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Preparation of An Instant Drink: Extruded Flour of Polished Red Rice (Oryza Sativa L) and Blackberry (Rubus Spp) Retentate By Microfiltration

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ABSTRACT

Red rice (Venetian rice or rice-da-terra) was first introduced to Brazil by Portuguese colonizers in the 17th century. Its cultivation is now limited to small areas in the Northeast, particularly in Paraíba, Rio Grande do Norte, and Pernambuco. This study aimed to develop an easy-to-reconstitute beverage using red rice flour, enhanced with a co-product from blackberry juice clarification through membrane microfiltration (blackberry retentate powder). The red rice flour was processed in a Clextral twin-screw extruder under controlled conditions and dried at 60°C to less than 4% moisture. Using the central composite rotational design and response surface methodology, 13 treatments were tested to optimize physicochemical properties like proximate composition, amino acids, minerals, anthocyanins, and expansion indices (REI, VEI, LEI). Water absorption and solubility indices (WSI, WAI) and paste viscosity were also evaluated. Three treatments were selected for producing beverages, which underwent sensory evaluation by trained tasters. Results showed red rice's superior nutritional value compared to white rice, particularly in amino acid and mineral content. The formulated beverage, containing pre-cooked red rice and blackberry powder as a functional ingredient, was well-received for its ease of reconstitution and sensory qualities.

Keywords: Food extrusion, characterization physic-chemical, anthocyanin, formulated beverage, by-products.

INTRODUCTION

According with Almeida, (2004), the red rice Oryza sativa L. is a traditional crop in some areas of Brazil, Argentina, Venezuela, Madagascar, Mozambique, Sri Lanka, India, Nepal, Bhutan, Japan and South Korea, and other countries. Among the 23 classified species of the Oryza L. genus, only two are cultivated, but all of them may present grains with the red pericarp. The cultivated species are Oryza glaberrima Steud, and Oryza sativa L. The former is originated from West Africa and its cropping is restricted to the African Continent. The later has its origin center in the Southeast Asia and is now being planted in more than a hundred countries. Besides having red grains, O. sativa L. presents white grains, that is, in fact, the type that is prevailing cultivated type.

Red rice is a versatile and nutritionally rich grain that offers numerous benefits over traditional white rice. Its unique physicochemical properties make it suitable for a variety of food products, and its health benefits, particularly its antioxidant content, make it a valuable addition to any diet. As the demand for healthy and functional foods continues to grow, red rice is poised to become an increasingly popular choice in both culinary and health-related applications. Red rice is a distinctive variety of rice known for its reddish-brown color, which comes from the anthocyanin pigments in its outer layers. This variety of rice is gaining attention for its unique physicochemical properties, diverse uses, and considerable nutritional benefits, Kothapalli, et al., (2023). In this work, were studied the properties of red rice, its applications in food products, its nutritional advantages compared to white rice, and other potential uses. Red rice has several physicochemical properties that differentiate it from other rice varieties. The presence of anthocyanins not only gives it its characteristic color but also contributes to its antioxidant properties. These antioxidants are known to help reduce oxidative stress in the body, which is linked to a lower risk of chronic diseases. The grain itself is often more robust than white rice, with a slightly nutty flavor and a chewy texture when cooked. The bran layer, which remains intact in red rice, contains a high level of dietary fiber, vitamins, and minerals. The amylose content in red rice can vary, but it generally has a moderate glycemic index, making it a healthier choice for managing blood sugar levels (Mazumdar, et al., 2022; Safitri, & Fatchiyah, 2021; Kaur, et al., 2015).

Red rice is versatile in its applications. Traditionally consumed as a whole grain, it can be used in a variety of dishes ranging from salads and pilafs to soups and stews. The unique texture and flavor of red rice make it a popular choice in gourmet cooking and health-conscious recipes. Beyond its use as a whole grain, red rice is increasingly being processed into other food products. It can be ground into flour, which is used in baking and as a gluten-free alternative in various recipes. Red rice flour is also used in the production of noodles, pasta, and snacks, offering a nutritious alternative to products made from refined white flour. Red rice is nutritionally superior to white rice due to its higher content of vitamins, minerals, and antioxidants. It is particularly rich in magnesium, iron, and zinc, which are essential for various bodily functions 9 Kothapalli, et al, 2023). The fiber content in red rice is significantly higher than that of white rice, promoting better digestive health and aiding in weight management, Ronie, et al., 2022; Finocchiaro, et al., (2007).

Comparatively, red rice has a lower glycemic index than white rice, making it a better option for individuals with diabetes or those looking to control their blood sugar levels. The presence of anthocyanins, which are absent in white rice, provides additional health benefits, including anti-inflammatory and anti-cancer properties, Saleh et al., (2019).

When compared to white rice, red rice stands out for its nutritional profile. White rice, which has been milled and polished to remove the bran and germ, loses many of its nutrients in the process. This leaves it with mostly carbohydrates and fewer vitamins and minerals. In contrast, red rice retains its bran and germ, ensuring that it maintains a higher nutritional content. Moreover, the fiber content in red rice helps in maintaining satiety, which can aid in weight management, whereas white rice may contribute to quick spikes in blood sugar due to its high glycemic index. Red rice also contains a higher level of proteins and essential amino acids compared to white rice, making it a more balanced food source, Safitri, & Fatchiyah, (2021).

The potential uses of red rice extend beyond direct consumption. Its flour can be used in the cosmetic industry for natural exfoliants and skincare products due to its antioxidant properties. Additionally, red rice bran oil, extracted from the bran layer, is rich in oryzanol and is used in culinary applications as well as in the production of health supplements. Furthermore, red rice is being explored for its potential in functional foods and nutraceuticals. The high antioxidant content makes it a candidate for food products aimed at health-conscious consumers, and research is ongoing into its role in preventing and managing lifestyle-related diseases, (Fitriyah, & Ayu, 2020).

MATERIAL AND METHODS

Red rice grains, processed, were supplied by Embrapa Mid-North, Teresina, PI, Brazil. The dry powder blackberry retentate was a byproduct of the microfiltration process and supplied by Pilot Plant II of Embrapa Food Technology. The red rice and white rice grains were milled to obtain a flour suitable for use in extrusion. Inputs such as maltodextrin, milk powder, whole milk, sugar, and flavoring were obtained from local stores.

