acidity were determined using the method described by the Association of Official Analytical Chemists (AOAC, 2019). The analyses were conducted in triplicate, with total titratable acidity expressed as a percentage of ferulic acid.

Sedimentation analysis was conducted in triplicate following the methodology proposed by Leite *et al*. (2017), with adaptations. After homogenization, 40 mL of each sample was transferred to 50 mL graduated cylinders and left undisturbed on a flat surface for 5 minutes, at room temperature. The sedimented volume was recorded, and the sedimentation percentage was calculated using Equation 1:

$$\text{Sedimentation}(\%) = \frac{Vi - Vs}{Vi} \times 100 \quad (1)$$

where Vi represents the initial volume of the water-soluble extract, and Vs is the sedimented volume after 5 minutes.

Instrumental color analysis was performed using spectrophotometry in the 360-740 nm wavelength range with a CM-5 Konica Minolta colorimeter spectrophotometer (Chiyoda, Japan). The test conditions included a D65 illuminant, a 10° viewing angle, and RSIN (Reflectance Specular Included) calibration mode. Readings were taken in triplicate using a Petri dish containing 20 g of a homogenized sample. Color measurements were expressed in terms of luminosity (L^*) and chromaticity parameters (a^* and b^*). Color analysis was conducted on both grain samples and water-soluble extracts. The color difference between germinated and control samples (non-germinated) (ΔE) was determined using Equation 2, while the whiteness index (WI) of the water-soluble extracts was calculated using Equation 3:

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

$$WI = 100 - \sqrt{(100 - L^*)^2 + (a^*)^2 + (b^*)^2} \quad (3)$$

The obtained data were subjected to analysis of variance (ANOVA). When significant differences were observed, Tukey's test at a 5% significance level was applied to compare means.

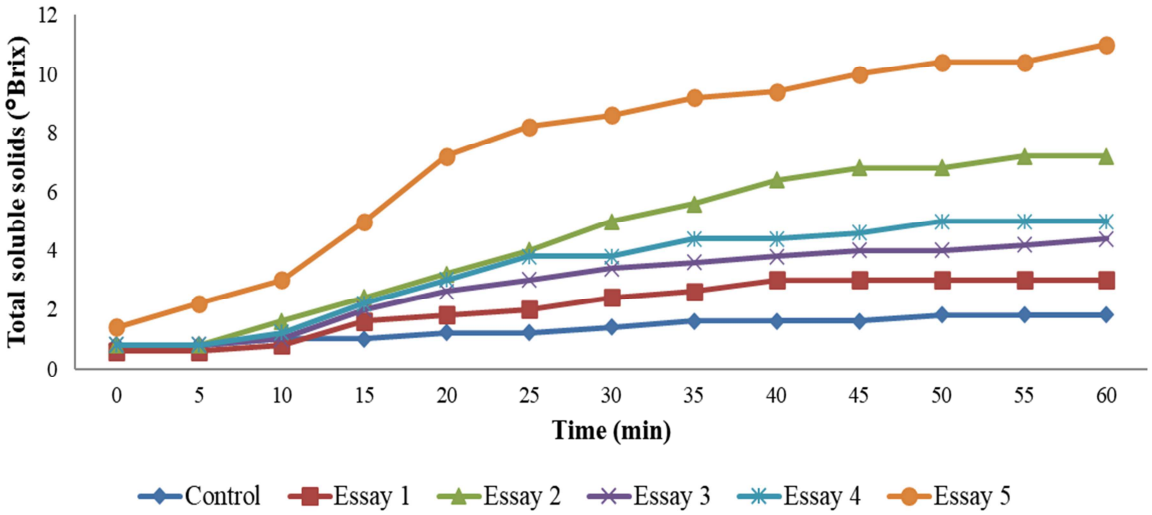
3 Results and discussions

The different germination conditions influenced the physical and physicochemical properties of the corn seeds, as detailed in the following discussion.

3.1 Soluble solids and total solids

The soluble solids and total solids content in the samples ranged from 1.2 ± 0.09 to 6.9 ± 0.05°Brix and from 8.65 ± 0.33 to 11.40 ± 1.92 g/100 g, respectively (Figure 1). During the mashing process, the elevated temperature enhanced enzymatic activity resulting from germination. Consequently, the concentration of soluble solids in the water-soluble extract gradually increased over time, as illustrated in Figure 1.

