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Use of rice on the development of plant-based milk with antioxidant properties: From raw material to residue

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ABSTRACT

Given the consumer demand for new, savory products without allergenic impact on people, this work aimed to study the behavior of different rice types (white, red and black) during its hydration and development of plant-based milks. Verification of the pasteurization and sterilization on product's nutritional, chemical and physical characteristics was also conducted. Hydration kinetics of rice grains was carried out and the Peleg model was adjusted satisfactorily. Milk solutions submitted to sterilization showed solid texture, invalidating this treatment for the production of plant-based milks. Rice's, milks and residues were characterized. Products have shown high nutritional value, varying depending on the rice type. Not only phenolic compounds content (77.03 mg GAE/100 g), but also antioxidant activity (21.30 g/g DPPH• and 10.35 μM trolox/g in ABTS•+), were higher in products made from black rice. Furthermore, it was observed that the residues are suitable to be added in the enrichment of new food products.

1. Introduction

The food industry is constantly looking for market opportunities and trends, and one category that is expanding is plant-based milk as alternatives to milk sourced from animals. The success of these products comes from several factors, including increasing levels of lactose intolerance, different diet types (such as vegetarianism, lacto-ovo vegetarianism and veganism), desire for a healthy lifestyle, concern about animal welfare and environmental concerns (Aydar, Tutuncu, & Ozcelik, 2020; Paul, Kumar, Kumar, & Sharma, 2020).

Plant-based milks are defined as aqueous extracts produced from raw materials of vegetable origin, representing a source of proteins and calories for human consumption (Izadi et al., 2013) with reduced fat percentage compared to cow milk and cholesterol-free. Consumption is growing. In Europe, for instance, the market grew about 9% in 2015 (Jeske, Zannini, & Arendt, 2017). This product is also lactose-free, the main carbohydrate present in cow milk, and can be indicated for people with lactose intolerance (Ikya, Gernah, Ojobo, & Oni, 2013). It also serves as an alternative for restricted vegetarians or vegans, who do not consume any type of animal product. There is around 75% of people around the world who presented lactose intolerance (Gasparin, Teles, & Araújo, 2010). In addition, the amount of vegetarian people is increasing significantly, being about 38, 13, 12, and 10% of people from India, Israel, Taiwan, and Italy, respectively (World Atlas, 2017).

Replacing cow milk with plant-based milk in ice cream production (soybean and coconut) (Aboulfazli, Shori, & Baba, 2016) or in yogurt production (oatmeal or almond) (Demir, Simsek, & Yildirim, 2021; Yilmaz-Ersan & Topcuoglu, 2022), poses an alternative for using these milks in the development of dairy products with functional claims, due to its high nutritional quality (Aboulfazli et al., 2016). This indicates that plant-based milk can be used to replace cow milk in dairy products, further expanding its potential and options of food products with technological and nutritional quality for consumers with restricted diets.

In addition to the positive impact on consumers through the nutritional contribution, plant-based milks are viable for the industry, as they can have a lower production cost when compared to cow milk production (Mang et al., 2016). Another benefit is the fact that residues from the food industry that are rich in carbohydrates and proteins can be used as raw materials. These products are often discarded or sold at a very low cost as feed and once upcycled, there is a positive impact on the environment, coming from the reduction of the water footprint required to treat the effluents, and the potential to reduce impact on climate

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change and ecotoxicity (Aydar et al., 2020).

Plant-based milks have high water activity, being highly susceptible to growth of microorganisms and having a short shelf life, thus requiring treatment through different methods of food preservation. The heat treatment in the case of a rice bran-based beverage is efficient in the elimination of microorganisms, leading to an increase in the product shelf life by 35 days (Faccin, Vieira, Miotto, Barreto, & Amante, 2009).

Rice (*Oryza sativa*) is one of the most consumed cereals worldwide, mainly in Asian countries (Folorunso, Omoniyi, & Habeeb, 2016). The high consumption of this cereal is linked not only to its nutritional value but also due to some special features of this grain, such as not being an allergenic food and not being toxic for celiacs, making it suitable for production of gluten-free products. Its nutritional value comes from the high amount of proteins, mineral salts and vitamin B complex. It also has low lipid content, being considered an excellent source of energy (Walter, Marchezan, & Avila, 2008).

Other rice varieties, such as the red one, are expanding their use in food industry. To use it in the development of new food products make complete sense as they are rich in nutritional components such phenolic compounds, anthocyanins and catechins, in addition to fibers (Hayashi & Yanase, 2016; Hu, Tang, Liu, Zhu, & Shao, 2017). It can also address issues at the field, as red rice is commonly considered a weed in white rice farms, one that is difficult to manage. Black rice is another example: it has a high amount of anthocyanins, mainly cyanidin-3-glucoside (Escribano-Bailón, Santos-Buelga, & Rivas-Gonzalo, 2004; Lee, 2010), in addition to other bioactive components, such as phenolic compounds, tocopherols, tocotrienols, γ-oryzanol, phytic acid and fibers (Choi & Lee, 2021; Mau, Lee, Chen, & Lin, 2017). Silva, Carvalho, Velasco, and Fakhouri (2020) studied white, red and black rice starches and concluded that starch extraction is a viable way of using this raw material with potential to be implemented in the food industry.

