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Functional and pasting properties of colorful bean (*Phaseolus vulgaris* L) flours: Influence of the cooking method

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Abstract

This research aimed to verify how the preparation method affects the functional and technological properties of colorful bean flours to expand their potential for application in various food products. The flour of the cultivar BRS Embaixador (dark red kidney bean) presented the highest total starch content (40.5 g·100 g^{-1}), and the lowest content of resistant starch (3.2 g·100 g^{-1}) and protein (20.9 g·100 g^{-1}), while Jalo Precoce (yellow bean) showed the highest amount of resistant starch (24.3 g·100 g^{-1}) and protein (25.8 g·100 g^{-1}). The cooked flours compared with the raw ones presented a reduction in water solubility index, peak viscosity, final viscosity, breakdown, seatback, hardness, adhesiveness, resilience, and emulsification capacity. These results were more evident in flours from presoaked and cooked beans once they had presented a significantly higher intensity of the starch pre-gelatinization. Finally, both preparation processes (presoaked cooked beans or unsoaked cooked beans) improved the technological characteristics of colorful bean flours.

Practical applications

We have obtained the cooked colorful bean flours by applying an unusual method previously tested. The bean grains (previously soaked or not) were cooked only by the effect of the pressured steam environment of the autoclave without immersion in water during cooking. Our interest is to expand the use of colorful bean flour by improving its acceptability in various food systems. We show that the flour of presoaked cooked grains presented a higher amount of resistant starch and lower viscosities values, which may be suitable for a food system that desires no viscosity changes (e.g., soups).

1 | INTRODUCTION

Dry beans (*Phaseolus vulgaris* L) from the Fabaceae family, have been recognized as healthy foods mainly due to their high contents of protein, dietary fiber, slowly digestible and resistant starch, saponins, and polyphenols (Bassinello et al., 2020; Bento, Bassinello, et al., 2020; Bento, Ribeiro, Bassinello, et al., 2021; Ramírez-Jiménez et al., 2018). Various types of commercial beans are cultivated around the world (navy, yellow, black, purple, brindle, pink, and red, amongst others). However, the most cultivated beans in Brazil are the carioca type (cream color) followed by black beans (Bento, Lanna, et al., 2020). However, colorful beans (red, yellow, and black) present the highest antioxidant activity and are healthier than carioca beans (Ganesan & Xu, 2017; Yang et al., 2018). The color of the seed coat is based on the incidence of polyphenols including anthocyanins, flavonols glucosides, and condensed tannins. The coat color of colorful

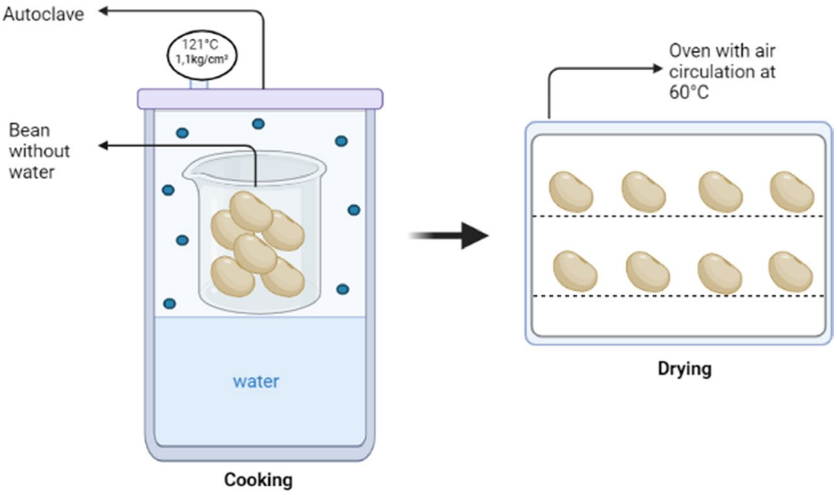

FIGURE 1 Preparation method: the washed grains (soaked or not) were cooked in a beaker without water; after cooking, the beans were dried in an oven with air circulation. Created with BioRender.com

genotypes (red, black, and pink-colored) is due to their anthocyanins; the colors of light yellow or pink spot of the seed coat are generally based on the presence of condensed tannins (Ganesan & Xu, 2017).

Among the forms in which beans are now being sold, flours based on whole, uncooked, and cooked beans are becoming more widely available. The flours constitute a new way of using materials with low added value, as aged beans, which can contribute to the sustainability of the food industries and still be aligned with new trends and consumption habits, based on sensory quality, practicality, diversity, and healthiness (FoodTrends, 2019). Bean flours can be used in the development of gluten-free products, which in turn is one of the most prosperous markets in the field of the food industry (Bascunan et al., 2017). Therefore, bean flours can be used as a base ingredient in various foods, such as spaghetti and ravioli (Gallegos-Infante et al., 2010; Ringuette et al., 2018), penne, baked snacks, and extruded snacks (Bassinello et al., 2015), snack bars (Ramírez-Jiménez et al., 2018), cookies (Pérez-Ramírez et al., 2018), and cakes (Bassinello et al., 2020; Gomes et al., 2015). Thus, colorful bean flour may be a way to introduce this healthier pulse in new products.

However, some sensory and functional attributes of beans and other pulses' flours, including texture, solubility, appearance, and unpleasant beany flavors (mainly due to the presence of some saponins) (Bento, Ribeiro, Alexandre e Silva, et al., 2021), affect their acceptability and the extent of inclusion in a given recipe (Felker et al., 2018). The thermal processes considerably decrease naturally existing antinutritional factors, increasing the availability of other nutrients, such as protein and starch, and modifying the technological properties of the legume flour (de Almeida Costa et al., 2006). Enhancing the effect of processing methods on textural properties, pasting characteristics, digestibility, and availability of nutrients of legumes has the following order: autoclaving > cooking > germination > soaking (Jeong et al., 2019; Kaur et al., 2015).

In our previous work (Bento, Ribeiro, Alexandre e Silva, et al., 2021), we had proposed an unusual method for obtaining bean flours from colorful beans, by cooking the bean grains (previously soaked or not) under the pressured steam of the autoclave environment without immersing them in water during the thermal process, which is different from the traditional autoclaving process where grains are immersed in water. This modified method was able to change the chemical profile (phenolics, saponins) of the colorful beans flours and retain some of their bioactive compounds (Bento, Ribeiro, Alexandre e Silva, et al., 2021). The resulting cooked bean flours might possibly present significant and interesting modifications on their physical, and technological properties too, making them more suitable for food formulation. Moreover, studies that aim to verify the technological and functional properties of colorful bean flours are scarce in the scientific literature. Thus, this research aimed to verify how the preparation method affects the functional and technological properties of colorful bean flours, and if they can improve their acceptability to expand their use in several food systems. Therefore, the main physicochemical, functional, thermal, and pasting properties of native flours (made with raw grains) were compared with those made with steamed bean grains with and without previous soaking step.

2 | MATERIALS AND METHODS

2.1 | Sampling and flour preparation

The samples as well as the flour preparation are described in our previous work (Bento, Ribeiro, Alexandre e Silva, et al., 2021). Briefly, the samples used was bean grains from the special color group: BRS Ártico (WAF 75) (Artico, white bean), BRSMG Realce (Realce, brindle bean), BRS Embaixador (Embaixador, red bean), and Jalo Precoce (yellow bean). After harvest they were stored in low-density polyethylene bags, in portions of 1 kg for 3 months, in a cool place (26.5 ± 1.95°C) with ambient lighting.