The blackberry (Rubus spp.) retentate resulted from obtaining fruit juice, in which the wet solid resulting from microfiltration (MF) was collected for use. The juice was obtained from the pulping of blackberry fruits in a pulper with a 0.8 mm sieve and subjected to centrifugation processes. MF processing was performed in a system with a frame and plate module with fluorinated polymer-based membranes with a pore size of 0.15 μm (MF), polysulfone membranes with a cut-off of 20 kDa, and recirculation of the retentate stream and continuous collection of the permeate, at 35°C and pressure applied to the membrane of 5 bar (MF). The retentate product was dehydrated and finished in powder form.

Experimental Design

The experimental model used, (Table 1) aiming to reduce combinations and optimize the data collection and analysis process, was the central rotational composite design (BOX et al, 1987), and the independent variables, screw rotation (rpm, X_1) and heating zone temperature (°C, X_2), were analyzed. The combined effect of the variables was analyzed to observe their incidence on the determining factors of the physical properties and extrusion parameters. A statistically designed experiment is proposed using the 2nd order central rotational composite response surface methodology.

Table 1: Complete experimental design with coded and decoded levels.

Variables	**Levels**				
	$-\alpha$=1.41	**-1**	**0**	**+1**	**$+\alpha$=1.41**
X_1 (rpm)	300.00	358.58	500.00	64.42	700.00
X_2 (°C)	120.00	128.79	150.00	171.21	180.00

Treatment	**Levels of coded variables**		**Levels of coded decoded variables**	
	x_1	**x_2**	**X_1**	**X_2**
1	-1	-1	358.58	128.79
2	1	-1	641.42	128.79
3	-1	1	358.58	171.21
4	1	1	641.42	171.21
5	$-\alpha$	0	300	150
6	α	0	700	150
7	0	$-\alpha$	500	120
8	0	α	500	180
9	0	0	500	150
10	0	0	500	150
11	0	0	500	150
12	0	0	500	150
13	0	0	500	150

X_1 e x_1 = Rotação do parafuso (rpm); X_2 e x_2 = Temperatura (°C); $\pm \alpha = \pm 1.414$

Figure 1, shows the flowchart for obtaining extrudates based on polished red and white rice flour.

Statistical Analyses

The adjustment of the experimental data to the model used was tested by analysis of variance (ANOVA) using the F distribution test at 5% probability, according to which a regression model is significant when the value of the calculated F test is greater than or equal to that of the tabulated F test, and the higher the calculated F test, the more predictive the model (BOX and WETZ, 1973). The adequacy of the polynomial model was assessed by comparing the proportion of the explained variation ($R^2 \geq 0.70$). In the response variables that did not generate a predictive model or trend ($R^2 < 0.70$), the results were discussed by comparing the means analyzed by the Tukey test using the Xlstat program, version 7.5.

Data processing and statistical analysis were performed using the Statistica software, version 6.0, with the independent variables coded. The response surface graphs were drawn with the aid of the Statistica program, version 6.0, using the mathematical model proposed at the real levels of the variables, maintaining the response as a function of the Z axis, with the X and Y axes representing the independent variables, while the other variables were kept constant at the central point (corresponding to the coded level 0).

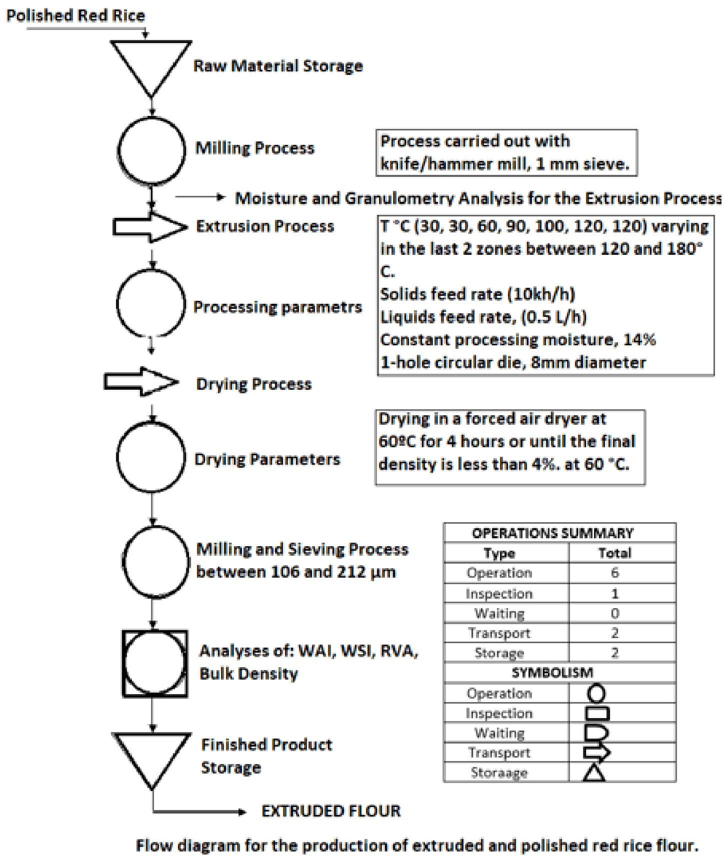

Figure 1: Flowchart of operations for obtaining red rice extrudates.

Thermoplastic Extrusion Process

To obtain the red and white rice extrudates, a *Clextral Evolun* HT25 twin-screw extruder (Firminy, France) was used. Controlled temperature conditions in the heating zones of the extruder barrel, solid feed flow rate (10 kg/h) and liquid feed flow rate (0.5 L/h), die diameter, and screw speed (300 rpm to 700 rpm). The parameters used in temperature control were: constant temperature in the first 8 heating zones (30, 30, 60, 90, 100, 100, 120, 120), varying in the last 2 zones between: 120°C to 180°C, for each treatment according to the proposed experimental design, constant processing moisture of 14%; and circular matrix with a hole of 8 mm in diameter.