Given the growing demand for cow milk substitutes with nutritional, sensory, technological characteristics with no allergenic impact, this work aims to study the behavior of different types of rice (white, red, black) during its hydration and development of plant-based milks and verify the influence of the pasteurization and sterilization on product's nutritional, chemical and physical characteristics.

2. Material and methods

2.1. Materials

To obtain plant-based milk, three different types of rice were used: white, black and red (Armazém Santa Filomena, São Paulo, Brazil). For the analysis, the following chemicals were used: acetone, boric acid, chloroform, ethanol, Folin-Ciocalteau reagent, gallic acid, methanol, sodium hydroxide, sodium sulfate, sulfuric acid (Dinámica Química Contemporânea LTDA, São Paulo, Brazil); $ABTS^{\bullet+}$ [2,2-azinobis(3-ethylbenzethiazoline-6-sulfonic acid)], $DPPH^{\bullet}$ (1,1-difenil-2-picril-hidrazil), potassium persulfate, Trolox (6-Hidroxi-2,5,7,8-tetrametil-chroman-2-carboxylic acid) (Sigma-Aldrich, Saint Louis, MI, USA).

2.2. Methods

2.2.1. Rice hydration kinetics

Water absorption kinetics was carried out on the three types of rice (white, red and black). For this, the previously weighed sample was immersed in distilled water (25 °C), in a 1:4 ratio and kept at a temperature of 25 °C for 450 min, in triplicate. During the entire period, samples were weighed every 30 min, on an analytical balance (PA214P, Ohaus, Nänikon, Switzerland) to the nearest 0.0001 g. At each weighing, grains were removed from immersion and left on paper towels for 2 min to remove surface water and then returned to immersion soon after weighing. The water content was determined based on the increase in total mass of samples in relation to the initial moisture content.

A rice hydration mathematical modeling was carried out through the empirical Peleg model (Peleg, 1988) (Equation (1)).

$$U_t = U_0 + \frac{t}{(C_1 + C_2 t)} \quad \text{(Equation 1)}$$

To obtain constants C_1 and C_2, the model was then linearized, as described by equation (2), where: t = time (hours); U_t = water content at a given time (% dry basis); U_0 = sample initial water content (% dry basis); C_1 = Peleg constant rate (100 h kg_{ms}/kg_a) and C_2 = Peleg constant capacity (100 kg_{ms}/kg_a).

$$\frac{t}{(U_t - U_0)} = C_1 + C_2 t \quad \text{(Equation 2)}$$

Gaining time to predict the kinetics of water sorption in foods is one of the advantages that the Peleg model presents. The product steady water content (U_e), expressed in % dry basis, can be obtained by equation (3), when the time, described in equation (1), tends to infinity.

$$U_e = U_0 + \frac{1}{C_2} \quad \text{(Equation 3)}$$

To verify the applied model adjustment degree, magnitudes of the determination coefficient (R^2), the mean relative error (P) and the estimate standard deviation (SE) were considered, with P and SE being calculated from equations (4) and (5), where: Y = experimentally observed value; $\hat{Y}$ = value estimated by the model; η = number of observed data and GLR = residual degrees of freedom (number of observed data minus number of model parameters).

$$P = \frac{100}{\eta} \sum \frac{|Y - \hat{Y}|}{Y} \quad \text{(Equation 4)}$$

$$SE = \sqrt{\frac{\sum (Y - \hat{Y})^2}{GLR}} \quad \text{(Equation 5)}$$

2.2.2. Product development

Plant-based milk production was carried out according to the methodology described by Mang et al. (2016) with some modifications. The raw material was hydrated in distilled water at a 1:4 ratio for 6 h, based on the results obtained from the rice hydration kinetics. After hydration, the water was discarded and the rice was mixed with distilled water at a 1:3 ratio, with the aid of a mixer (Philips Walita/400 w, São Paulo, Brazil), for 3 min. The obtained paste was subjected to filtration (mesh 60). Filtered liquids (milks) were subjected to stirring with the aid of a magnetic stirrer, for 30 min, at a temperature of 45 °C (30 rpm), for starch gelatinization. Plant-based milks obtained were submitted to slow pasteurization (65 °C/30 min) and sterilization in an autoclave (120 °C/20 min). After heat treatment, samples were separated in sterile vials (50 mL) and stored in a freezer (−10 °C) until the moment of analysis. Analyses were performed on unheated, sterilized and pasteurized milks in order to verify the influence of heat treatment on product properties.

Residues generated after milk filtration were placed in stainless steel trays and dried in an air circulation oven (NG Científica, Campo Grande, Brazil), at a temperature of 60 °C for 8 h. Afterwards, they were stored, protected from light, at room temperature (25 °C), until the analysis.

2.2.3. Product characterization

Characterization of the three different types of rice was carried out, in addition to plant-based milks produced and residues generated in the process.

Moisture content was quantified according to the methodology described by Association of official agriculture chemists (2005). Samples were submitted to drying in an oven with controlled air circulation (MA035/1, Marconi, São Paulo, Brazil), at 70 °C for 24 h, and the results expressed in percentage of moisture on a wet basis. Ash was determined by incineration in a muffle furnace (Q318M, Quimis, Diadema, SP, Brazil) at 550 °C (Association of official agriculture chemists, 2005), and the results expressed as ash percentage. Lipids were determined by cold extraction (Bligh & Dyer, 1959) and expressed as lipid percentage. For protein determination, the micro Kjeldahl method was used and the result was calculated considering the conversion factor used for rice (5.95) and expressed as protein percentage. Total carbohydrate content was calculated by the difference (Nifext Fraction). The total caloric value was calculated by multiplying values of lipids, proteins and carbohydrates by the Atwater constants and expressed in kcal/100 g sample.