In order to prepare the samples of cooked bean flours, we have followed our accessible methods proposed before (Bento, Ribeiro, Alexandre e Silva, et al., 2021), which reduced the off-flavor and preserved some bioactive compounds in the final flour (Figure 1). Three repetitions of each bean cultivar flour were obtained and named as: Raw [native flour from milled raw grains used as comparison reference], C5′ (raw grains were soaked in distilled water [6h] and drained grains were cooked without extra water under the effect of the autoclave steam [121°C·for 5 min at 1.1 kg·cm^2] [Prismatec, CS, Brazil]) and C20′ (made with unsoaked raw grains cooked without extra water under the effect of the autoclave steam [121°C for·20 min at 1.1 kg·cm^2]). The cooked grains were dried in an oven (Nova Ética, 400/5, Brazil) with air circulation at 60°C for 12 hr. Then they were ground in a hammer mill with a 0.5 mm opening sieve. The flours obtained (Raw, C5′ and C20′) showed similar moisture content (~7.5 g·100 g^{-1}) and a particle size between 106 and 425 μm. They were stored at −20°C until analysis.

2.2 | Protein content and total dietary fiber (TDF)

The nitrogen content was quantified by the micro-Kjeldahl method and then multiplied by a factor of 6.25 recommended for bean samples to obtain the crude protein content (AOAC, 2012). The **total dietary fiber** (TDF) was determined using a K-TDFR Kit (Megazyme International Ireland, Bray, Ireland), according to standardized enzymatic-gravimetric method 985.29 (AOAC, 1997).

2.3 | Total starch and resistant starch (RS)

The total starch and RS content of bean flour were determined using an RS assay kit K-RSTAR (Megazyme International Ireland, Bray, Ireland), with some modifications. Briefly, pancreatic α-amylase and amyloglucosidase were added directly to 100 mg of bean flour in 50 ml test tubes, and tubes were incubated at 37°C for 16 hr with shaking (100 rpm). After the addition of ethanol and centrifugation, the supernatant (nonresistant starch—NRS) was removed and the precipitate was homogenized using a magnetic stirrer. To solubilize RS, 2 M KOH was added to the homogenized precipitate on the ice bath. Sodium acetate buffer (1.2 M, pH 3.8) was added and incubated with amyloglucosidase to convert the solubilized RS to glucose. The glucose content of NRS and RS fraction was determined by the glucose oxidase/peroxidase reagent (GOPOD) method. Total starch was the sum of RS and NRS.

2.4 | Water solubility index and the water and oil absorption index

The water solubility index (WSI) and the water absorption index (WAI) were determined according to the method described by Anderson et al. (1969). To determine the oil absorption index (OAI), the same methodology with adaptations was also used, since the water was replaced by soybean oil.

2.5 | Pasting properties

The paste temperature (°C), peak viscosity, final viscosity, breakdown, and setback (Cp) were obtained in a Rapid Viscoanalyser (Perten Instruments, RVA 4,500, Macquarie Park, Australia), using the flour method (RVA Method 5, Version 4, March 2010). In 3.5 g of sample (moisture 14 g·100 g^{-1}), 25.0 ml of distilled water was added, then the sample was kept at 25°C for 2 min, heated (14°C min^{-1}) at 95°C and kept at this temperature for 3 min, and cooled (14°C min^{-1}) at 25°C.

2.6 | Gel texture profile

After being subjected to the RVA test, the sample (gel) was kept in the RVA canister and refrigerated (7°C) overnight. The textural properties of RVA gels were evaluated by carrying out texture profile analysis (TPA) measured by a texturometer (TA HD Plus Stable Micro Systems, Surrey, England), with a 20 mm cylindrical probe using a TPA (Texture Profile Analyses) mode. Test condition: test speed of 0.5 mm·s^{-1}, pre-test speed of 1.0 mm·s^{-1}, post-test speed of 10.0 mm·s^{-1}, with force contact depth of 10 gf, and with probe penetration distance/depth of 6 mm, at a temperature of 25°C (Wani et al., 2010). The hardness, adhesiveness, springiness, cohesiveness, and resilience were determined from the texture profile curve using the Exponent Connect software. The maximum force of the first compression was hardness and the area of work during the second compression divided by the area of work during the first compression was cohesiveness. Springiness was measured by the distance of the detected height during the second compression divided by the original compression distance; adhesiveness was measured as the negative work between the two cycles, and resilience was calculated by dividing the upstroke energy of the first compression by the downstroke energy of the first compression.

2.7 | Thermal properties

The thermal properties were determined using a differential scanning calorimeter (TA Instruments, Q20, New Castle, UK). The sample of 2 mg (dry base) was weighed in aluminum containers, suitable for the equipment. Distilled water (6 μl) was added, and the sample holders were sealed in a specific press. These were kept for 12 hr at room temperature and heated in the range between 35 and 120°C, at a heating rate of 10°C min^{-1}. From the obtained curve, the temperature of peak gelatinization and glass transition was calculated using the TA Universal Analysis application (TA Instruments, New Castle, UK).

2.8 | Emulsifying capacity and stability

The emulsifying properties were determined according to Kaur and Singh (2005). The emulsifying activity was calculated by dividing the volume of the emulsified layer by the total volume before centrifugation. The stability of the emulsion was determined, following the same procedure to determine the emulsifying activity. However, before centrifuging the samples, they were subjected to heat treatment at 85°C for 15 min and centrifuged after cooling. Emulsion stability was expressed as the percentage of the remaining emulsifying activity after heating.

2.9 | Statistical analyses

All results were obtained in triplicate and presented as means ± standard deviation, evaluated by analysis of variance, using the Statistic 10.0® software (StatSoft®, Tulsa, USA). Levene test was applied to verify the variance homogeneity, and the differences among the means were certified by the Tukey test ($p < .05$). The similarity among the samples was analyzed by principal component analysis (PCA). To conduct the PCA it was used the standardized or normalized PCA, based on Pearson's correlation matrix provided by XLSTAT software (Addinsoft, 2021). Five components were analyzed, and the PCA biplot was made based on the Euclidean distance in the p-dimensional variable space (distance biplot).

3 | RESULTS AND DISCUSSION

3.1 | Protein, total starch, resistant starch, and total dietary fiber

Beans are an important source of proteins and complex carbohydrates, such as dietary fiber and starch (Kan et al., 2017; Liu et al., 2020; Yadav et al., 2018). The cultivar Jalo Precoce (24.34 g·100 g^{-1}) presented the highest content of protein and the cultivar Embaixador had the lowest value (20.90 g·100 g^{-1}) (Table 1). The results are similar to those reported for navy bean (23.0 g·100g^{-1}), red kidney bean (21.8 g·100 g^{-1}), garbanzo bean (20.3 g·100 g^{-1}), and adzuki bean accessions (18.82–24.52 g·100 g^{-1}; Romero & Zhang, 2019; Yadav et al., 2018).

The cultivar Embaixador presented the highest content of total starch (40.46 g·100 g^{-1}) and the cultivar Artico presented the lowest amount (33.93 g·100 g^{-1}), of which about 69% is resistant starch (Table 1). The results are following other studies since starch content ranged from 33.6 to 39.1 g·100g^{-1} for common beans, and from 38.4% to 41.8 g·100 g^{-1} for faba beans (Abdel-Aal et al. 2018; Liu et al., 2020; Romero & Zhang, 2019). Finally, starch content has been found to vary among pulse types, genotypes, and growing environments (Abdel-Aal et al., 2018), which may explain some variations observed in our results.