Figure 1 – Soluble solids content (°Brix) over time during the mashing process for germinated yellow corn and the control sample (without germination)



Source: research data

Germination activates respiration, protein synthesis (enzymes), and the production of secondary metabolites (Milala; Addy, 2014). It also initiates mitotic processes and the activation of phytohormones in embryo cells. During maceration, gibberellins are transported to the aleurone layer, triggering the synthesis of hydrolases, including amylases responsible for degrading starchy polysaccharides (Klang *et al*., 2020). Amylolytic enzymes hydrolyse endosperm starch by cleaving α-1,4 glycosidic bonds of D-glucopyranose, releasing maltose, maltotriose, maltotetrose, and dextrins. These enzymes, also known as liquefaction enzymes, reduce the viscosity of the medium by decreasing the molar mass of starch macromolecules (Wong, 2018). Additionally, proteolytic enzymes break down proteins, releasing free amino acids (Srinivasan; Parking, 2017), which support radicle development (Paucar-Menacho *et al*., 2017).

Figure 1 suggests a close relationship between the quantity of amylolytic enzymes produced during germination and the subsequent increase in soluble solids during mashing, with both time and germination temperature playing key roles. This is particularly evident in trials with the same duration of germination (Trials 1 and 2, as well as 4 and 5), where higher temperatures (32°C for Trials 2 and 5) resulted in more pronounced curves of soluble solids. However, the influence of germination time should also be considered, as Trial 3 (60 hours at 25°C) exhibited a lower increase in soluble solids during mashing compared to Trial 4 (72 hours at 18°C).

Similar to the findings of this study, previous research has demonstrated that germination time is the primary factor influencing the enzymatic hydrolysis of macromolecules, leading to an increased concentration of soluble solids in grains of Creole corn (Nascimento et al., 2024), sunflower (Andressa et al., 2024a), and corn (Chang; Chen; Jiao, 2025). According to Gunathunga et al. (2024), this phenomenon occurs because, as with carbohydrates, β-amylases are activated during the initial stages of germination, facilitating starch hydrolysis. Only in the later stages does maltose hydrolysis occur with the activation of α-amylase, reducing the molecular size.

3.2 Total reducing sugars in carbohydrates

The concentration of total reducing sugars in carbohydrates ranged from 0.10 ± 0.01% to 3.69 ± 0.19% (expressed as glucose), as shown in Table 2. A significant increase in reduced sugar content was observed in the experimental samples compared to the control, correlating with prolonged germination and higher temperatures. This increase is attributed to the activity of endogenous α-amylase during germination, which hydrolyzes starch macromolecules (Klang *et al*., 2019).

Table 2 – Physicochemical properties: total reducing sugars in carbohydrates, pH, total titratable acidity, and sedimentation of water-soluble extracts of germinated yellow corn and control sample (without germination)

Assay	Total reducing groups of carbohydrates (%, in glucose)	pH	Total titratable acidity (% in ferulic acid)	Sedimentation (%)
Control	0.10 ± 0.01 ^{e}	5.95 ± 0.01 ^{b}	0.18 ± 0.01 ^{d}	5.00 ± 0.01 ^{a}
Assay 1	0.26 ± 0.01 ^{de}	6.08 ± 0.02 ^{a}	0.16 ± 0.01 ^{d}	2.33 ± 0.24 ^{b}
Assay 2	2.06 ± 0.10 ^{b}	5.76 ± 0.02 ^{c}	0.25 ± 0.01 ^{b}	1.25 ± 0.01 ^{c}
Assay 3	1.30 ± 0.03 ^{c}	5.70 ± 0.01 ^{c}	0.27 ± 0.01 ^{b}	1.67 ± 0.59 ^{bc}
Assay 4	0.44 ± 0.02 ^{d}	5.99 ± 0.01 ^{b}	0.19 ± 0.01 ^{c}	0.25 ± 0.01 ^{d}
Assay 5	3.69 ± 0.19 ^{a}	5.43 ± 0.03 ^{d}	0.41 ± 0.01 ^{a}	1.17 ± 0.12 ^{c}

Note: Means followed by the same letter in the column do not differ statistically at a 5% probability level, according to Tukey's test
Source: research data

As indicated in Table 2, both germination time and temperature influenced the increase in total reducing sugars in the water-soluble extracts ($p > 0.05$). This effect was more pronounced in trials conducted at higher germination temperatures (Trials 2 and 5, 32°C). According to Nascimento *et al.* (2024), this temperature range promotes the synthesis and activity of amylolytic enzymes, leading to greater starch hydrolysis and, consequently, higher concentrations of reducing sugars.