Water activity (Aw) was determined with direct reading in a digital hygrometer (Aqualab, Decagon, 3. 0 Series). pH was evaluated by direct reading with a potentiometer (mPA-210, MS TECPON Equipamentos Especiais, Piracicaba, SP, Brazil), with the dilution of 10 g of sample in 100 mL of distilled water. Titratable acidity was determined by titration with sodium hydroxide (Association of official agriculture chemists, 2005) and results expressed in % citric acid. The soluble solids content of milks was determined by reading in a bench-top refractometer, type Abbe (RTA100, Instrutherm, São Paulo, Brazil), and expressed in °Brix.

The color was determined by instrumental method, using a digital colorimeter CR 400 (Konica Minolta, New Jersey, USA), with determination of L* values (luminance parameter), a* (green to red color variation parameter) and b* (blue to yellow color variation parameter). A volume of 50 mL of samples (rice, plant-based milk and residue) was placed in a Petri dish and the reading was carried out at five different points. For comparison purpose, the color of commercial soy milk without added sugar was determined. With a* and b* values the chromaticity (C*) was calculated (Equation (6)). The color difference (ΔE) was calculated from the data obtained, considering commercial soy milk without added sugar as standard (Equation (7)).

$$C^* = \sqrt{a^{*2} + b^{*2}} \qquad \text{(Equation 6)}$$

$$\Delta E = \sqrt{\left(a_2^* - a_1^*\right) + \left(b_2^* - b_1^*\right) + \left(L_2^* - L_1^*\right)} \qquad \text{(Equation 7)}$$

The viscosity of the final products was determined by instrumental method, using a Brookfield viscometer model DV II + Pro (Brookfield, São Paulo, Brazil) with a coupled thermostatic bath to control samples temperature. The analysis was performed at a temperature of 25 °C with a rotation speed of 100 rpm and readings were obtained after 1 min, to ensure milks' optimal stability (parameters defined after pre-tests). A device for small samples was used, with the aid of the SC4-34 spindle. Results are presented in mPa.s. For comparison purposes, the analysis was performed under the same conditions on commercial soy milk without added sugar.

For the determination of phenolic compounds and antioxidant activity, extracts from rice, prepared milk and process residues were prepared according to Rufino et al. (2007a). The total phenolic compounds determination followed the Folin and Ciocalteau (1927) method, developed by Singleton and Rossi Junior (1965), in triplicate, using gallic acid as standard. Results were expressed in mgGAE/100 g. The antioxidant activity determination was evaluated by reduction of the free radical $DPPH^{\bullet}$ (1,1-diphenyl-2-picryl-hydrazyl) (Rufino et al., 2007a), expressed in g/g $DPPH^{\bullet}$ and by the capture of the free radical $ABTS^{\bullet +}$ [2,2-azinobis (3- ethylbenzothiazoline-6-sulfonic acid)] (Rufino et al., 2007b), expressed in μM trolox/g.

2.2.4. Statistical analysis

Results were analyzed separately (rice grains, rice milk, and residues). All analyses were performed in triplicate and results presented as a mean standard deviation (n = 3). For statistical analysis, one-way analysis of variance (ANOVA) followed by Tukey's test ($P < 0.05$) was carried out to determine differences among samples. STATISTICA 9.0 for Windows (StatSoft, Inc., Tulsa, OK, USA) was used for this purpose.

3. Results and discussion

3.1. Rice hydration kinetics

Moisture increase overtime on different types of rice (white, black and red) submerged in water are shown in Fig. 1a. All three types of rice studied showed typical behavior of cereals when subjected to hydration, which is to absorb water until an equilibrium moisture is reached. It was observed that in the first hours of hydration, grains had a higher absorption rate, tending to decrease with time, as the equilibrium moisture gets closer. Botelho, Corrêa, Goneli, Martins, and Baptestini (2010) studied the water absorption of rice during parboiling and concluded that the increase in temperature contributes to the increase in water absorption rate. However, this study aims at the use of grains for the development of plant-based milks that have functional and nutritional properties, and some important compounds may be degraded with the increase in hydration water temperature.

The adjustment of values observed in this study to values estimated by the linearized Peleg model can be seen in Fig. 1b and confirmed through values obtained for mean relative error (P), standard deviation of the estimate (SE) and determination coefficient (R^2), presented in Table 1.

All rice varieties studied showed satisfactory fit with R^2 above 99%, as well as P values lower than 3. Thus, it is possible to describe the hydration process of rice (white, black or red) through the Peleg mathematical model.

In regards to the mass transfer rate, low values for the Peleg C_1 constant indicate a higher initial rate of water absorption by the product (Turhan, Sayar, & Gunasekaran, 2002). Thus, white rice has a higher water absorption rate at the beginning of the process, when compared to black and red rice. This fact can be observed both through the values of C_1 constant (Table 1) and through the increase in grain moisture shown in Fig. 1a and b.