The total starch content decreased ($p < .05$) for the cultivar Artico flour submitted to preparation method C5′, but increased when the flour was obtained from grains cooked without the soaking step (C20′) (Table 1). The cooking conditions cause the discrepancy of results in starch content, and a possible reason could be that modification of starch and reduction of antinutrients during treatment provided greater accessibility of α-amylase enzymes to the starch digestion assay (Liu et al., 2020; Simons & Hall Iii, 2018). On the other hand, the cooking methods did not significantly affect ($p > .05$) the total starch contents for the other cultivars (e.g., Jalo Precoce) when compared with the flours of the raw material.

Common bean is a significant source of resistant starch (RS) (Kan et al., 2017; Kim et al., 2018). RS extensively varied among bean varieties and processing methods as shown in Table 1. Both the type of bean (cultivar) and the preparation methods used to produce the bean flours significantly influenced ($p < .05$) the RS content (Supplementary Table S1). The cultivar Embaixador (raw flours) presented the lowest RS content (3.21 g·100 g^{-1}), which may be related to their chain-length distribution and crystallinity of starch, as well with their enzymatic content since the natural RS present in plant material is due to the enzymatic de-branching of the amylose and amylopectin branch (Hung et al., 2016). On the other hand, the

TABLE 1 Protein content of flour from raw beans, and total starch, resistant starch, and total dietary fiber of raw and cooked beans (preparation methods) of different cultivars (g·100 g^{-1} dry weight)

Constituents	Method	Realce	Artico	Jalo Precoce	Embaixador
Protein	Raw	21.49 ± 0.49^{c}	23.48 ± 0.15^{b}	24.34 ± 0.20^{a}	20.90 ± 0.01^{d}
Total starch	Raw	35.58 ± 0.55^{bAB}	33.93 ± 0.53^{cB}	35.66 ± 0.16^{bA}	40.46 ± 0.22^{aAB}
	C 5′	35.02 ± 0.45^{bB}	32.32 ± 0.43^{cC}	35.63 ± 0.26^{bA}	39.79 ± 0.29^{aB}
	C 20′	36.13 ± 0.65^{bA}	36.32 ± 0.75^{bA}	35.69 ± 0.53^{bA}	41.13 ± 0.52^{aA}
RS	Raw	24.33 ± 0.49^{bB}	23.34 ± 0.47^{bC}	25.86 ± 0.52^{aB}	3.21 ± 0.06^{cC}
	C 5′	29.66 ± 0.59^{aA}	29.08 ± 0.58^{aB}	29.47 ± 0.60^{aA}	5.04 ± 0.10^{bB}
	C 20′	30.46 ± 0.61^{bA}	32.80 ± 0.66^{aA}	28.90 ± 0.58^{cA}	5.41 ± 0.11^{dA}
TDF	Raw	18.82 ± 0.42^{abB}	20.98 ± 1.71^{aA}	18.21 ± 0.17^{bB}	18.78 ± 0.51^{abA}
	C 5′	19.89 ± 0.19^{aA}	20.13 ± 0.45^{aA}	19.99 ± 0.85^{aA}	19.78 ± 0.04^{aA}
	C 20′	18.72 ± 0.51^{abB}	20.00 ± 0.95^{aA}	18.09 ± 0.20^{bB}	19.81 ± 1.01^{aA}

Note: Mean of three replicates ± standard deviation. Preparation method: raw, C5′ (presoaked beans cooked for 5 min), and C20′ (beans cooked for 20 min without previous soaking). Different lower-case letters in the same row and uppercase letters in the columns show statistical differences between cultivars and preparation methods ($p < .05$), respectively.

cultivar Jalo Precoce (raw flour) has the highest one (25.86 g·100 g^{-1}; Table 1). With exception of Embaixador's RS, the results of RS are higher than those of 26 kidney bean cultivars that ranged between 9.16 and 18.09 g·100 g^{-1} (Kan et al., 2017). Additionally, the RS contents of the Embaixador cultivar' flours were higher than a pea (2.45 g·100g^{-1}) and similar to chickpea (3.39 g·100 g^{-1}), and lentils (3.25 g·100 g^{-1}) (de Almeida Costa et al., 2006), while the other cultivar bean flours were higher. These differences may be attributed to the bean varieties as well their chain-length distribution and starch crystallinity (Hung et al., 2016; Kan et al., 2017).

The heat preparation methods applied in the bean grains to produce flours contributed to the increase in RS (Table 1). These results were expected since thermal treatment is one of the main factors that affect digestibility and bioavailability of starch in plant foods, and it is acknowledged that starch from legumes is disposed to retrograde when cooked, producing resistant fractions that can be further increased by applying an additional heat treatment such as dehydration. Thermal processing promotes an increase in RS values, mainly due to amylose retrogradation (Ramírez-Jiménez et al., 2014, 2015). Moreover, the preparation method C20′ contributed to the highest amount of RS. A reason for these results is the fact that in the method C20′ beans were not soaked before cooking. According to other researchers, unsoaked and cooked beans showed a greater content of RS compared to soaked and cooked beans (Ramírez-Jiménez et al., 2014, 2015). Regarding the cultivars, the flour of cultivar Artico presented a higher increase of RS (Table 1), which might be related to their amylose content, since starch with high content of amylose tends to form the biggest amount of RS (Hung et al., 2016).

In general, the TDF content of bean flours showed significant variation ($p < .05$) between cultivars and preparation methods, where the cultivar Artico and the flours with C5′ treatment (e.g., Jalo Precoce) showed the highest values (20.0 g·100 g^{-1}; Table 1). The overall TDF values obtained in this study were within the range of 16.2 to 24.9 g·100 g^{-1}, previously reported by Felker et al. (2018). These effects of heat preparations on TDF amount are consistent with previous reports on thermal processing effects on pulse seeds or fractions thereof (Felker et al., 2018). This increase may be related to an increase of insoluble dietary fiber due to the formation of protein–fiber complexes by chemical modification induced by the cooking of bean grains (Wang et al., 2009).

3.2 | WSI, WAI, and OAI

The WAI is the capacity of flour to be associated with water molecules (Shafi et al., 2016). Only the type of flour treatment significantly influenced ($p < .05$) the WAI of the flour. The raw flour presented a similar value of WAI (4.5 g·g^{-1}) for all cultivars (Figure 2a). The cooking method presented a decrease in WAI in the C20′ flours of cultivar Embaixador. The WAI depends on the ratio of hydrophilic proteins and carbohydrates (mainly starch) proportions in the flours due to their strong bonds of the hydrogens of the polar or charged side chains (Prasad et al., 2012). Then, the reduction in water absorption of these flour may be related to their starch modification, since the heat-moisture treatment increase the interactions between amylose and amylopectin molecules, strengthened intramolecular bonds, and the formation of amylose–lipid complexes, resulting in low water absorption capacity (Hung et al., 2016).

Regarding WSI property, it was found that both the type of flour (treatment) and the cultivar used, as well as the interaction between them significantly, influenced ($p < .05$) the results obtained (Supplementary Table S1). The raw flour from cultivar Artico presented the highest value of WSI (31 g·100 g^{-1}) and the flour of Embaixador the lowest one (28 g·100 g^{-1}; Figure 2b). These results could be related to the content of proteins and starch since the cultivar Artico presented higher protein content and lower content of starch compared with the cultivar Embaixador (Table 1). The heat treatment promoted the reduction of WSI for all bean flours, and the flour from Embaixador cooked for 20 min presented the lowest value (19 g·100 g^{-1}; Figure 2b). These results are higher than those found by Simons and Hall Iii (2018) for cooked Pinto beans flours (10.4 g·100 g^{-1}). Flour with low values of WSI is suitable for pasta development since it could reduce the loss of solids in water and the optimum cooking time, due to their low water solubilization capacity (Fideles et al., 2019). So, the cooked bean flours might be best suitable for pasta development than raw flours.