Immediately after extrusion, the extrudates were collected, placed on trays and sent to the drying process in an oven with air circulation at a temperature of 60 °C for 4 hours, so that the final moisture content of the extrudates would reach a level below 4%. After the drying process, the extrudates were placed in plastic bags, sealed, labeled and stored in a dry place at room temperature for later use in chemical, physical and technological functional and sensory analyses. In order to perform some of the analyses, such as paste viscosity, water solubility index, water absorption index, centesimal composition, amino acid and mineral profile, it was necessary to grind the extrudates; initially, a Laboratory Mill 3600 disc mill was used, and later a hammer mill equipped with a 0.8 mm opening sieve, Perten 3100, was used, thus obtaining the extrudates flour.

Proximate Composition and Apparent Amylose Content, Mineral Composition and Amino Acid Profile

Proximate composition determinations were performed in duplicate following the methodologies described by the Association of Official Agricultural Chemists, AOAC (2010). Moisture was determined using AOAC (2010) method 925.09. Ash was determined according to AOAC (2005) method 923.03. Ether extract was determined according to AOAC (2005) method 945.38. Lipid content was determined according to AOCS methodology. Nitrogen content was determined using modified AOAC method 2001.11 (conversion factor 5.75), with total carbohydrate content calculated by difference; Total Carbohydrates = 100 – (moisture + ash + protein + ether extract). The mineral content was determined in duplicate by the Millestone microwave digestion method (USA) (AOAC, 2005, rev. 2010 - Method 999.10, item 9.1. 08) and was quantified following the procedures of the ICP-OES method - AOAC 2005, rev. 2010 - Method 990.08, item 9.2. 39 in an ICP spectroflama Flame plasma emission spectrophotometer, with the determination being made by atomic emission spectrometry, after complete digestion of the sample with nitric acid and perchloric acid. The amino acid profile was performed according to the AOAC 994.12/2000 and Liu, H. J.; Chang, B. Y. et al. Journal of AOAC International. 78(3): 736-744, 1995, determining the following essential amino acids: asparagine, glutamine, serine, histidine, glycine, threonine, alanine, arginine, valine, isoleucine, leucine, lysine and proline, as well as the sulfur amino acids phenylalanine + tyrosine, with the quantification of the amino acids being performed in a high-performance liquid chromatograph (HPLC), model Alliance, Waters 2695, with a fluorescence detector model Alliance, Waters 2475 (USA).

The amylose content was determined following the methodology described by Juliano et al, (1965), using the following classification scale: Waxy: 00% - 0.2%; Very low: 0.3% - 0.9%; Low: 10% - 19%; Intermediate: 20% - 25% and High: > 25%.

Determination of Anthocyanins in Red Rice and Blackberry Retentate

The samples were weighed (1g) and subjected to extraction following the methodology (SANTIAGO et al., 2010). Three extractions were performed in duplicate, and the extracts remained refrigerated in glass containers protected from light until the time of analysis. On the day of analysis, 1 mL aliquots were dried under a flow of compressed air and then resuspended in 200 µL of injection solution, 10% methanol in 10% formic acid. For the chromatographic analysis, a Waters® Alliance 2695 high-performance chromatograph, Waters® 2996 photodiode array detector, C18 column (150mm x 4.6mm; 3.5µm), flow rate of 1.0mL/min, injection volume of 50µL and gradient elution mode with methanol and 10% formic acid in aqueous medium (ARAUJO et al., 2008) were used. The blackberry retentate analyzed came from the stream retained in the microfiltration (MF) process. The sample was dried in an oven at 60°C. The material presented an intense violet coloration, appearing as a fine and fibrous tissue. Anthocyanin extractions were performed based on the extraction methodology of

Santiago et al. (2010). The analyses were performed using the same equipment described in item 3.2.3.2. The methodology used was developed by GOUVÊA (2011), which consists of gradient elution mode with solvent A (formic acid 5%) and solvent B (acetonitrile) flow of 1.3mL/min, C18 column (100 x 4.6 mm: 2.4µm) at 35°C and analysis time of 20 minutes.

Particle Size Distribution

The polished red and white rice flours were fractionated on a set of 8 sieves with openings of: 1000µm; 850µm; 600µm; 500µm; 420µm; 300µm; 212µm and bottom, and placed on a Granutest brand sieve shaker, model RO-TAP RX-29-10 for 10 minutes. The granulometric classification was performed in duplicate for each sample. Then, the contents retained on each sieve were weighed and expressed in retention percentages, following the standard procedure described by Germani, Benassi and Carvalho (1997).

Color Analysis

For the instrumental color analysis, 30g samples with particle sizes between 212µm and 106µm was used, and were performed by reflectance on the Color Quest XE device, CIELAB and CIELCh scale, with an aperture of 0.375mm in diameter, with illuminant D65/10, proposed by the Commission International de l'Eclairage, CIE (1978). The color parameters measured were: L = luminosity (0 = black and 100 = white); a = (-80 to zero = green, from zero to +100 = red); b = (-100 to zero = blue, from zero to +70 = yellow). The total color difference (DE) was calculated from equation 1, as follows:

$$\Delta E = \sqrt{(\Delta L)^2} + (\Delta a^2) + (\Delta b^2) \qquad \text{Equation 1}$$

The sample was placed in a 10 mm quartz cuvette to perform the test. Four repetitions were performed.

Expansion Index

The Radial expansion index, (REI), Longitudinal Expansion Index (LIE), and Volumetric expansion index (VEI) of the extrudates was calculated following the methodology described by Alvarez-Martinez et al. (1988).

Specific Mechanical Energy (SME)

The specific mechanical energy was calculated following the methodology described by Fane et al. (1996), according to equation 2:

$$SME = \frac{\tau.\omega 2\text{x}\pi\text{x}2}{S\text{x}60} \qquad \text{Equation 2}$$

Were, τ is the torque of the screws (N·m). To extruder Clextral Evolum HT 25 the τ =107, 6 N·m; ω is the rotation speed of the screws (rpm); S is the solids feed flow rate ($kg\cdot h^{-1}$).

Índice de solubilidade em água (WSI) e índice de absorção de água (WAI)

As determinações de WSI e WAI foram realizadas segundo os princípios básicos do método descrito por Anderson et al., (1969).