C_2 constant indicates the maximum capacity that the product has to absorb water. Products with a lower C_2 value are able to absorb more water in a hydration process. This can be seen in Fig. 1a and b, where red rice showed less water absorption, followed by black and white rice. This difference may also be related to grains chemical and physical composition as they were subjected to hydration in whole.

The equilibrium moisture (U_e) of rice grains was 11.14, 11.32 and 11.31 100 kg_a/kg_{ms} for white, black and red rice, respectively. Based on this result, the hydration time of rice grains for the production of plant-based milks was determined, since U_e was reached after 6 h of hydration for all samples. After this period, the grain water absorption rate was very low so it is preferable to complete the hydration process so the rice can move on to the next process stages, increasing efficiency and saving time.

3.2. Rice characterization

The characterization of the three different types of rice is shown in Table 2. White rice had lower moisture content showing statistical difference from the other rice types (black and red). The maximum moisture content in white rice is 14% were in accordance with technical regulations for rice (BRAZIL, 2009). The low amount of water is a common feature in several grains, such as soybean (Coutinho, Omoto, Andrade, & Jorge, 2005) or peas (Omoto, Andrade, Jorge, Coutinho, & Paraíso, 2009), not adding extra weight during transport and storage, increasing its economic viability. The same was observed in water activity of samples where red rice had a higher value for this parameter (0.5825 ± 0.0025), which is still below 0.600 and indicates that rice grains can be microbiologically stable, since the microbial growth rate in this water activity range is low (Fennema, Damodaran, & Parkin, 2010).

The ash content showed statistical difference between all samples studied, with black rice with higher amount (1.66 ± 0.01%), followed by red rice (1.23 ± 0.03%) and white rice (0.54 ± 0.07%). Renuka,

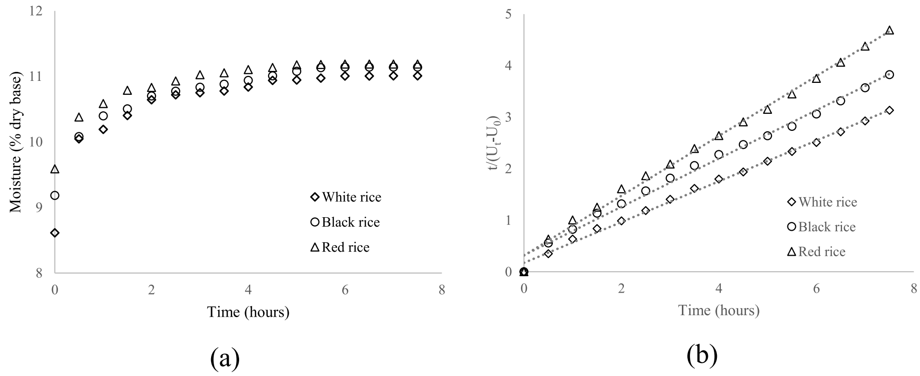

Fig. 1. Moisture of different types of rice subjected to hydration (a) and values observed and estimated by the linearized Peleg model (b).

Table 1
Peleg model parameters and equilibrium moisture of different types of rice subjected to hydration.

Rice	C_1 (100 h kg_{ms}/kg_a)	C_2 (100 kg_{ms}/kg_a)	U_e (100 kg_a/kg_{ms})	R^2 (%)	P (%)	SE (100 kg_a/kg_{ms})
White	0.1744	0.3951	11.1440	99.61	2.7545	0.0609
Black	0.3202	0.4687	11.3158	99.12	2.9394	0.1091
Red	0.3163	0.5801	11.3129	99.45	2.7061	0.1059

C_1 and C_2: Peleg constants; Ue: Equilibrium moisture; R^2: Determination coefficient; P: Mean relative error; SE: Estimate standard deviation.

Sarika, Mathure, Zanan, and Thengane (2016) studied the mineral composition in rice, found that this product can be considered a source of important micronutrients in the diet, specially iron, zinc, calcium, magnesium.

There was a significant difference in the lipid content of red and black rice; white rice was statistically similar to the others for this parameter. Walter et al. (2008) indicated that lipids in grains are influenced by their genotypic characteristics. Despite the low lipid content present in this cereal, it has saturated and unsaturated fatty acids that act in physiological processes of the human body and need to be supplied by the diet.

Rice has an average of 7% protein (Walter et al., 2008), being considered a low-protein food; however, the content of this nutrient varies according to the grain variety and cultivation methods. This can be confirmed with the difference shown in the amount of proteins in white (9.88%), black (8.52%) and red (7.62%) rice (Table 2).

The main constituents of rice are carbohydrates, which represent more than 80% of the product, being basically composed of starches. According to Frei, Siddhuraju, and Becker (2003) the starch concentration varies due to genetic, environmental and cultivation factors, as

Table 2
Characterization of white, black and red rice grains based milks produced, without heat treatment (ST) and pasteurized (^{P}), and residues from the filtration.