OAI was not significantly affected ($p > .05$) by the preparation methods or by the cultivars used (Supplementary Table S1). The OAI of raw bean flours was around 1.9 g g^{-1} (Figure 2c) which is comparable to that reported in other pulse flours and pinto bean flours (1.4 g·g^{-1}) (Lin & Fernández-Fraguas, 2020; Setia et al., 2019). The absorption of oil is important, as the triacylglycerides act as retainers of flavor, to increase the oral sensation of food, enhancing palatability and shelf life, particularly in bread and meat products, where fat absorption is desired (Julianti et al., 2017).

3.3 | Pasting properties

All bean flour viscosity parameters were significantly affected by the treatment used, by the cultivars as well as by the interaction between treatment and cultivar ($p < .05$; Table 2). So, both cultivars and the method used for flour production contributed to the differences presented in the pasting properties. These differences between different cultivars are attributed to the difference in starch, protein, dietary fiber content, swelling, and hydration properties of flours (Kim et al., 2018). Finally, the cooked method promotes total or partial gelatinization of the starch, which affects the pasting properties (Kaur et al., 2015).

The raw Realce, Artico, and Jalo Precoce flours exhibited similar pasting temperatures ($p > .05$), between 79.00 and 79.73°C, while the raw Embaixador flour had a lower pasting temperature of 76.53°C (Table 2). These pasting temperature results are lower than reported by Felker et al. (2018) for the raw navy, black, and pinto bean flours (between 80 and 83°C), and higher than 72°C for chickpea flour. The higher pasting temperatures were expected

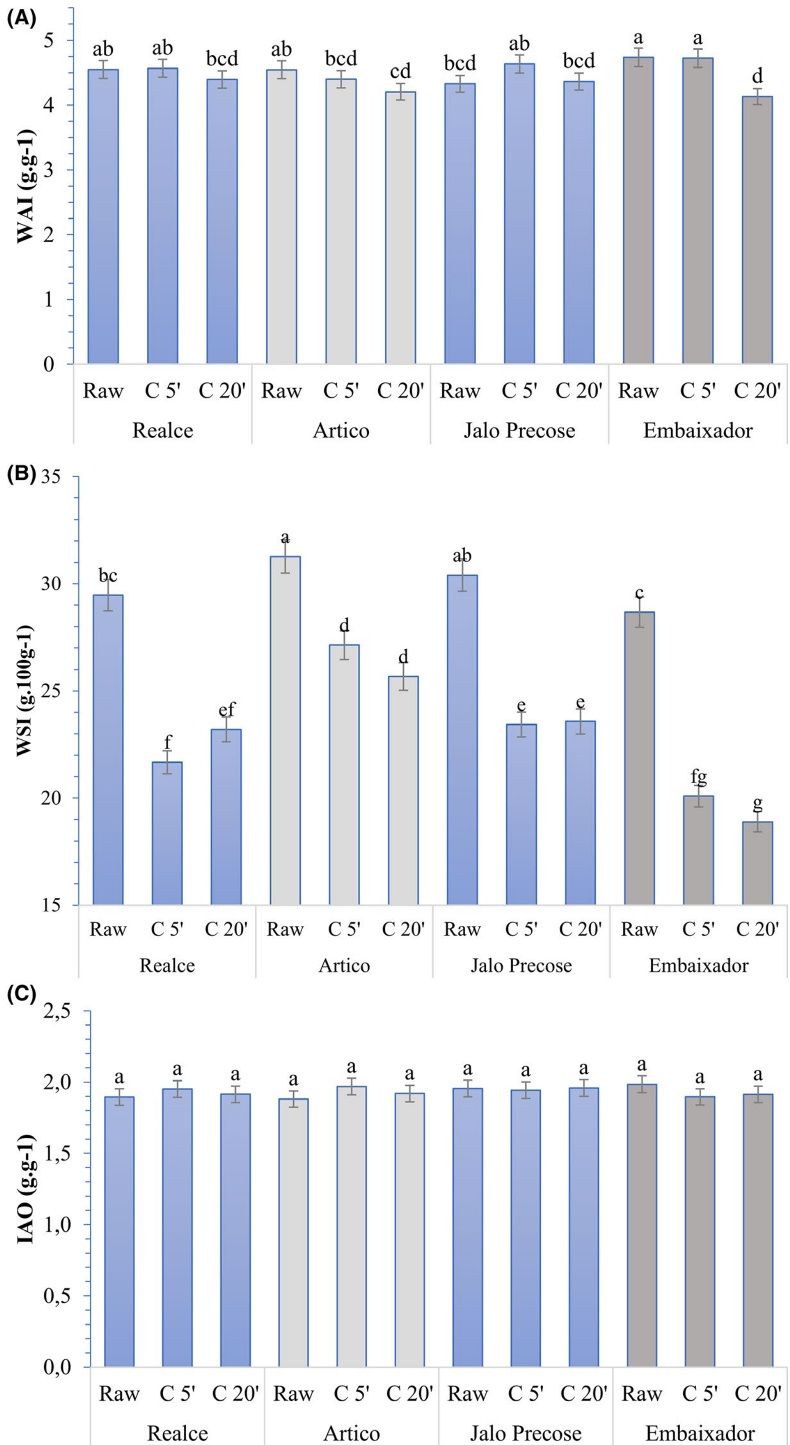

FIGURE 2 Water absorption index (a), water solubility index (B), and oil absorption index (C). Preparation method: raw, C5′ (presoaked beans cooked for 5 min), and C20′ (beans cooked for 20 min without previous soaking). Different letters show statistical differences between samples ($p < .05$)

for bean flours since they are rich in proteins and TDF, which in turn are believed to form a matrix network that could entrap and protect the integrity of starch granules. Their presence in flours has also been related to a reduction of the water availability to starch and to an increase in the temperatures at which starch granules start to absorb water (Lin & Fernández-Fraguas, 2020; Prazeres et al. 2020; Romero & Zhang, 2019). So, this higher viscosity-temperature of bean flours indicates a greater resistance to swelling, which is following the low WSI as well, with their decrease in the cooked flours (Figure 2).

The C5′ and C20′ increased the flours pasting temperature, with C20′ flours showing the highest values, due to the increased RS

TABLE 2 Pasting properties of flour from raw and cooked beans (P.M.: preparations methods) of different cultivars