The hydrolysis of starch can have a positive effect on both the sensory and technological attributes of the final product. The presence of low-molecular-weight compounds derived from starch polysaccharides enhances the product's sweetness, potentially reducing the need for added sucrose (a simple carbohydrate) in plant-based beverages (Stephano *et al.*, 2018). Furthermore, this characteristic renders the product more suitable for developing fermented beverages that utilise beneficial microorganisms.

This outcome is promising, considering that a high glycemic index is one of the primary factors limiting the consumption of such products (Andressa *et al.*, 2024). Furthermore, germination serves as an enzymatic method for starch modification, reducing granule thickening capacity and minimizing excessive viscosity caused by heat treatment without requiring dilution. The intrinsic hydrolysis occurring during germination can also enhance starch digestibility in the final beverage (Gunathunga et al., 2024).

3.3 pH and total titratable acidity

The pH of the water-soluble extracts ranged from 5.95 ± 0.01 to 6.08 ± 0.02, while the total titratable acidity varied from 0.16 ± 0.01% to 0.41 ± 0.01% (expressed as ferulic acid), as shown in Table 2. The data indicate that the lowest pH and highest titratable acidity were observed in the trial with the longest germination time and highest temperature (72 hours at 32°C), specifically in Trial 5 (pH = 5.43 and total titratable acidity = 0.41% as ferulic acid).

Variations in pH and acidity in the samples can be attributed to changes in organic acid composition. These changes may result from the action of endogenous enzymes responsible for hydrolyzing complex components in the pericarp fiber fraction, such as ferulic acid and phytic acid (Chavan *et al.*, 2018; Wong, 2018). Additionally, prolonged germination time and exposure to heat and humidity may have facilitated the development of microorganisms naturally present in the grain or introduced through handling and environmental contact (Bao; Wang; Yu, 2025).

3.4 Sedimentation of solids

The sedimentation of solids in the water-soluble extracts ranged from 0.25 ± 0.01% to 5.00 ± 0.01%, as shown in Table 2. Generally, water-soluble extracts exhibit low colloidal stability due to the large particle size of starch and proteins, which have high molecular weights and consequently tend to sediment. These macromolecules, particularly starch—comprising approximately 70% of the grain—are perceptible to the palate, producing an undesirable “gritty” sensation for consumers. Furthermore, water-soluble extracts derived from starchy raw materials, such as corn, tend to develop excessive viscosity when subjected to heat treatments designed to extend shelf life.

The enzymatic breakdown of starch releases low (maltose, maltotriose, and maltotetrose) and medium (dextrins) molecular weight compounds, which are anticipated to diminish the gritty sensation of the product (Andressa et al., 2024b). During the germination process, the production of hydrolytic enzymes that target the seed's macronutrients, particularly starch, aids in reducing these molecules, promoting their suspension in the medium rather than their sedimentation. Consequently, a decrease in particle sedimentation was noted in the samples compared to the control (Table 2).

3.5 Instrumental color

The luminosity (L^* = white / $-L^*$ = black) of the samples ranged from 72.17 ± 0.16 to 70.03 ± 0.26 for the water-soluble extracts and from 83.18 ± 0.03 to 74.60 ± 0.62 for the flours. According to Table 3, a significant increase ($p > 0.05$) in the L^* value of the germinated corn flours was observed compared to the control. This increase is attributed to enzymatic hydrolysis during germination, which reduced grain resistance to grinding and led to greater exposure of starch granules. Consequently, this resulted in increased light refraction, enhancing the luminosity value of the germinated corn flour.

For the water-soluble extracts, a notable reduction ($p > 0.05$) in luminosity was observed in the control (non-germinated corn), indicating product darkening. This effect was most pronounced in Trial 5, which experienced the longest germination time and highest temperature (72 hours at 32°C). The increase in total reducing carbohydrates aligns with the decrease in the L^* value of the water-soluble extracts, attributed to the Maillard reaction, which was promoted by the rise in temperature throughout the mashing process.