	Moisture (%)	Ash(%)	Lipids(%)	Proteins (%)	Carbohydrates (%)	Total caloric value [a]	Aw	pH	Titratable acidity(%)	Soluble solids (°Brix)
Rice										
White	7.93 ± 0.08^{b}	0.54 ± 0.07^{c}	0.49 ± 0.09^{ab}	9.88 ± 0.05^{a}	81.11 ± 0.08^{b}	368.38 ± 0.78^{a}	0.5030 ± 0.0010^{c}	6.28 ± 0.02^{b}	1.85 ± 0.05^{c}	–
Black	8.41 ± 0.01^{a}	1.66 ± 0.01^{a}	0.35 ± 0.04^{b}	8.52 ± 0.33^{b}	80.86 ± 0.09^{c}	360.71 ± 1.33^{b}	0.5615 ± 0.0055^{b}	6.35 ± 0.01^{a}	4.21 ± 0.08^{a}	–
Red	8.75 ± 0.32^{a}	1.23 ± 0.03^{b}	0.60 ± 0.03^{a}	7.62 ± 0.19^{c}	82.06 ± 0.06^{a}	364.13 ± 1.12^{c}	0.5825 ± 0.0025^{a}	6.34 ± 0.05^{a}	3.12 ± 0.02^{b}	–
Plant-based milk										
WhiteST	87.39 ± 0.01^{c}	0.13 ± 0.00^{c}	0.42 ± 0.04^{c}	1.48 ± 0.03^{b}	11.33 ± 0.06^{b}	52.03 ± 0.14^{c}	0.974 ± 0.001^{d}	5.94 ± 0.01^{e}	0.38 ± 0.06^{c}	0.4 ± 0.06^{b}
White^{P}	94.22 ± 0.89^{a}	0.12 ± 0.01^{c}	0.15 ± 0.02^{d}	1.52 ± 0.02^{b}	4.43 ± 0.42^{e}	24.21 ± 0.94^{f}	0.983 ± 0.001^{c}	6.22 ± 0.01^{c}	0.27 ± 0.09^{c}	0.4 ± 0.05^{b}
BlackST	88.19 ± 0.18^{c}	0.34 ± 0.01^{a}	0.51 ± 0.01^{c}	1.69 ± 0.09^{a}	10.13 ± 0.02^{c}	47.85 ± 0.48^{d}	0.982 ± 0.001^{bc}	6.17 ± 0.01^{d}	0.96 ± 0.06^{b}	0.8 ± 0.10^{a}
Black^{P}	90.41 ± 0.08^{b}	0.36 ± 0.03^{a}	0.57 ± 0.01^{bc}	1.75 ± 0.00^{a}	6.95 ± 0.04^{d}	39.91 ± 0.20^{e}	0.984 ± 0.001^{bc}	6.25 ± 0.01^{b}	1.57 ± 0.46^{a}	0.8 ± 0.11^{a}
RedST	87.00 ± 0.94^{c}	0.24 ± 0.00^{b}	1.02 ± 0.17^{a}	1.19 ± 0.01^{c}	12.52 ± 0.02^{a}	62.71 ± 0.79^{a}	0.983 ± 0.001^{b}	6.22 ± 0.01^{c}	0.46 ± 0.07^{bc}	0.9 ± 0.05^{a}
Red^{P}	84.66 ± 0.67^{d}	0.25 ± 0.00^{b}	0.72 ± 0.05^{b}	1.14 ± 0.11^{c}	10.92 ± 0.38^{b}	56.04 ± 0.06^{b}	0.987 ± 0.001^{a}	6.27 ± 0.01^{a}	0.71 ± 0.04^{bc}	0.9 ± 0.05^{a}
Residues										
White	4.11 ± 0.10^{b}	0.45 ± 0.01^{c}	0.45 ± 0.07^{b}	7.56 ± 0.32^{c}	87.43 ± 0.49^{a}	384.05 ± 0.10^{b}	0.248 ± 0.005^{b}	5.93 ± 0.07^{b}	1.65 ± 0.07^{c}	–
Black	2.13 ± 0.04^{c}	1.19 ± 0.07^{a}	1.81 ± 0.16^{a}	10.75 ± 0.02^{b}	84.12 ± 0.06^{b}	395.13 ± 0.63^{a}	0.195 ± 0.000^{c}	6.20 ± 0.02^{a}	3.98 ± 0.09^{a}	–
Red	7.85 ± 0.56^{a}	0.99 ± 0.04^{b}	2.05 ± 0.13^{a}	12.39 ± 0.08^{a}	76.73 ± 0.64^{c}	374.01 ± 0.70^{c}	0.527 ± 0.002^{a}	6.11 ± 0.07^{a}	2.61 ± 0.07^{b}	–

Results were analyzed separately (rice, plant-based milk, and residues). Means followed by the same letter, in the column, do not differ significantly from each other by the Tukey test, at the 5% level.

[a] (kcal/100 g).

observed in this study, in which the different types of rice presented a significant difference between them (Table 2).

pH values ranged from 6.28 (white rice) to 6.35 (black rice), indicating that the product is close to neutrality (7.0). The titratable acidity showed higher result for black rice (4.21%) and all samples showed a statistical difference between them at the 95% significance level. Together with the low water activity presented by rice, the acidity of a food acts as an agent to combat microbial growth, which is an important determining factor (Ordonez, 2005).