RVA	P.M.	Realce	Artico	Jalo Precoce	Embaixador
Pasting Temperature[1]	Raw	79.73 ± 0.67^{aC}	79.00 ± 0.88^{aB}	79.00 ± 0.07^{aB}	76.53 ± 0.04^{bB}
	C 5′	86.85 ± 2.09^{aA}	Nd	Nd	82.38 ± 0.59^{bA}
	C 20′	82.43 ± 0.40^{aB}	81.90 ± 0.43^{aA}	82.65 ± 0.53^{aA}	83.07 ± 0.89^{aA}
Peak viscosity[2]	Raw	585.33 ± 15.37^{bA}	494.33 ± 22.01^{dA}	543.50 ± 3.54^{cA}	$1,069.00 \pm 8.49^{aA}$
	C 5′	260.00 ± 25.51^{bC}	182.33 ± 15.95^{dC}	222.67 ± 3.21^{cC}	309.00 ± 8.66^{aC}
	C 20′	403.67 ± 4.73^{bB}	388.67 ± 1.15^{cB}	380.00 ± 8.72^{cB}	483.67 ± 42.78^{aB}
Final Viscosity[2]	Raw	$1,046.67 \pm 31.34^{bA}$	886.00 ± 38.04^{dA}	998.50 ± 7.78^{cA}	1801.50 ± 27.58^{aA}
	C 5′	514.00 ± 37.51^{abC}	394.33 ± 23.46^{cC}	481.00 ± 4.58^{bC}	552.67 ± 12.90^{aC}
	C 20′	769.33 ± 6.66^{cB}	833.00 ± 4.95^{aB}	791.0 ± 12.53^{bB}	865.00 ± 63.00^{abB}
Breakdown[2]	Raw	118.67 ± 7.64^{abA}	67.33 ± 4.16^{cA}	120.50 ± 3.54^{aA}	112.50 ± 3.54^{bA}
	C 5′	32.33 ± 0.58^{aC}	18.33 ± 1.53^{bC}	31.00 ± 1.73^{aC}	30.00 ± 1.73^{aC}
	C 20′	65.00 ± 2.65^{bB}	51.67 ± 0.58^{cB}	62.00 ± 2.00^{bB}	70.33 ± 6.43^{aB}
Setback[2]	Raw	580.00 ± 13.89^{bA}	459.00 ± 12.00^{cB}	575.5 ± 7.78^{bA}	845.00 ± 15.56^{aA}
	C 5′	286.33 ± 12.70^{abC}	230.33 ± 9.07^{cC}	289.33 ± 2.52^{aC}	273.67 ± 6.81^{bC}
	C 20′	430.67 ± 1.53^{dB}	497.00 ± 4.24^{aA}	473.00 ± 7.00^{bB}	451.67 ± 13.28^{cB}

Note: Mean of three replicates ± standard deviation. Preparation method: raw, C5′ (presoaked beans cooked for 5 min), and C20′ (beans cooked for 20 min without previous soaking). Different lower-case letters in the same row and upper-case letters in the columns show statistical differences between cultivars and the preparation method ($p < .05$), respectively.

[1]°C;

[2]cP, centipoise; Nd, not detected.

content in these materials (Table 1). After the holding period at 95°C, the cooling portion of the curves displayed the expected further increase in apparent viscosity (Supplementary Figure S2). Setback, as the amylose and amylopectin polymers began to re-associate and presumably form networks in the presence of protein and fiber components (Felker et al., 2018). There were small differences between the four cultivars, most probably reflecting characteristic dissimilarities in starch, protein, and dietary fiber composition of the flours, with highlights for the cultivar Embaixador, which presented the highest amount of starch and the lowest protein content (Supplementary Figure S2 and Table 1).

The cultivar Embaixador (raw flour) presented the highest viscosities (1,069.0 cP, 1801.5 cP, 112.5 cP, and 845.0 cP for peak viscosity, final viscosity, breakdown, and setback, respectively). These results are attributed to the highest content of total starch and lower protein content in the cultivar Embaixador (Tables 1 and 2). On the other hand, the cultivar Artico (raw flour) showed the lowest values of viscosity (886 cP and 459 cP for final viscosity and setback) and the lowest starch content. These values are lower than that found for Mangalô bean starch that had a maximum viscosity of 4,205 cP (Prazeres et al., 2020).

The raw bean flours showed the highest viscosities (peak viscosity, final viscosity, breakdown, and seatback), while those of type C5′ had the lowest ones. This occurred because C5′ had a higher degree of pre-gelatinization of starch. Since in the soaking step, present in this preparation method, the bean grains (and consequentially the starch granules) absorb a significant amount of water, which contributed to starch gelatinization during the cooking step in the autoclave; unlike, the flours made without the soaking step, where the grains absorbed less water and, as consequence, the starch gelatinization during cooking was reduced. Low breakdown and setback values (i.e., flours made with the cooked method C5′) indicate greater paste stability during mechanical processes and less tendency to retrogradation upon cooling (Kim et al., 2018; Prazeres et al., 2020), which are suitable for various food systems.

3.4 | Thermal properties

The bean flours showed two endothermic peaks and a glass transition point (Table 3). The first endothermic peak with T onset between 72.38 and 76.6°C (peak 1), refers to the beginning of gelatinization of the starch granules. The second endothermic peak with T onset between 86.92 and 92.65°C (peak 2) refers to the fusion of lipid-amylose complexes and protein denaturation. Lipid-amylose complexes have a higher melting temperature when compared to the starch gelatinization temperature, as they have high thermal stability; and the greater the length of the complex chains, the greater the physical stability (Garcia et al., 2016; Kawai et al., 2012; Lin & Fernández-Fraguas, 2020). The thermal properties of bean flours were significantly affected by the treatment used (with exception of onset, peak, and end gelatinization temperature of the Artico and Jalo Precoce cultivars, and glass transition temperature of the cultivar Embaixador); by the cultivars, as well as, by the interaction between preparation method and cultivar ($p < .05$; Supplementary

TABLE 3 Thermal properties of flour of raw and cooked beans from different cultivars Artico (A); Realce (R); Embaixador (E); Jalo (J)

	Peak 1				Peak 2				Tg[2]
P.M.[1]	T_{onset} (°C)	T_{peak} (°C)	T_{end} (°C)	ΔH (J/g)	T_{onset} (°C)	T_{peak} (°C)	T_{end} (°C)	ΔH (J/g)	$T_{midpoint}$ (°C)
R-Raw	72.67 ± 1.09^{b}	78.06 ± 1.01^{b}	85.4 ± 1.13^{b}	2.7 ± 0.15^{a}	87.65 ± 1.01^{b}	88.1 ± 1.09^{b}	89.52 ± 1.13^{b}	1.36 ± 0.15^{a}	104.23 ± 1.45^{b}
R-C 5′	76.25 ± 1.05^{a}	80.89 ± 1.21^{a}	86.6 ± 1.15^{ab}	1.04 ± 0.18^{c}	88.11 ± 1.04^{ab}	91.9 ± 1.14^{a}	97.28 ± 1.25^{a}	0.68 ± 0.05^{b}	109.76 ± 1.23^{a}
R-C 20′	74.55 ± 1.35^{ab}	80.06 ± 1.12^{ab}	87.21 ± 1.05^{a}	2.19 ± 0.23^{b}	90.35 ± 1.45^{a}	94.12 ± 1.23^{a}	98.79 ± 1.27^{a}	0.59 ± 0.07^{b}	110.65 ± 1.42^{a}
A-Raw	73.44 ± 1.02^{a}	79.31 ± 1.11^{a}	86.98 ± 1.11^{a}	2.63 ± 0.32^{a}	90.87 ± 1.24^{a}	95.29 ± 1.01^{a}	102.49 ± 1.04^{a}	1.5 ± 0.11^{a}	99.74 ± 1.01^{b}
A-C 5′	75.27 ± 1.15^{a}	79.79 ± 1.15^{a}	85.84 ± 1.04^{a}	1.19 ± 0.15^{c}	87.62 ± 1.30^{b}	92.25 ± 1.31^{b}	98.27 ± 1.03^{b}	1.05 ± 0.09^{b}	113.98 ± 1.21^{a}
A-C 20′	74.1 ± 1.17^{a}	79.47 ± 1.17^{a}	85.915 ± 1.12^{a}	2.0 ± 0.23^{b}	88.76 ± 1.15^{ab}	93.02 ± 1.08^{ab}	99.04 ± 1.11^{b}	1.06 ± 0.08^{b}	115 ± 1.08^{a}
JP-Raw	73.17 ± 1.05^{a}	78.75 ± 1.03^{a}	84.73 ± 1.01^{a}	2.1 ± 0.17^{a}	89.67 ± 1.09^{a}	94.56 ± 1.12^{a}	100.91 ± 1.04^{a}	1.28 ± 0.10^{a}	107.86 ± 1.05^{b}
JP-C 5′	74.35 ± 1.19^{a}	79.66 ± 1.08^{a}	85.14 ± 1.05^{a}	0.85 ± 0.10^{c}	86.92 ± 1.05^{b}	91.25 ± 1.04^{b}	96.83 ± 1.28^{b}	0.77 ± 0.05^{b}	112.04 ± 1.13^{a}
JP-C 20′	74.26 ± 1.30^{a}	79.93 ± 1.09^{a}	86.44 ± 1.13^{a}	1.64 ± 0.19^{b}	88.67 ± 1.07^{ab}	93.66 ± 1.11^{ab}	100.74 ± 1.31^{a}	0.88 ± 0.10^{b}	111.63 ± 1.26^{a}
E-Raw	72.38 ± 1.01^{b}	78.21 ± 1.12^{b}	85.28 ± 1.14^{b}	3.1 ± 0.35^{a}	92.65 ± 1.13^{a}	97.01 ± 1.05^{a}	102.82 ± 1.45^{a}	1.58 ± 0.19^{a}	109.99 ± 1.54^{a}
E-C 5′	76.6 ± 1.21^{a}	81.38 ± 1.17^{a}	87.44 ± 1.50^{b}	1.19 ± 0.15^{b}	88.62 ± 1.67^{b}	92.02 ± 1.17^{b}	97.25 ± 1.24^{b}	0.75 ± 0.11^{b}	109.75 ± 1.21^{a}
E-C 20′	75.23 ± 1.31^{a}	81.31 ± 1.05^{a}	91.45 ± 2.01^{a}	3.0 ± 0.10^{a}	89.62 ± 1.60^{ab}	93.02 ± 1.32^{b}	98.25 ± 1.07^{b}	0.65 ± 0.11^{b}	110.62 ± 1.12^{a}