Table 3 – Color analysis of germinated corn flours and their respective water-soluble extracts

Sprouted corn flour					
Assay	***L****	***a****	***b****		**ΔE**
Control	74.60 ± 0.62^{e}	6.70 ±0.47^{a}	36.06 ± 0.85^{a}		-
Assay 1	76.33 ± 0.15^{dc}	6.00 ±0.11^{ab}	32.90 ± 0.24^{b}		3.68 ± 0.21^{c}
Assay 2	81.93 ± 0.33^{b}	4.71 ± 0.16^{c}	28.26 ± 0.01^{c}		10.90 ± 0.24^{b}
Assay 3	75.43 ± 0.12^{ed}	5.23 ± 0.20^{cb}	32.07 ± 0.34^{b}		4.34 ± 0.37^{c}
Assay 4	76.78 ± 0.42^{c}	5.49 ±0.25^{cb}	32.20 ± 0.28^{b}		4.61 ± 0.47^{c}
Assay 5	83.18 ±0.03^{a}	3.13 ± 0.05^{d}	22.85 ± 0.07^{d}		16.15 ± 0.05^{a}
Water-soluble extracts of germinated corn					
Assay	***L****	***a****	***b****	**WI**	**ΔE**
Control	72.17 ± 0.16^{a}	–0.64 ± 0.05^{b}	25.07 ± 0.16^{b}	62.54 ± 0.16^{b}	-
Assay 1	71.82 ± 0.39^{d}	–0.99 ± 0.05^{b}	24.68 ± 0.16^{b}	62.53 ± 0.27^{b}	0.72 ± 0.25^{d}
Assay 2	71.92 ± 0.17^{c}	–0.47 ± 0.05^{b}	20.12 ± 0.04^{d}	65.45 ± 0.12^{a}	5.01 ± 0.05^{b}
Assay 3	70.03 ± 0.26^{e}	0.45 ± 1.07^{b}	23.47 ± 0.31^{c}	61.92 ± 0.02^{c}	3.05 ± 0.62^{c}
Assay 4	72.04 ± 0.44^{b}	0.46 ± 0.24^{b}	28.72 ± 0.39^{a}	59.91 ± 0.06^{c}	3.84 ± 0.44^{c}

Legend: WI: whiteness index; ΔE: instrumental color variation
Note: Means followed by the same letter in the column do not differ statistically at a 5% probability level, according to Tukey's test
Source: research data

The a^* parameter ($+a^*$ = red / $-a^*$ = green) ranged from 6.70 ± 0.47 to 3.13 ± 0.05 for the flours and from 2.53 ± 0.04 to -0.99 ± 0.05 for the water-soluble extracts, as shown in Table 3. Red pigmentation was significantly reduced in the control samples for both flour and water-soluble extracts. The b^* parameter ($+b^*$ = yellow / $-b^*$ = blue) exhibited a similar trend, ranging from 36.06 ± 0.85 to 22.85 ± 0.07 for the flours and from 28.72 ± 0.39 to 18.93 ± 0.07 for the water-soluble extracts. These findings suggest carotenoid degradation in the grains due to oxygen exposure and elevated temperatures during germination, flour drying, and mashing for beverage production.

The water-soluble extracts' whiteness index (WI) ranged from 54.56 ± 0.08 to 65.45 ± 0.12. According to Jeske *et al.* (2017), the average whiteness index of milk is 81.89, a critical factor for the sensory acceptance of dairy alternative products. A deviation in color from that of milk may reduce consumer acceptance due to sensory memory associations with traditional dairy products. One possible strategy to mitigate this effect is the development of packaging that highlights the product's

potential health benefits and the absence of components that may trigger adverse immunological reactions, such as lactose and bovine milk proteins.

Mokrzycki and Tatol (2012) indicate that when the ΔE value reaches or exceeds 5, the colour difference becomes perceptible to the human eye for both trained and untrained observers. Therefore, the colour differences between Assays 2 and 5 and the control sample are visually noticeable for beverages and flours.

In summary, the germination of yellow corn emerges as a promising technology for large-scale applications. In addition to enhancing the colloidal stability of beverages, it offers potential nutritional and technological benefits. These advantages include improved nutritional value, possible enhancements in amino acid profiles, increased digestibility, and optimization of industrial processes. A deeper exploration of these properties may open new opportunities for the plant-based beverage industry, particularly regarding the utilization of alternative raw materials and the pursuit of more sustainable solutions. However, further investigation is required to assess its actual impact on the sector.