3.3. Plant-based milk characterization

Plant-based milks from three different types of rice (white, black and red) were developed. Milks produced were submitted to two types of heat treatments, pasteurization (65 °C/30 min) and sterilization (120 °C/20 min). However, milks submitted to sterilization showed a solid texture, invalidating the use of this treatment for the production of plant-based milks. This heat treatment possibly gelatinized the starch present in the product to the point where it remains solid and cannot return to a liquid state, since the starch, after gelatinized and subsequently cooled, undergoes a retrogradation process, which is irreversible. Since there is no standardization of heat treatments in plant-based milk, this test was important to demonstrate that sterilization did not prove to be efficient in rice milk. However, the technique can be indicated when dealing with other food products such as flan or pudding. In addition, the product obtained, due to characteristics of the gel formed, can be used in products that require studies on freezing and thawing cycles, since it was able to retain a large amount of water, with no syneresis observed during the gel characterization. Therefore, Table 2 shows the composition of plant-based milks produced from different types of rice, with and without heat treatment.

The moisture content of samples ranged from 84.66% (pasteurized red rice) to 94.22% (pasteurized white rice). Soares Junior et al. (2010) observed a moisture content of 77.99% and 79.73%, respectively when working on the development of broken rice and brown rice plant-based milks,. The difference with values obtained in this work is related to both the initial moisture of vegetables and the amount of water used in the process.

The ash content did not differ significantly between samples submitted to heat treatment and samples not submitted to heat treatment, but there was statistical difference between different rice types. This difference is in line with the ash content found in the raw materials. Pasteurization impacted the percentage of lipids in samples, lowering it in milks made from white and red rice and keeping it statistically equal in black rice. This loss of lipids during heat treatment is justified by oxidation reactions that occur in fats with the use of temperature. The plant-based milks had lipid contents $\leq$1.02%, which highlights their advantageous consumption in relation to the animal version, which has an average of 4.20% fat (Voges, Thaler Neto, & Kazama, 2015).

Plant-based milks based on different types of rice had a protein content ranging between 1.14 $\pm$ 0.11 and 1.75 $\pm$ 0.00%, and pasteurization did not significantly influence the protein level in samples (Table 2). Values found support plant-based milks produced with whole rice (1.55%) and broken rice (1.42%) (Soares Junior et al., 2010). Faccin et al. (2009) found higher protein values in plant-based milks produced with broken rice; however, they were flavored with coconut and strawberry, explaining the difference with those obtained in this study.

The carbohydrate content, as well as the total caloric value of plant-based milks were significantly influenced by pasteurization. Indicating that there was degradation of carbohydrates during the heat treatment applied to the products.

The pH of plant-based milks increased in function of pasteurization, and these results are aligned with the titratable acidity values, which had the same trend (Table 2). The soluble solids content did not show statistical difference between the samples with or without pasteurization, however, milks produced from white rice had lower soluble solids values (Table 2).

3.4. Residue characterization

Residues obtained in the filtration of plant-based milks were dehydrated (60 °C/8 h). Their composition is shown in Table 2. Moisture analyses on the residues showed statistical difference between samples, with the residue from red rice milk having higher moisture content (7.85%). These results are aligned with the current Brazilian legislation for vegetable flours, as it can be used as a flour, which defines a 15% moisture limit for this type of product (BRAZIL, 1978).

Following what happened with rice, residues' analyses showed statistical difference in ash, lipids, proteins and carbohydrates content. Comparing the protein content of the residues with the amount in plant-based milks and in the raw materials (Table 2), it is possible to observe that proteins in white rice dissociated better in the production of milks, since this was the most proteinaceous rice compared to the others studied. However, red rice, which has a lower amount of protein in its composition, generated a residue rich in this nutrient. Possibly their proteins did not dissociate properly in the product development process.

The characterization of residues from the food industry is needed for their proper use, for use in other processes or even for application in the development of new food products such as cereal bars (Damasceno, Gonçalves, Pereira, & Costa, 2016), cookies (Gassi et al., 2016), among others, thus taking advantage of integral food nutrients and avoiding the disposal of waste with high nutritional value, ensuring the process sustainability.

3.5. Color

The pasteurization of plant-based milks did not significantly impact the white rice-based milk luminosity; however, there was a significant change in this parameter in black- and red-based milk (Table 3). This change in luminosity comes from the impact of temperature on the product, which causes browning reactions in foods.

Compared to commercial soy milk without added sugar, milks made from black rice showed greater difference in color (ΔE), followed by red rice and white rice milk.

The rice color determination and the residues coming from the process can be seen in Table 3. Results showed that there was a lightning of the rice after processing, thus generating residues with higher luminosity values (L^*). The change in color of these cereals during their processing is related to the degradation of compounds present in the raw material, causing changes in the food color. Hayashi and Yanase (2016), while studying the color change of red rice during storage, found that the change in this parameter is related to the oxidative degradation of proanthocyanidins present in the grain.

3.6. Viscosity

Pasteurization impacted significantly the apparent viscosity of plant-based milks based on different rice types (Fig. 2). All analyzed samples showed a statistical difference between them, at the 95% significance level.

It is observed that after heat treatment, all plant-based milk samples showed higher viscosity. Greater stability in this parameter can be seen by the standard deviation, which is smaller in pasteurized samples. Probably, with the increase in temperature during pasteurization, the starch present achieved its complete gelatinization and remained stable, also stabilizing the mixture. Faccin et al. (2009), while studying the effects of temperature on the viscosity of broken rice vegetable milks, concluded that there is an increase in this parameter with increasing temperature, which is a typical characteristic of cereal starches.