Note: Results are presented as the mean of three replicates ± standard deviation.

[1]Preparation method: raw, C5′ (presoaked beans cooked for 5 min), and C20′ (beans cooked for 20 min without previous soaking).

[2]Glass transition temperature (°C). Different letters in the columns show statistical differences between the preparation method ($p < .05$).

Table S1). The differences in these thermal properties between different cultivars are attributed mainly to the difference in starch properties, as their crystallinity, and the protein content (Paixão e Silva et al., 2020). Finally, the cooked method promotes the gelatinization of the starch and the denaturation of proteins, which affects the parameters of DSC analyses. The observed Tp (gelatinization peak temperature) (between 78.06 and 81.38°C) values in raw samples (Table 3) are following the pasting temperature (Table 2), but lower than the Tp corresponding to starch gelatinization reported for pinto bean (84°C) (Lin & Fernández-Fraguas, 2020).

The raw flours presented a fusion of amylose-lipids complexes and protein denaturation peak temperature ranging from 88.10 to 97.01°C, which are lower values than those found by Lin and Fernández-Fraguas (2020) for protein denaturation of pinto bean flours (around 98°C). The flours from presoaked grains cooked for 5 min (C5′) presented a significant reduction in the T onset, T peak, T end of protein denaturation (peak 2), except for the cultivar Realce.

The enthalpies of starch gelatinization and fusion of the amylose-lipid complex of bean flours were significantly affected ($p < .05$) by how the flours were prepared, by the type of cultivar, as well as by their interaction (Supplementary Table S1). So, both heat treatments significantly decreased ΔH values (Table 3) indicating a high degree of protein denaturation and microstructural modification (Lin & Fernández-Fraguas, 2020). The bean flours C5′ presented the lowest values to require energy for gelatinization, which confirms that these flours presented a higher degree of pre-gelatinization.

The Tg (glass transition temperature) varied between 99.74 and 115.00°C and was also significantly affected by the preparation method, cultivar, and their interaction ($p < .05$), where the cooked grain flours had the highest Tg values, except for Embaixador cultivar flour. This cultivar showed the highest thermal stability since it did not present a significant variation between raw and cooked flours. The Tg of the food shows an important role in the processing and storage stability, as when food is subjected to a temperature above the Tg, its physicochemical properties are modified. Thus, the use of temperatures below Tg favors the maintenance of quality and reduces the thermal degradation of the product (Xin et al., 2013).

3.5 | Gel texture profile

The texture parameters of the bean flour gel were significantly affected by the treatment used, by the cultivars as well as by the interaction between treatment and cultivar ($p < .05$) (Supplementary Table S1 and Table 4). Textural characteristics are affected by the amylose matrix, the volume fraction, the rigidity of the gelatinized starch granules, and the interactions between dispersed and continuous phases of the gel (Kim et al., 2018). Thus, the differences between cultivars were expected since they presented dissimilarities in the amount of starch, proteins, and TDF (Table 1). Lastly, the cooked flour has gelatinized starch as well as denaturized proteins, which also influence the texture parameters.

In general, the raw bean flours presented the highest hardness, adhesiveness, and resilience, while the flours from presoaked beans cooked for 5 min (C5′) presented the lowest hardness and adhesiveness (Table 4). The hardness indicates the resistance of the gel structure to compression and the adhesiveness is defined as the area of negative force under the curve obtained between cycles (Liu et al., 2019; Wang et al., 2019). The higher value of these aforementioned properties in raw flours confirmed they are more elastic and have a stronger structure network than the flours made with cooked beans. Furthermore, pre-gelatinized starches have less capacity to form a strong network, favoring the reduction of gel hardness (Romero & Zhang, 2019), so it was expected that C5′ flours present the lowest values because these flours are more pre-gelatinized. The weak structure of the cooked flours is following their pasting properties since they also presented low viscosities. The raw Jalo Precoce flour presented the highest adhesiveness (−18.78 g.s; Table 4), but lower than those reported for cowpea and mung bean starch gels (range of−4 to−16 g·s, respectively) (Kim et al., 2018). Flours with low adhesiveness may be suitable for pasta development (Fideles et al., 2019), so our cooked flour is better than raw flour.

Cohesiveness is the internal bonding force required to maintain the shape, and springiness is the recovery ability against deformation (Kim et al., 2018). The raw flours had significant ($p < .05$) lower values of springiness and cohesiveness than the C5′ flours, indicating a low intermolecular force in the gel matrix (Table 4). This seems plausible since raw flours had higher WSI (Figure 2b) and peak viscosity (Table 2). A decrease in the springiness value, therefore, indicates that the gel has lost elasticity (Teng et al., 2013). Regarding the cultivars, the cultivar Embaixador presented the highest springiness (0.91), which could be related to their higher starch content (Table 1) since starch contributes to the gel network, as well as the elasticity.