5 Conclusions

Water-soluble corn extracts offer a promising alternative for individuals who are lactose intolerant or have adverse reactions to milk proteins, enabling the partial or complete replacement of dairy beverages. Corn, a cereal rich in nutritional value, undergoes significant physicochemical improvements through the germination process. Specifically, germination temperature is essential, as higher temperatures lead to increased °Brix values and greater levels of total reducing carbohydrates. These findings are particularly significant as they indicate that the resulting beverage may naturally possess a sweet taste, requiring little to no added sugars, and could serve as an ideal substrate for fermentation by probiotic microorganisms.

Moreover, germination has been shown to significantly enhance the colloidal stability of these beverages, reducing solid sedimentation by up to 20 times compared to the control ($p<0.05$). This implies that germination may reduce or eliminate the need for hydrocolloid additives, aligning with the growing consumer preference for 'clean' labels. In addition to minimizing sedimentation, the amylolytic enzymes naturally activated during germination may improve starch digestibility while preventing excessive viscosity, a common issue associated with heat treatments used to extend product shelf life.

Thus, the use of germinated corn grains represents a viable and cost-effective strategy for developing non-dairy beverages, offering substantial benefits for the final product's sensory and functional quality.

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Declaration of competing interest

The authors declare that they have no conflicts of interest regarding the work presented in this manuscript.

Contributions to the article

ANDRESSA, A.; BENASSI, V. M.; SCHMIELE, M.: research design; data analysis and interpretation; final revision with critical and intellectual contributions to the manuscript. **NASCIMENTO, G. K. S.; TEOTÔNIO, D. O.:** research design; data analysis and interpretation. **NEVES, N. A.:** data analysis and interpretation; final revision with critical and intellectual contributions to the manuscript. All authors participated in the writing, discussion, reading, and approval of the final version of the article.

References

AACCI – The American Association of Cereal Chemists International. Approved Methods of AACCI, 11th ed. St. Paul: AACCI, 2010.

ANDRESSA, I.; PAIVA, M. J. A.; PACHECO, F. C.; SANTOS, F. R.; CUNHA, J. S.; PACHECO, A. F. C.; NEVES, N. A.; VENDRUSCOLO, R. G.; SCHMIELE, M.; TRIBST, A. A. L.; VIEIRA, É. N. R.; LEITE JÚNIOR, B. R. C. Germination as a strategy to improve the characteristics of flour and water-soluble extracts obtained from sunflower seed. **Food Bioscience**, v. 61, 104763, 2024a. DOI: https://doi.org/10.1016/j.fbio.2024.104763.

ANDRESSA, I.; NASCIMENTO, G. K. S.; SANTOS, T. M.; RODRIGUES, R. S., TEOTÔNIO, D. O.; PAUCAR-MENACHO, L. M.; BENASSI, V. M.; SCHMIELE, M. Technological and health properties and main challenges in the production of vegetable beverages and dairy analogs. **Food & Function**, v. 15, n. 2, p. 4660-480, 2024b. DOI: https://doi.org/10.1039/D3FO04199A

AOAC – Association of Official Analytical Chemists. Official methods of analysis of the Association of Official Analysis Chemists, 21 ed. Washington: AOAC, 2019.

BAO, J.; WANG, L.; YU, Z. Effect of lactic acid bacteria and propionic acid on fermentation characteristics, chemical composition, and aerobic stability of high-moisture corn grain silage. **Microorganisms**, v. 13, n. 1, 33, 2025. DOI: https://doi.org/10.3390/microorganisms13010033.

BUENO, D. B.; SILVA JÚNIOR, S. I.; CHIAROTTO, A. B. S.; CARDOSO, T. M.; ALVES NETO, J.; REIS, G. C. L.; GLÓRIA, M. B. A. TAVANO, O. L. The germination of soybeans increases the water-soluble components and could generate innovations in soy-based foods. **LWT - Food Science and Technology,** v. 117, 108599, 2020. DOI: https://doi.org/10.1016/j.lwt.2019.108599.

CHALORCHAROENYING, W.; LOMTHAISONG, K.; SURIHARN, B.; LERTRAT, K. Germination process increases phytochemicals in corn. **International Food Research Journal**, v. 24, n. 2, p. 552-558, 2017. Available at: http://www.ifrj.upm.edu.my/24%20(02)%202017/(12).pdf. Accessed on: 12 Feb. 2025.