Commercial soy milk without added sugar had an apparent viscosity of 13.9 mPa s, which was above the value found for black rice-based milk untreated (5.0 mPa s).

Table 3
Color parameters of plant-based milks based on different rice types, without heat treatment (ST) and pasteurized (^{P}), different rice types and residues from the production of plant-based milks based on these cereals.

	L[a]	a[a]	b[a]	C[a]	ΔE
Plant-based milk					
WhiteST	83.61 ± 0.46^{a}	−2.14 ± 0.08^{g}	2.92 ± 0.18^{e}	3.62 ± 0.18^{g}	15.40
White^{P}	84.59 ± 0.53^{a}	−1.44 ± 0.03^{f}	4.12 ± 0.06^{d}	4.37 ± 0.06^{f}	14.62
BlackST	30.19 ± 0.58^{e}	10.37 ± 0.34^{c}	−0.95 ± 0.10^{f}	10.41 ± 0.33^{d}	50.91
Black^{P}	28.11 ± 0.63^{f}	7.05 ± 0.14^{d}	−0.94 ± 0.05^{f}	7.12 ± 0.14^{e}	52.42
RedST	61.67 ± 0.16^{c}	12.03 ± 0.16^{b}	14.24 ± 0.25^{b}	18.64 ± 0.09^{a}	18.69
Red^{P}	51.40 ± 0.57^{d}	13.81 ± 0.17^{a}	11.67 ± 0.18^{c}	18.08 ± 0.15^{b}	28.86
Commercial[a]	77.35 ± 0.13^{b}	2.09 ± 0.20^{e}	16.34 ± 0.07^{a}	16.47 ± 0.04^{c}	–
Rice					
White	78.70 ± 0.25^{b}	1.73 ± 0.04^{e}	16.10 ± 0.03^{b}	16.19 ± 0.02^{b}	[b]
White^{Residue}	97.28 ± 0.24^{a}	0.23 ± 0.04^{f}	7.19 ± 0.13^{d}	7.19 ± 0.13^{d}	20.66
Black	23.83 ± 0.34^{f}	2.63 ± 0.17^{d}	−1.25 ± 0.05^{f}	2.91 ± 0.13^{e}	[b]
Black^{Residue}	45.83 ± 0.22^{d}	9.21 ± 0.09^{c}	0.33 ± 0.03^{e}	9.22 ± 0.10^{c}	23.02
Red	40.36 ± 0.29^{e}	14.73 ± 0.18^{a}	16.86 ± 0.25^{a}	22.40 ± 0.30^{a}	[b]
Red^{Residue}	70.43 ± 0.40^{c}	9.59 ± 0.08^{b}	13.26 ± 0.15^{c}	16.37 ± 0.16^{b}	30.71

Results were analyzed separately (rice, and Plant-based milk). Means followed by the same letter, in the column, do not differ significantly from each other by the Tukey test, at the 5% level.

[a] Commercial soy milk without added sugar.

[b] The color difference was calculated assuming each type of rice as a standard for its respective residue.

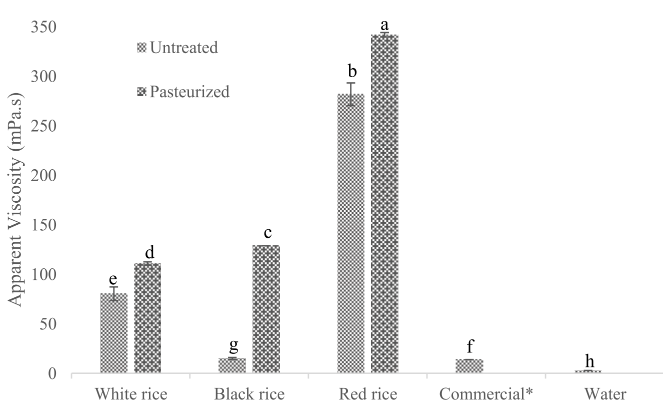

Fig. 2. Apparent viscosity of plant-based milks based on different rice types, untreated and pasteurized. *Apparent viscosity of commercial soy milk without added sugar. Columns with the same letter do not differ significantly from each other by Tukey test, at the 5% level.

3.7. Phenolic compounds and antioxidant activity

There was a significant difference in the phenolic compounds content in the different rice types studied (Fig. 3a), with black rice showing a higher amount (122.05 mg GAE/100 g). Pedro, Granato, and Rosso (2016) found a higher value of phenolic compounds in black rice, a difference that can be explained by the extraction method (extracts made with 1.0 mol/L ethanol and citric acid at different extraction times and temperatures) and location where the analyzed material was acquired, since the environmental, climatic and agronomic conditions influence vegetable characteristics.