Pasting Viscosity

The paste viscosity of the flours was determined using a Rapid Visco Analyser (RVA), series 4, from Newport Scientific, equipped with Thermocline for Windows software, using its methodology for extruded materials. According to Becker et al., (2001), the difference in particle size between the samples can lead to misinterpretation of the results. Therefore, the authors recommend that the material be sieved to obtain particles between approximately 125 and 250 µm. Following this methodology, the extruded and dried samples were ground in a disc mill and sieved in a RO-TAP model RX-29-10 sieve shaker, with the fraction retained between the 212 and 106 µm sieves being used for this analysis, in duplicate, for each treatment. For analysis in the Rapid Visco Analyser – RVA, 3 g of extruded flour with moisture corrected to 14% (on a wet basis) will be added with distilled water until the final weight is 28 g (Ascheri, 2024).

The analysis profile used was “extrusion 1 no-alcohol”, characterized as follows: initially, the system was kept at 25 °C for 2 minutes. Heating occurred immediately afterwards and reached the maximum temperature (95 °C) at 7 minutes, where it remained for 3 minutes. Soon after, cooling began to a temperature of 25 °C again, totaling 20 minutes of analysis. The following parameters were used to interpret the amylograms: Initial viscosity or cold viscosity (VInitial): is the viscosity value in cP (Centipoise), at a temperature of 25 °C, at the beginning of the heating cycle; Maximum viscosity (Vmaximum.): is the viscosity value at the maximum point of the curve, obtained during the heating cycle, expressed in cP; Minimum viscosity after the heating cycle at 95 °C (Vminimum); Viscosity break (QV) or “Breakdown”: is the difference between the maximum and minimum viscosity during maintenance at 95 °C; Final viscosity in the cooling cycle (VEnd): is the viscosity value in cP, at the end of the analysis (at 25 °C); Tendency to retrogradation (TR) or “Setback”: is the difference between the final viscosity and the lowest viscosity value during maintenance at 95 °C.

Beverage Formulation

For the beverage formulation, the extruded flours with the best functional characteristics were chosen in terms of Water Solubility Index and Paste Viscosity. These flours are from treatments: T2, T6, and T7. The following ingredients were used to make the beverage: extruded polished red rice flour, sugar, powdered milk, maltodextrin, oat flour, dried blackberry powder retentate, and flavoring. The percentages of the ingredients were determined through sensory tests with trained tasters for the final formulation.

Sensory Evaluation

Preliminary tests were performed to adjust the percentage of ingredients in the formulations, through product characterization tests compared to commercial products and difference tests (triangular tests), using a team of selected tasters. The parameters analyzed were the preparation attributes (solubilization, homogeneity, and dissolution), appearance, flavor, and consistency. The triangular test is used to determine if there is a perceivable difference between two products. It helps assess if changes in formulation, ingredients, or processing affect the sensory characteristics of the product. The procedure includes, (a) Three samples are presented to participants—two identical and one different. (b) Participants are asked to identify the odd sample. (3) The samples are randomized to prevent bias. The results, if a significant number of participants correctly identify the odd sample, it indicates a perceivable difference between the products. Results are analyzed statistically to confirm if the observed differences are significant.

RESULTS AND DISCUSION

Proximate Composition, Mineral and Amino Acid Profile and Amylose Content

The results regarding the centesimal composition and amylose content of polished red rice flour and white rice flour are shown in Table 2.

The data provided in Table 2 gives us a comprehensive view of the proximate composition of polished red rice flour and white rice flour, revealing key differences in their nutritional profiles. This discussion will analyze these differences, considering the nutritional implications of each component, and highlight the overall nutritional potential of rice in human diets. White rice flour has a significantly higher moisture content than red rice flour. This increased moisture can affect both the texture and shelf-life of the flour. Typically, a higher moisture content in food products can reduce shelf stability, as it increases the susceptibility to microbial growth. Help reduce the risk of chronic diseases like cardiovascular disease and cancer. White rice, in contrast, has had its bran and germ removed, resulting in the loss of these valuable nutrients.

Glycemic Index and Energy Regulation:

The slightly lower amylose content in red rice may make it more digestible, providing quicker energy release compared to white rice. However, its higher protein, fat, and mineral content may help moderate blood sugar spikes, making it a better option for individuals managing their blood glucose levels, though both red and white rice should be consumed in moderation by those with diabetes or insulin resistance. Consequently, polished red rice flour generally offers superior nutritional benefits compared to polished white rice flour. It contains more protein, fat, and minerals, making it a more nutrient-dense option. While both types of rice provide essential carbohydrates, red rice's added benefits in terms of fiber, protein, and antioxidants make it a better choice for improving overall nutrition and addressing deficiencies in micronutrients such as iron and magnesium. However, both rice varieties have their place in a balanced diet, and their nutritional potential can be maximized by pairing them with other nutrient-rich foods to complement any deficiencies, especially in amino acids.

In contrast, the lower moisture content in red rice flour suggests that it may have a longer shelf-life and be more suitable for storage in dry conditions (Ribeiro-Filho, et al. 2024). About the Ash Content (Minerals), polished red rice flour whit 1.39% and white rice flour whit 0.34%. The ash content is a measure of the total mineral content in the flour. Polished red rice contains significantly more ash than white rice, which suggests a higher concentration of essential minerals, such as iron, calcium, magnesium, and potassium. This mineral content is important for various bodily functions, including bone health, nerve function, and enzyme activity. The rich mineral profile of red rice, particularly its iron content, can help address issues of micronutrient deficiencies, particularly in populations prone to anemia. About protein content, polished red rice flour whit 9.08%, white rice flour whit 6.67%. Polished red rice flour contains substantially more protein than white rice flour (Kothapalli et. al, 2023). Protein is an essential macronutrient that supports muscle growth, tissue repair, and enzyme production. The difference in protein content reflects the nutritional superiority of red rice in providing plant-based protein. This makes red rice a better option for individuals seeking to increase protein intake, especially in plant-based or vegetarian diets. However, it is also important to note that rice protein lacks certain essential amino acids, like lysine, and therefore should be combined with other lysine-rich foods such as beans or lentils for a complete protein source. Ether Extract (Fat Content), polished red rice flour, 1.58% and white rice flour, below detection limit. The ether extract represents the fat content of the flour. Red rice flour contains a detectable level of fat (1.58%), while white rice has an undetectable fat content (below 0.47%). Fats, while calorically dense, are essential for the absorption of fat-soluble vitamins (A, D, E, K) and provide essential fatty acids that are important for brain health and cell function. The presence of fat in red rice may also contribute to a better flavor profile and texture compared to white rice, although the difference is modest. Whit reference the total carbohydrates polished red rice flour whit 76.37% and white rice flour whit 78.19%. Carbohydrates are the primary energy source in rice. Both red and white rice have high carbohydrate content, but white rice has a slightly higher carbohydrate percentage. The difference in carbohydrate content is marginal, with red rice providing a slightly lower carbohydrate load due to its higher protein and fat content. Carbohydrates in rice are predominantly in the form of starch, which is digested to glucose, providing energy to the body (Paiva et al, 2014).