3.6 | Emulsifying properties

Regarding the emulsifying capacity index (ECI) of bean flours, the cultivar type, the method of flour preparation and the interaction between them presented significant differences ($p < .05$) (Supplementary Table S1). The flour of Realce raw beans presented the lowest ECI (53.0%) when compared with the other cultivars ($p < .05$; Figure 3a). The results for raw beans were highest than that found by Lin and Fernández-Fraguas (2020) (42.0%) who reported that raw bean flours are good emulsifiers. Emulsion capacity was also higher than those presented by flours of raw yellow pea flour (44.0%) and raw faba bean (47.7%) (Setia et al., 2019). The ECI indicates the capacity of proteins and other surface-active molecules present in beans to adsorb to the oil-water interface and then contribute to the development of an emulsion. Some factors could affect the ECI, such as the hydrophilic/hydrophobic balance of amino acids of a protein, especially on the protein surface; and the carbohydrates content, such as starch and fiber, which assist in entrapping and binding with oil and/or water (Gupta et al., 2018; Lin & Fernández-Fraguas, 2020). So, the differences observed in the cultivars may be related to their

TABLE 4 Gel textural profile of flour from raw and cooked (P.M.) beans of different cultivars

TPA	P.M.	Realce	Artico	Jalo Precoce	Embaixador
Hardness (*N*)	Raw	1.95 ± 0.23^{bA}	1.34 ± 0.16^{cA}	1.73 ± 0.19^{bA}	3.48 ± 0.18^{aA}
	C 5′	-0.06 ± 0.01^{bC}	0.60 ± 0.10^{aB}	-0.04 ± 0.01^{bC}	0.47 ± 0.07^{aC}
	C 20′	0.98 ± 0.11^{abB}	1.20 ± 0.14^{aA}	0.90 ± 0.06^{bB}	0.67 ± 0.02^{cB}
Adhesiveness (g s)	Raw	-31.60 ± 5.24^{bA}	-30.61 ± 2.75^{bA}	-18.78 ± 2.72^{aA}	-87.16 ± 7.37^{cA}
	C 5′	-53.15 ± 5.56^{aB}	-104.55 ± 6.27^{dB}	-71.98 ± 2.39^{bB}	-87.05 ± 6.84^{cA}
	C 20′	-79.35 ± 4.39^{aC}	-112.39 ± 6.36^{cB}	-124.77 ± 5.16^{dC}	-93.33 ± 1.35^{bB}
Springiness (mm)	Raw	0.82 ± 0.02^{bB}	0.80 ± 0.11^{abB}	0.84 ± 0.02^{bB}	0.91 ± 0.04^{aAB}
	C 5′	0.93 ± 0.02^{abA}	0.89 ± 0.02^{bA}	0.95 ± 0.03^{aA}	0.94 ± 0.00^{aA}
	C 20′	0.84 ± 0.02^{bB}	0.89 ± 0.02^{aA}	0.90 ± 0.04^{abAB}	0.90 ± 0.01^{aB}
Cohesiveness	Raw	0.46 ± 0.04^{abB}	0.44 ± 0.03^{abA}	0.50 ± 0.03^{aB}	0.42 ± 0.04^{bC}
	C 5′	0.58 ± 0.02^{aA}	0.50 ± 0.04^{cA}	0.55 ± 0.01^{bA}	0.57 ± 0.01^{aA}
	C 20′	0.45 ± 0.0^{bB}	0.47 ± 0.03^{abA}	0.45 ± 0.03^{bC}	0.49 ± 0.00^{aB}
Resilience	Raw	13.65 ± 2.19^{aA}	11.27 ± 3.30^{aA}	13.77 ± 1.72^{aA}	12.64 ± 1.03^{aA}
	C 5′	5.18 ± 0.97^{abB}	4.31 ± 0.27^{bC}	5.09 ± 0.42^{aB}	5.39 ± 0.54^{aB}
	C 20′	6.80 ± 1.01^{abB}	7.24 ± 0.06^{aB}	5.54 ± 0.29^{bcB}	5.13 ± 0.31^{cB}

Note: Mean of three replicates ± standard deviation. P.M., preparation method: raw, C5′ (presoaked beans cooked for 5 min), and C20′ (beans cooked for 20 min without previous soaking). Different lower-case letters in the same row and upper-case letters in the columns show statistical difference between cultivars and preparation method ($p < .05$), respectively.

protein profile, starch, and TDF content. Regarding the treatment, with exception of the flours from Realce, the ECI presented a reduction in the flours of cooked grains (Figure 3a). Moreover, the cooking method interfered in ECI only for Embaixador flours, with C20′ flours presenting the lowest ECI. These results must be associated with their higher starch content. The ECI of flours is critical for bakery products, including cakes, bread, and muffins (Foschia et al., 2017; Gupta et al., 2018), so our cooked bean flours can be used as a good emulsifier even the cooked ones (Lin & Fernández-Fraguas, 2020).

The emulsion stability index (ESI) indicates the stability of the adsorbed layer in a period (Lin & Fernández-Fraguas, 2020). The flours from the raw grains of cultivar Artico presented the highest ESI (66%) (Figure 3b). The cultivars Jalo Precoce and Realce presented the lowest ESI values (56.8% and 57.6%, respectively). These values were higher than those presented by flours of raw yellow pea (52.0%) and raw faba bean (53.8%) (Setia et al., 2019). So, the bean flours studied presented a good emulsion stability index. The ESI was significantly ($p < .05$) reduced in thermally treated flours, with C5′ and C20′ being statistically equal (Supplementary Table S1). ESI is attributed to the adsorption power of the protein layer, and starch and fiber might also provide emulsion stability by increasing the viscosity of the constant phase, which would avoid droplet aggregation (Lin & Fernández-Fraguas, 2020). As the cooked method promoted a gelatinization of starch granules and a denaturation of proteins, the decrease of ESI is justified. Moreover, WSI and ECI presented a positive correlation with ESI ($r = 0.70$, $p < .001$; $r = 0.66$, $p < .001$, respectively), and these properties also presented a decrease in flours made with cooked grains (Figure 3b; Figure 2b).

3.7 | Principal components analysis—PCA

The technological parameters that showed some degree of correlation are presented in the PCA (Figure 4) created to describe differences among the flours with a total variance of 79.26%. The PC1 clustered the flours by treatment (raw, C5′, and C20′), which indicates that the preparation methods promote significant changes of flours properties with different intensities since the preparation's methods are clustered as two independent groups. For technological properties, PC1 identified that flours with higher RS, cohesiveness, and springiness had lower viscosity values, gelatinization enthalpy, WSI, gumminess, and adhesiveness. Finally, the flours made with soaked and cooked beans (C5′) (in the negative zone) had more drastic changes in technological properties. This happens because of the pre-gelatinization of the starch and the denaturation of the proteins present in the flours during the cooking step. Moreover, the C5′ presented a drastic degree of pre-gelatinization when compared with those cooked without soaking. This was confirmed by the increase of peak temperature of starch gelatinization, followed by a decrease of energy for gelatinization in cooked flours. Thus, the cooked flours presented the highest amount of RS, and the lowest values for pasting properties, the energy of starch gelatinization, and presented a low resistance of the gel structure to compression.