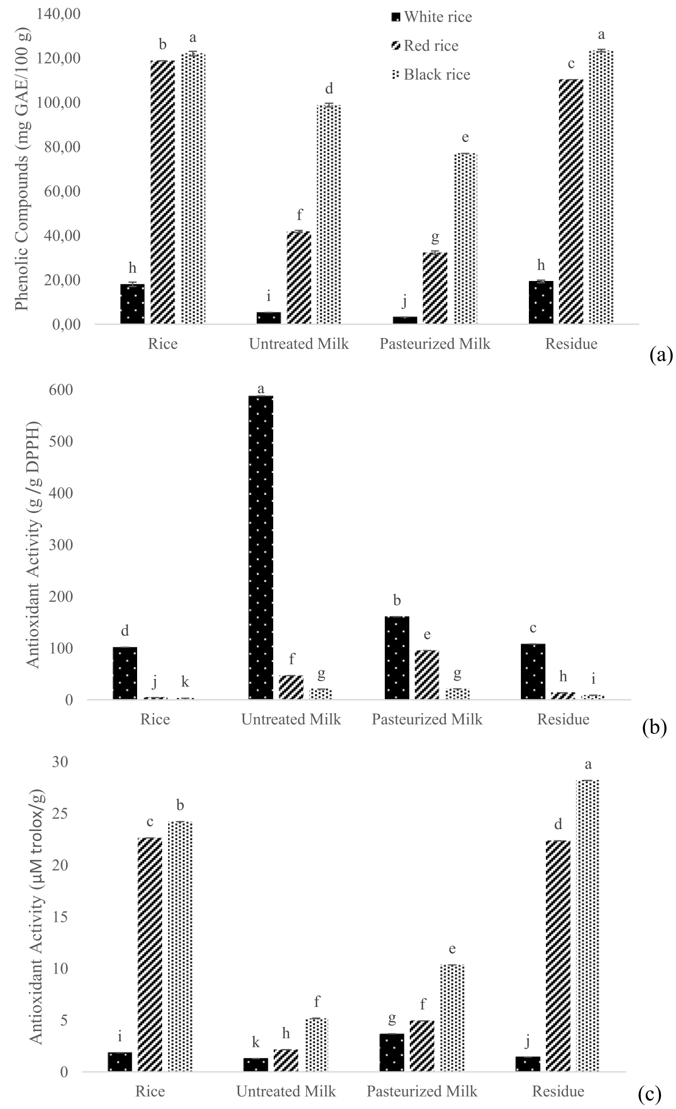

Fig. 3. Phenolic compounds (a) and antioxidant activity by DPPH (b) and ABTS (c) of different types of rice, plant-based milks and process residues. Columns with the same letter do not differ significantly from each other by Tukey's test, at the 5% level.

The same difference among rice types was observed in plant-based milks and in process residues. Analyzing the non-pasteurized and pasteurized plant-based milks, it is possible to verify that the application of slow pasteurization method is effective in maintaining a final product with a significant amount of phenolic compounds. The same was observed by Bhawamai, Lin, Hou, and Chen (2016) during black rice cooking, where most of the compounds were retained even after heating the samples. In addition, it is observed that residues generated in the process also have these compounds, and residues of white and black rice do not show statistical difference from their raw materials.

Following the same trend of the amount of phenolic compounds, the antioxidant activity of rice, plant-based milk and residues can be seen in Fig. 3b and c. To indicate that a product has antioxidant capacity, it is necessary to perform the test with more than one method. Therefore, the different types of rice studied, as well as their plant-based milks and residues presented antioxidant activity against DPPH$^{\bullet}$ and ABTS$^{\bullet+}$ free radicals.

Black rice milk after pasteurization showed no statistical difference for its antioxidant activity by the DPPH• method, indicating that the use of heat for product conservation does not affect its antioxidant capacity. The antioxidant activity indicates that a product has the ability to neutralize free radicals in the organism, thus being able, in the right dosage, to present benefits to human health, such as prevention of premature aging.

The production of rice-based milks is a viable alternative for the inclusion of products in the human diet with significant antioxidant capacity, fighting free radicals and acting in the prevention of diseases.

Residues from the processing of rice-based milks showed high antioxidant activity against the free radicals tested. Mau et al. (2017) while using black rice flour in cake formulations, verified a significant contribution of bioactive compounds in the elaborated product. This reinforces the importance of using these in the development of co-products, so that the complete use of the present components is possible, in addition to ensuring a sustainable process, without the generation of waste.

4. Conclusion

It is possible to develop plant-based milks based on white, black and red rice. White, black and red rice grains fit satisfactorily in the Peleg model as their hydration and equilibrium moisture content is 11.14; 11.32 and 11.31% dry basis, respectively, requiring 6 h for grain hydration in water at 25 °C. Slow pasteurization is the most suitable heat treatment for this type of product when compared to the sterilization technique. The different types of rice, as well as their vegetable milks and residues, had a high content of phenolic compounds, presenting 122.05, 77.03, and 123.41 mg GAE/100 g for black rice, its vegetable milk, and residue, respectively. In addition, we had the most significant results in antioxidant capacity to black rice, and its products. Black rice presented 3.28 g/g DPPH and 24.22 μM trolox/g, by the DPPH• and ABTS•+ free radical method, respectively. The produced residue has shown important properties and it has a great potential to be applied in other products in order to avoid waste and ensure a sustainable production process.

CRediT authorship contribution statement

Luan Ramos da Silva: Formal analysis, Investigation, Data curation, Writing – original draft, preparation, Methodology. **José Ignacio Velasco:** Validation, Investigation, Resources, Writing – review & editing, Supervision, Funding acquisition. **Farayde Matta Fakhouri:** Conceptualization, Methodology, Validation, Investigation, Writing – review & editing, Supervision, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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