About the amylose content, polished red rice flour 16.41% and white rice flour whit 19.84%. Amylose is a component of starch that influences the texture and digestibility of rice. White rice has a higher amylose content compared to red rice. High amylose content is associated with firmer, less sticky rice after cooking, whereas lower amylose rice tends to be softer and stickier. Foods with lower amylose content, such as red rice, generally have a higher glycemic index (GI), meaning they may cause a quicker rise in blood sugar levels compared to foods with high amylose content like white rice. However, the difference in amylose content here is relatively small and may not drastically impact the glycemic response in most cases (Martínez & Añon, 1996).

Nutritional Potential and Health Implications:

About the fiber content, these varieties of rice offer significantly higher fiber content compared to polished white rice, which has about 3.0 to 5.0 grams of fiber per 100 grams. Incorporating these high-fiber rice varieties into the diet can improve digestive health, help regulate blood sugar, and contribute to overall cardiovascular health. They are ideal for individuals seeking a more nutrient-dense alternative to white rice. Whole-grain red rice is typically higher in dietary fiber because the bran and germ are retained. Fiber is critical for maintaining digestive health, regulating blood sugar, and lowering cholesterol levels (Camire et al., 1990). The fiber in red rice can contribute to satiety, which may help with weight management. Mineral Density, as discussed under ash content, red rice has a richer mineral profile, making it nutritionally superior for addressing micronutrient deficiencies. For instance, red rice often contains higher levels of iron and magnesium, which are essential for oxygen transport and muscle function, respectively. Vitamins and Phytochemicals. - Red rice is also a better source of certain vitamins and antioxidants, especially the anthocyanins responsible for its red pigmentation (Sumczynski, et al., 2016).

Table 2: Proximate composition and amylose content of raw polished red, white rice flours, extruded white rice flour, including the best treatments considered in the experimental design: T2, T6 and T7.

Components (g/100g)	**Polished Red Rice Flour**	**Flour White Rice Flour**	**Extruded white rice flour**	**T2**	**T6**	**T7**
Moisture	$11.58^{b} \pm 0.01^{\alpha}$	$14.80^{a} \pm 0.01$	$4.62^{de} \pm 0.06^{\alpha}$	$4.27^{e} \pm 0.04^{\alpha}$	$4.92^{e} \pm 0.23^{cd}$	$5.02^{e} \pm 0.23^{c}$
Ash	$1.39^{a} \pm 0.00$	0.34 ± 0.021^{d}	0.46 ± 0.01	$0.64^{b} \pm 0.01$	$0.62^{b} \pm 0.01$	$0.65^{b} \pm 0.02$
Protein*	$9.08^{a} \pm 0.37$	$6.67^{b} \pm 0.16$	$7.25^{a} \pm 0.08$	$7.22^{a} \pm 0.08$	$7.62^{a} \pm 0.04$	$7.85^{a} \pm 0.04$
Ether extract	1.58 ± 0.14	LD***	LD***	LD***	LD***	LD***
Total carbohydrates**	$76.37^{b} \pm 0.37$	$78.19^{a} \pm 0.18$	$87.67^{a} \pm 0.08$	$87.86^{a} \pm 0.04$	$87.27^{a} \pm 0.08$	$86.41^{a} \pm 0.04$
Amylose content	16.41 ± 0.20^{b}	19.84 ± 1.01^{a}	$19.90^{a} \pm 0.08$	$15.10^{a} \pm 0.26$	$15.62^{a} \pm 0.38$	$15.37^{b} \pm 0.29$
Dietary fiber (d.b.)	1.81 ± 0.18	1.41 ± 0.25	1.22 ± 0.35	1.92 ± 0.35	1.72 ± 0.22	1.82 ± 0.12

*Protein, conversion factor: 5.57. **Total carbohydrates calculated by difference: 100 – (moisture + ash + protein + ether extract). ***LD: below the detection limit. LD value of the method <0.47. $^{\alpha}$Average ± standard deviation of duplicate evaluations, means followed by the same letters, do not differ significantly from each other by Tukey's test at the 95% level. Best treatments trials: T2 (641.42 rpm /128.79 °C), T6 (700 rpm /150 °C) and T7 (500 rpm /120 °C).

Particle Size Results

Particle size is a fundamental parameter in food extrusion, influencing various aspects of the process and the quality of the final product. A thorough understanding of the relationship between particle size and extrudates properties allows food manufacturers to optimize processing conditions, improve product quality, and expand the range of products that can be produced through extrusion. The degree of cooking during extrusion is significantly influenced by the particle size of the raw materials (Martínez, et al, (1914). Smaller particles have a larger surface area relative to their volume, which allows for more efficient heat and mass transfer. This results in a higher degree of cooking, as starch gelatinization and protein denaturation occur more readily Carvalho, et al., 2010; Gao, Y., et al. 2018). Conversely, larger particles may not fully gelatinize, leading to a heterogeneous product with varying levels of cooking. Figure 2 shows the particle size and distribution values using different sieves. It can be seen that there are differences between polished white rice and polished red rice. This is also due to the fact that the mill was used under the same conditions. Evidently, these differences can cause variations in cooking degrees in the treatments, depending on the variation in the parameters in the extrusion system (Ilo, & Berghofer, 2003).