CHANG, Y.; CHEN, H.; JIAO, Y. Improvement in textural, structural and digestive characteristics of maize gruel using malt amylase obtained by germination and ultrasonic extraction. **LWT- Food Science and Technology**, v. 220, 117576, 2025. DOI: https://doi.org/10.1016/j.lwt.2025.117576.

CHAVAN, M.; GAT, Y.; HARMALKAR, M.; WAGHMARE, R. Development of non-dairy fermented probiotic drink based on germinated and ungerminated cereals and legume. **LWT - Food Science and Technology**, v. 91, p. 339-344, 2018. DOI: https://doi.org/10.1016/j.lwt.2018.01.070.

GUNATHUNGA, C.; SENANAYAKE, S.; JAYASINGHE, M. A.; BRENNAN, C. S.; TRUONG, T.; MARAPANA, U.; CHANDRAPALA, J. Germination effects on nutritional quality: a comprehensive review of selected cereals and pulses changes. **Journal of Food Composition and Analysis**, v. 128, 106024, 2024. DOI: https://doi.org/10.1016/j.jfca.2024.106024.

JESKE, S., ZANNINI, E., ARENDT, E. K. Evaluation of physicochemical and glycaemic properties of commercial plant-based milk substitutes. **Plant Foods for Human Nutrition**, v. 72, p. 26-33, 2017. DOI: https://doi.org/10.1007/s11130-016-0583-0.

KATHURIA, D.; HAMID; CHAVAN, P.; JAISWAL, A. K.; THAKUR, A.; DHIMAN, A. K. A Comprehensive review on sprouted seeds bioactives, the impact of novel processing techniques and

health benefits. **Food Reviews International**, v. 40, n. 1, p. 370-398, 2024. DOI https://doi.org/10.1080/87559129.2023.2169453.

KLANG, J. M.; TENE, S. T.; FOMBASSO, A. D.; TSOPONG, A. B. T.; WOMENI, H. M. Application of germinated corn flour on the reduction of flow velocities of the gruels made from corn, soybean, *Moringa oleifera* leaf powder and cassava. **Journal of Food Processing & Technology**, v. 10, n. 7, 1000800, 2019. Available at: https://www.walshmedicalmedia.com/open-access/application-of-germinated-corn-flour-on-the-reduction-of-flow-velocities-of-the-gruels-made-from-corn-soybean-emmoringa-oleiferaem-44002.html. Accessed on: 12 Feb. 2025.

KLANG, J. M.; WOUATIDEM-NANFACK, S.-L.; TENE, S. T.; BOUNGO, G. T.; WOMENI, H. M. Optimisation of the production of corn amylase flour from corn Atp and Kassaï varieties for the fluidification and energy density increase of cassava gruel. **Heliyon**, v. 6, n. 10, e05344, 2020. DOI: https://doi.org/10.1016/j.heliyon.2020.e05344.

LEITE, T. S.; JESUS, A. L. T.; SCHMIELE, M.; TRIBST, A. A. L.; CRISTIANINI, M. High pressure processing (HPP) of pea starch: effect on the gelatinization properties. **LWT - Food Science and Technology**, v. 76, Part B, p. 361-369, 2017. DOI: https://doi.org/10.1016/j.lwt.2016.07.036.

LUO, H.; HE, W. LI, D.; BAO, Y.; RIAZ, A.; XIAO, Y.; SONG, J.; LIU, C. Effect of methyl jasmonate on carotenoids biosynthesis in germinated maize kernels. **Food Chemistry**, v. 307, 125525, 2020. DOI: https://doi.org/10.1016/j.foodchem.2019.125525.

MÄKINEN, O. E.; WANHALINNA, V.; ZANNINI, E.; ARENDT, E. K. Foods for special dietary needs: non-dairy plant-based milk substitutes and fermented dairy-type products. **Critical Reviews in Food Science and Nutrition**, v. 56, n. 3, p. 339-349, 2015. DOI: https://doi.org/10.1080/10408398.2012.761950.

MILALA, M. A.; ADDY, E. O. Hydrolytic enzyme levels in malted cereals. **Advances in Biochemistry**, v. 2, n. 5, p. 76-79, 2014. DOI: https://doi.org/10.11648/j.ab.20140205.14.

MOKRZYCKI, W.; TATOL, M. Color difference Delta E: a survey. **Machine Graphics and Vision**, v. 20, n. 4, p. 383-411, 2011.