In PC2, it was found that higher values of RS presented a negative correlation with cohesiveness and springiness and the pasting properties, thus contributing to their reduction (Figure 4). Regarding the flours, PC2 shows that the raw flour of the cultivar Embaixador did not cluster with the other raw flours. These results reflect the

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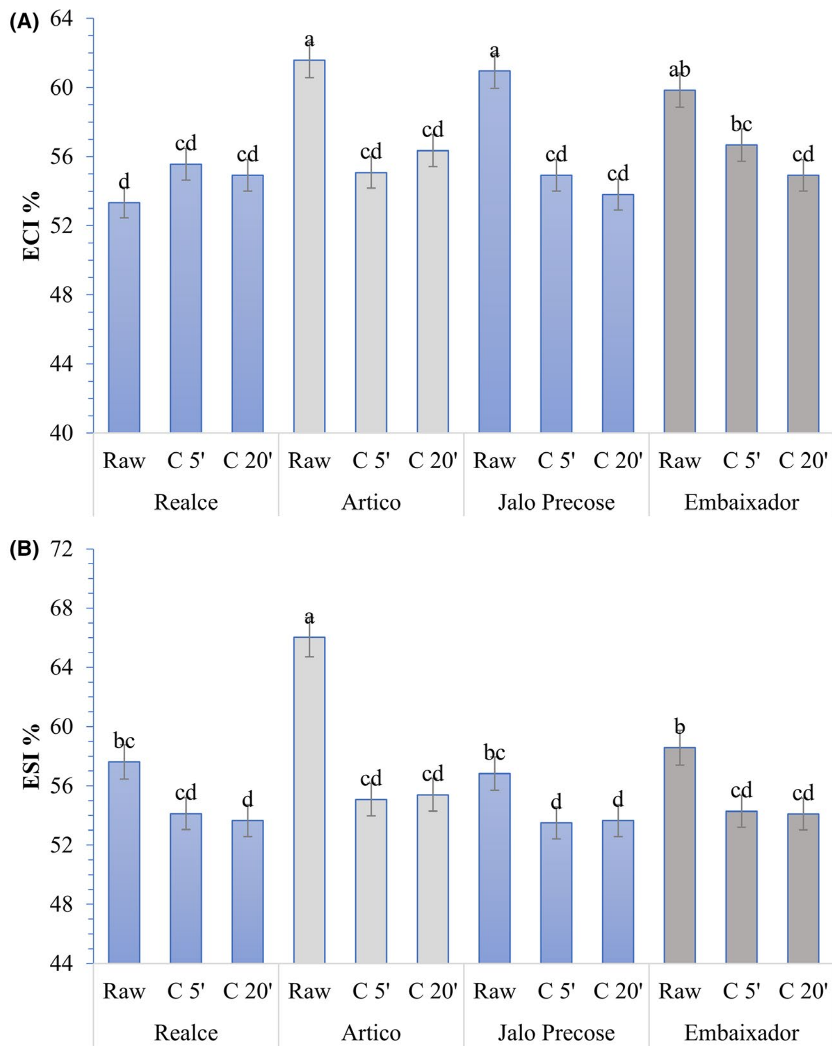

FIGURE 3 Emulsifying capacity index (a) and emulsifying stability index (b). Preparation method: raw, C5′ (presoaked beans cooked for 5 min), and C20′ (beans cooked for 20 min without previous soaking). Different letters show statistical differences between samples ($p < .05$)

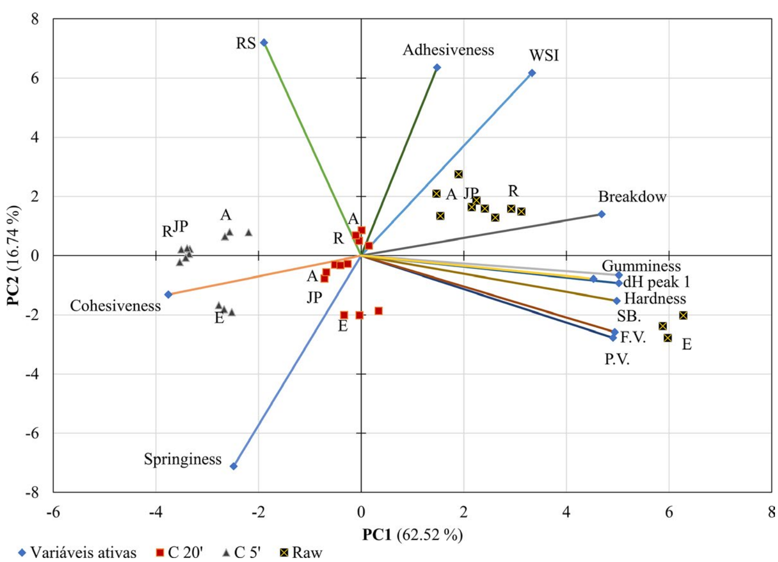

FIGURE 4 Principal component analysis. A, Artico; dH peak1, enthalpy of starch gelatinization; E, Embaixador; F.V., final viscosity; JP, Jalo Precoce; P.V., peak viscosity; R, Realce; RS, resistant starch; SB, setback; WSI, water solubility index. Preparation method: raw (purple points), C5′ (blue points) (presoaked beans cooked for 5 min), and C20′ (green points) (beans cooked for 20 min without previous soaking)

dissimilarities of that cultivar when compared with the others, especially the highest amount of starch and low content of protein.

In general, cooking the colorful beans (presoaked or not) with steam in an autoclave (C5′ and C20′) proves to be a potential method of cooking to produce bean-cooked flours, since the flours presented significant changes in their functional properties that made them more suitable for some food applications. For example, pasta presents better palatability when produced with flours with less adhesiveness, as these parameters simulate the strength with which the product adheres to the palate or teeth after compression between the tongue and palate (Paixão e Silva et al., 2020; Palabiyik et al., 2016). As our bean-cooked flours (primarily C5′) presented low adhesiveness, they might be suitable for pasta preparation. Moreover, the cooked flours presented low values of viscosity (principally C5′), which are advantageous for food systems application, since high levels of supplementation with pulse components are desired without causing a major texture difference or potential syneresis (i.e., soups, puddings) (Felker et al., 2018). Finally, cooked flours (mainly the flour cooked for 20 min without soaking step) showed an increase in RS. This increase is interesting since the RS presents health benefits (Chávez-Mendoza & Sánchez, 2017).

4 | CONCLUSION

The flours from colorful beans presented significant differences in their protein, total starch, resistant starch, and dietary fiber profiles, wherein the cultivar Embaixador (dark red kidney beans) presented the highest total starch content and the lowest content of resistant starch and protein. On the other hand, the cultivar Jalo Precoce (yellow beans) showed the highest amount of resistant starch and protein. The cooked flours (C5′: presoaked beans cooked for 5 min, and C20′: beans cooked for 20min without previous soaking) compared with the raw ones presented a reduction in the values of WSI, pasting properties (peak viscosity, final viscosity, breakdown, and seatback), hardness, adhesiveness, resilience, emulsifying capacity, and stability. The intensity of these aforementioned reductions was dependent on the cultivar and on the cooking method, wherein C5′ promoted more drastic changes. Thus C5′ flours are advantageous for food systems application when high levels of supplementation with pulse components are desired without causing a major texture discrepancy the flours presented an increase in resistant starch, which are nutritionally interesting. Finally, the proposed methods (C5′ stood out) for the obtention of cooked colorful bean flours showed potential for industry application, since they improved the functional characteristics of the cooked flours which could increase their acceptability as a base ingredient and expand their potential use in different food systems.

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CONFLICT OF INTEREST

The author declares that there is no conflict of interest that could be perceived as prejudicing the impartiality of the research reported.

AUTHOR CONTRIBUTIONS

Conceptualization; Formal analysis; Investigation; Methodology; Validation; Writing-original draft; Writing-review & editing: Juliana Aparecida Correia Bento. *Conceptualization; Resources; Supervision; Validation; Visualization; Writing-review & editing*: Priscila Zaczuk Bassinello. *Investigation; Methodology*: Rosângela Nunes Carvalho. *Investigation; Methodology*: Menandes Alves de Souza Neto. *Resources*: Márcio Caliari. *Supervision; Writing-review & editing*: Manoel S. Soares Junior.

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SUPPORTING INFORMATION

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