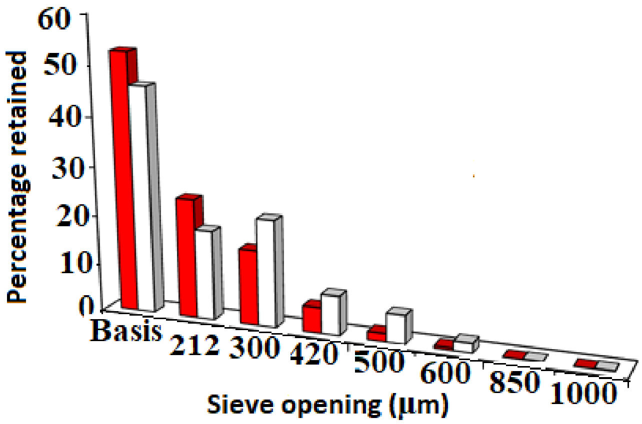

Figure 2: Distribution of red (🟥) and white (☐) rice flour particles.

Water diffusivity is a crucial principle in understanding how particle size affects the extrusion process. Smaller particles have a greater surface area-to-volume ratio, which enhances their ability to absorb water quickly. This rapid water absorption can lead to a more uniform and faster gelatinization of starches and hydration of proteins, contributing to a more consistent and thorough cooking process (Matínez et al., 2014; Gao et al, 2018)). Larger particles, however, absorb water more slowly due to their reduced surface area, which can result in uneven cooking and variations in texture and hardness within the extrudates. This difference in water absorption rates between particles of varying sizes directly affects the final product's structural integrity, expansion, and mouthfeel. Uniformity in particle size is crucial for producing a consistent product. Variations in particle size can lead to uneven cooking and inconsistent product texture. Fine particles can overcook, while coarser particles may remain undercooked, resulting in textural inconsistencies and potentially affecting product quality. Homogeneous particle size distribution helps in achieving a uniform structure and texture throughout the extrudates. Smaller particles can lead to smoother surfaces, as they create a more uniform melt flow during extrusion. In contrast, larger particles can cause a rougher surface texture due to their inability to completely blend into the melt, which may cause disruptions in the flow. This is particularly important in applications where a smooth surface finish is desired, such as in puffed snacks and breakfast cereals (da Silva, et al., 2023; Shruti, et al, 2024).

Retentate Characteristics

As a result of microfiltration, there is considerable residual material, in this case called retentate. The properties of this material are presented in Table 3.

Table 3: Characteristics of blackberry retentate obtained by microfiltration (MF)

Analysis	Feed rate	Permeated	Retained
Acidity (g citric acid/100g)	1.18	1.15	1.36
pH	3.05	3.04	3.04
°Brix	7.00	7.00	9.00
Moisture (g/100g	92.09	93.00	92.10
Dry extract (g/100g)	8.55	7.50	8.90

The material retained after microfiltration, after drying, had 8.90% moisture and 9% and 9.0 °Brix. Data considered important, since, in addition to the fiber content, the Brix degrees influence the characteristics of the expanded products in formulations with red rice.

The proximal composition of blackberry juice retentate after microfiltration and drying typically includes the following components, moisture, after drying, content is usually reduced to around 8-9%, depending on the drying process. Proteins, blackberry retentate is not particularly rich in proteins, but it can contain around 1-3%. Lipids, similar to proteins, the content is low, generally around 0.5-1%. Carbohydrates, this constitutes the major portion, including simple sugars, polysaccharides, and dietary fibers. The total carbohydrate content can range from 70-80%, with significant contributions from dietary fibers (around 20-40%) and residual sugars. Fiber, blackberry retentate is particularly high in dietary fiber, especially insoluble fiber (hemicellulose, cellulose, lignin), which can constitute 20-30% of the dry matter.

Ash, representing the mineral composition, is usually between 2-5%, including elements like potassium, magnesium, calcium, and trace elements (Čechovičienė, et al., 2024).

According with the Table 4, the amino acid content of polished red rice flour and white rice flour, highlighting significant differences between the two in terms of specific amino acids. The analyze results, focusing on essential amino acids, nutritional potential, and limiting amino acids for human nutrition.

Table 4: Amino acid profile of raw materials, and flour processed by extrusion, including the best treatments considered in the experimental design trials.