NASCIMENTO, G. K. S.; SILVA, M. S.; ANDRESSA, I.; FAGUNDES, M. B.; VENDRUSCOLO, R. G.; OLIVEIRA, J. R.; BARCIA, M. T.; BENASSI, V. M.; NEVES, N. A.; LIMA, C. T.; SCHMIELE, M. A new advancement in germination biotechnology of purple creole corn: bioactive compounds and in situ enzyme activity for water-soluble extract and pan bread. **Metabolites**, v. 14, n. 1, 35, 2024. DOI: https://doi.org/10.3390/metabo14010035.

PACHECO, F. C.; CUNHA, J. S.; ANDRESSA, I.; SANTOS, F. R.; PACHECO, A. F. C.; NALON, G. A.; PAIVA, P. H. C.; TRIBST, A. A. L.; AUGUSTO, P. E. D.; LEITE JÚNIOR, B. R. C. Ultrasound-assisted intermittent hydration of pumpkin seeds: improving the water uptake, germination, and quality of a clean label ingredient. **Food Bioprocess Technology**, v. 18, p. 618-632, 2025.DOI: https://doi.org/10.1007/s11947-024-03487-w.

PAIVA, M. J. A.; COSTA, N. A.; PEREIRA, G. C.; GONÇALVES, D. J. R.; OLIVEIRA, V. C.; LOURENÇO, M. T.; COSTA, A. A. S. X.; LEITE JÚNIOR, B. R. C.; MACHADO, S. G.; OLIVEIRA, E. B.; SALDAÑA, M. D. A.; VIEIRA, É. N. R. Probiotic plant-based beverage with coconut, mango, and yam as a carrier of *Lactiplantibacillus plantarum*, *Lacticaseibacillus rhamnosus* GG, and *Lactobacillus acidophilus*: impact on viability and quality. **Journal of Food Science and Technology**, v. 61, n. 4, p. 897-910, 2024. DOI: https://doi.org/10.1007/s13197-024-06129-3.

PAUCAR-MENACHO, L. M.; MARTÍNEZ-VILLALUENGA. C.; DUEÑAS, M.; FRIAS, J.; PEÑAS, E. Optimization of germination time and temperature to maximize the content of bioactive compounds and the antioxidant activity of purple corn (*Zea mays* L.) by response surface methodology. **LWT - Food Science and Technology**, v. 76, Part B, p. 236-244, 2017. DOI: https://doi.org/10.1016/j.lwt.2016.07.064.

SETHI, S.; TYAGI, S. K.; ANURAG, R. K. Plant-based milk alternatives an emerging segment of functional beverages: a review. **Journal of Food Science and Technology**, v. 53, n. 9, p. 3408-3423, 2016. DOI: https://doi.org/10.1007/s13197-016-2328-3.

SHARMA, E.; YEASMEN, N.; DUBÉ, L.; ORSAT, V. A review on current scenario and key challenges of plant-based functional beverages. **Food Bioscience**, v. 60, 104320, 2024. https://doi.org/10.1016/j.fbio.2024.104320.

SHENG, S.; LI, T.; LIU, R. H. Corn phytochemicals and their health benefits. **Food Science and Human Wellness**, v. 7, n. 3, p. 185-195, 2018. DOI: https://doi.org/10.1016/j.fshw.2018.09.003.

SRINIVASAN, D.; PARKING, K. L. **Fennema's food chemistry**. CRC Press, Boca Raton, 2017.

STEPHANO, T. T.; MATHILDE, K. J.; CYRILLE, N. H. S.; GIRES, T. B.; ARANTES, K. F. H.; MACAIRE, W. H. Characterisation of amylase crude extracts of germinated corn (Kassaï and Atp varieties) and sweet potato flours (Local and 1112 varieties). **International Journal of Advanced Research in Biological Sciences**, v. 5, n. 5, p. 230-240, 2018. DOI: https://doi.org/10.1016/j.foodchem.2019.125525.

TARIQ, Z.; QADEER, M. I.; ANJUM, I.; ANJUM, S.; HASAN, M. Nondiagnostic advancements in revolutionizing lactose intolerance: a minireview for health sciences. **Hybrid Advances**, v. 6, 100264, 2024. DOI: https://doi.org/10.1016/j.hybadv.2024.100264.

WONG, D. W. S. **Mechanism and theory in food chemistry**. 2. ed. Springer, 2018. DOI https://doi.org/10.1007/978-3-319-50766-8.