Amino acids (mg/100g)	Polished red rice flour	White rice flour	Extruded white rice flour	T2	T6	T7
Asparagine	*$0.52^{e} \pm 0.01^{\alpha}$	$0.44^{b} \pm 0.02$	$0.50^{b} \pm 0.02$	$0.49^{c} \pm 0.04$	$0.50^{b} \pm 0.04$	$0.54^{b} \pm 0.01$
Serine	$0.37^{f} \pm 0.00$	$0.34^{c} \pm 0.01$	$0.31^{c} \pm 0.01$	$0.33^{d} \pm 0.01$	$0.34^{c} \pm 0.02$	$0.36^{c} \pm 0.00$
Glutamine	$1.03^{c} \pm 0.01$	0.99a ± 0.06	$0.99^{a} \pm 0.04$	$1.00^{a} \pm 0.06$	$1.03^{a} \pm 0.08$	$1.10^{a} \pm 0.03$
Glycine	$3.95^{a} \pm 0.07$	$0.29^{cde} \pm 0.00$	$0.28^{cdef} \pm 0.01$	$0.29^{de} \pm 0.01$	$0.30^{cd} \pm 0.02$	$0.32^{cde} \pm 0.01$
Histidine	$0.21^{h} \pm 0.00$	$0.15^{f} \pm 0.01$	$0.14^{g} \pm 0.01$	$0.15^{f} \pm 0.01$	$0.14^{e} \pm 0.00$	$0.16^{h} \pm 0.01$
Arginine	$0.75^{d} \pm 0.01$	$0.46^{b} \pm 0.03$	$0.43^{b} \pm 0.03$	$0.60^{b} \pm 0.01$	$0.52^{b} \pm 0.08$	$0.51^{b} \pm 0.04$
Threonine	$0.29^{gh} \pm 0.01$	$0.23d^{ef} \pm 0.01$	$0.21^{efg} \pm 0.01$	$0.23^{ef} \pm 0.01$	$0.22^{cde} \pm 0.01$	$0.24^{fg} \pm 0.00$
Alanine	$0.41^{f} \pm 0.01$	$0.33^{c} \pm 0.01$	$0.32^{c} \pm 0.01$	$0.34^{d} \pm 0.02$	$0.34^{c} \pm 0.03$	$0.36^{c} \pm 0.01$
Proline	$0.39^{f} \pm 0.01$	$0.28^{cde} \pm 0.01$	$0.27^{cdef} \pm 0.02$	$0.29^{de} \pm 0.01$	$0.28^{cde} \pm 0.01$	$0.29^{def} \pm 0.00$
Tyrosine	$1.19^{b} \pm 0.02$	$0.26^{cde} \pm 0.01$	$0.23^{def} \pm 0.02$	$0.29^{de} \pm 0.01$	$0.28^{cde} \pm 0.00$	$0.30^{de} \pm 0.01$
Valine	$0.01^{i} \pm 0.00$	$0.31^{cd} \pm 0.01$	$0.30^{cd} \pm 0.02$	$0.32^{d} \pm 0.02$	$0.31^{cd} \pm 0.01$	$0.33^{cd} \pm 0.00$
Lysine	$0.05^{i} \pm 0.00$	$0.30^{cde} \pm 0.01$	$0.28^{cde} \pm 0.01$	$0.18^{f} \pm 0.01$	$0.18^{de} \pm 0.02$	$0.27^{efg} \pm 0.01$
Isoleucine	$0.34^{fg} \pm 0.01$	$0.21^{ef} \pm 0.01$	$0.20^{fg} \pm 0.01$	$0.22^{ef} \pm 0.01$	$0.21^{cde} \pm 0.01$	$0.23^{g} \pm 0.01$
Leucine	$0.70^{d} \pm 0.02$	$0.48^{b} \pm 0.01$	$0.45^{b} \pm 0.02$	$0.52^{bc} \pm 0.02$	$0.50^{b} \pm 0.03$	$0.53^{b} \pm 0.00$
Phenylalanine	$0.52^{e} \pm 0.01$	$0.32^{cd} \pm 0.02$	$0.30^{cd} \pm 0.02$	$0.35^{d} \pm 0.01$	$0.33^{c} \pm 0.00$	$0.37^{c} \pm 0.01$

*Mean values followed by the same letters do not differ significantly from each other according to the Tukey test at the 95% level; $^{\alpha}$Means ± standard deviation of duplicate assessments.

Essential Amino Acids and Comparison:

Essential amino acids are those that the human body cannot synthesize and must obtain from the diet. These include histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan, and valine. Histidine: Red rice flour has a higher histidine content (0.21 mg/100g) compared to white rice flour (0.15 mg/100g). Although histidine is needed in small amounts, it is essential for children's growth and tissue repair. The significantly higher amount in red rice suggests a slightly superior nutritional profile in this regard. Isoleucine and Leucine: Red rice flour shows higher levels of isoleucine (0.34 mg/100g) and leucine (0.70 mg/100g) compared to white rice flour (0.21 mg/100g for isoleucine and 0.48 mg/100g for leucine). These amino acids are crucial for muscle protein synthesis and energy production. The better levels in red rice may indicate a greater potential for supporting muscle health and recovery. Phenylalanine and Tyrosine: Phenylalanine in red rice (0.52 mg/100g) is higher than in white rice (0.32 mg/100g). Phenylalanine is essential for the synthesis of neurotransmitters like dopamine. Red rice also has much more tyrosine (1.19 mg/100g) compared to white rice (0.26 mg/100g), enhancing the nutritional advantage of red rice for brain function. Threonine: Red rice also has a higher threonine content (0.29 mg/100g) compared to white rice (0.23 mg/100g). Threonine plays a role in immune function and fat metabolism. Valine: Interestingly, red rice has a very low valine content (0.01 mg/100g), while white rice has 0.31 mg/100g. Valine is essential for muscle metabolism and tissue repair. This indicates that despite red rice's superiority in most other essential amino acids, its low valine content is a notable drawback. Lysine: Red rice has a significantly lower lysine content (0.05 mg/100g) compared to white rice (0.30 mg/100g). Lysine is often a limiting amino acid in grains and is crucial for protein synthesis, enzyme production, and calcium absorption. White rice's higher lysine content compensates for this grain's known deficiency in this essential amino acid.

Nutritional Potential of Red and White Rice in Human Nutrition:

Both polished red and white rice provide valuable nutrients, but red rice appears to have an overall superior amino acid profile, particularly in terms of essential amino acids like leucine, isoleucine, histidine, and phenylalanine. Red rice is also richer in arginine, an amino acid important for blood vessel dilation and wound healing. However, white rice flour has a higher lysine content, which is a critical aspect given that lysine is often the limiting amino acid in rice and other cereal-based diets. Additionally, white rice has a higher valine content, which is important for muscle metabolism. These differences suggest that while red rice may offer a richer nutritional profile in most essential amino acids, the inclusion of white rice in the diet may help compensate for its lower lysine and valine content (Tiozon, et al., 2023).

Limiting Amino Acids in Rice:

In both red and white rice, lysine is considered a limiting amino acid, especially in red rice, where it's content is notably low (0.05 mg/100g). Lysine is critical for the formation of proteins, enzyme activity, and immune function. A diet based primarily on rice should ideally be complemented with foods rich in lysine, such as legumes (beans, lentils, peas) or animal proteins (milk, eggs, meat), to ensure balanced amino acid intake. Additionally, in red rice, valine is significantly low (0.01 mg/100g), which could also limit the complete protein synthesis required by the body. This reinforces the importance of consuming a variety of protein sources to balance out these deficiencies.

Non-Essential Amino Acids:

Glutamine and Asparagine, both amino acids are more abundant in red rice (glutamine 1.03 mg/100g and asparagine 0.52 mg/100g) compared to white rice (glutamine 0.99 mg/100g and asparagine 0.44 mg/100g). Glutamine is essential for immune system health and digestive function, while asparagine is involved in protein synthesis and ammonia detoxification. The higher levels of these amino acids in red rice contribute to its enhanced nutritional value. Glycine: Red rice flour has an extremely high glycine content (3.95 mg/100g) compared to white rice (0.29 mg/100g). Glycine is important for collagen formation, muscle repair, and the regulation of blood sugar. According whit these results, polished red rice generally offers a superior amino acid profile compared to white rice, particularly in essential amino acids like leucine, isoleucine, and phenylalanine. However, white rice flour compensates with higher levels of lysine and valine, making it a valuable complement to red rice or other low-lysine grains. A balanced diet that includes both types of rice, along with other protein sources, can ensure an adequate intake of essential and non-essential amino acids for optimal human nutrition. This approach helps overcome the limitations posed by individual grains and supports overall health, muscle function, and immune system performance.

Overall, while extrusion can enhance the digestibility and certain nutritional aspects of rice flour, it may also degrade heat-sensitive amino acids like lysine. Polished red rice flour has a superior amino acid profile compared to white rice, but its amino acid profile can be further optimized by careful control of extrusion parameters or by blending with other protein sources.

Comparative Study of Amino Acid Profiles in Raw and Extruded Rice Flours

1. Essential Amino Acids are those that cannot be synthesized by the human body and must be obtained through the diet. In the provided table, the essential amino acids include lysine, leucine, isoleucine, threonine, valine, phenylalanine, and histidine. Lysine, raw materials, the polished red rice flour has a very low lysine content (0.05 mg/100g), making it a limiting amino acid for this flour. White rice flour has a higher content (0.30 mg/100g), but it remains relatively low. Processed materials, extruded flours show a decrease in lysine content, particularly in T6 and T7 treatments, indicating that the extrusion process may degrade lysine. T2 treatment maintains lysine levels comparable to raw white rice flour. Leucine and Isoleucine, both leucine and isoleucine are essential for protein synthesis and muscle repair. Polished red rice flour shows higher levels of these amino acids compared to white rice flour, which improves after extrusion, particularly in treatments T6 and T7. This indicates that the extrusion process can enhance the availability of these amino acids. Histidine content is higher in polished red rice compared to white rice flour. Post-extrusion, there is a noticeable reduction in histidine levels, particularly in treatment T7, which may affect its contribution to the diet (Meline, et al., 2019).
2. Limiting amino acids, is the essential amino acid found in the smallest quantity relative to the body's needs. Lysine, as mentioned, lysine is a limiting amino acid in both raw and processed forms of rice flours. The reduction of lysine content in extruded samples (T6 and T7) further emphasizes the need for supplementation or blending with other protein sources to meet nutritional requirements. Methionine and cysteine, while not listed in the table, these sulfur-containing amino acids are often limiting in cereal grains. The focus on improving the protein quality of rice should consider these amino acids as well (Saleh, et al., 2019).
3. Non-Limiting Amino Acids, are those that are present in sufficient quantities in the food product. Glutamine and asparagine, both are present in high amounts across all samples. Glutamine, in particular, remains relatively stable post-extrusion, which is beneficial for gut health and the immune system. Asparagine also shows minimal variation, indicating that these non-essential amino acids are not significantly impacted by processing (Shruti, et al., 2024).
4. Nutritional Contributions to Health: The consumption of polished red rice, due to its higher levels of amino acids like leucine and glutamine, can contribute to muscle protein synthesis and overall nitrogen balance in the body. The higher glycine content in polished red rice also suggests potential benefits for joint and skin health (Safitri & Fatchiyah, 2021).

   Extruded white rice flour: The extrusion process generally increases the digestibility and availability of some amino acids. However, it may reduce heat-sensitive amino acids like lysine. Therefore, while the process can improve certain nutritional aspects, care must be taken to avoid degradation of key amino acids.

5. Processing Impact on Amino Acid Profile: Degree of Cooking: Extrusion parameters such as temperature and screw speed can influence the degree of cooking and, consequently, the amino acid profile. Higher temperatures, as seen in treatment T6 (700 rpm/150 °C), might result in more significant degradation of sensitive amino acids. Interaction with other ingredients, of extruded flour in a food matrix can affect protein quality. For instance, combining extruded rice flour with legumes can complement the amino acid profile, particularly for lysine (Finocchiaro, et al., 2007; Paiva et al., 2014).

The mineral composition of rice (Table 5), particularly red polished rice, shows that it is a superior source of many minerals important for human nutrition compared to white rice. These minerals play essential roles in maintaining health, preventing several diseases associated with mineral deficiency, such as anemia, bone and muscle problems, and immune disorders. Although rice is not a major source of minerals in the diet, choosing more nutritious varieties can contribute significantly to the recommended daily intake of essential minerals.

Rice is one of the most widely consumed foods in the world, being an important source of energy in the diet of millions of people. In addition to carbohydrates, rice, both polished and brown, provides essential minerals for the proper functioning of the human body. Analysis of the mineral composition of red polished rice flour and white rice, as described in Table 4, highlights significant differences in the presence of several minerals, which directly influence the nutritional quality and bioavailability of these nutrients in the body (Tiwari, et al, 2024). The sodium content is extremely low in red polished rice flour (0.21 mg/100 g), while in white rice it is below the detection limit (Kothapalli, et al., 2023).

Table 5: Mineral composition of raw polished red and white rice flours, and flour processed by extrusion, including the best treatments considered in the experimental design: T2, T6, and T7

Mineral (mg/100g)	**Polished red rice flour**	**White rice flour**	**Extruded white rice flour**	**T2**	**T6**	**T7**
Sodium	0.21 ± 0.004$^{\alpha}$	ND*	ND	ND	ND	ND
Potassium	161.02^{b} ± 1.245	64.22^{b} ± 0.967	86.42b ± 0.89	130.31b ± 0.08	111.29 b ± 3.38	116.38b ± 0.82
Magnesium	80.52^{c} ± 0.380	17.46^{c} ± 0.209	32.58c ± 0.17	57.10c ± 0.21	50.22c ± 0.70	54.34c ± 0.27
Calcium	**6.71^{d} ± 0.051	4.39^{d} ± 0.203	5.05d ± 0.11	7.87d ± 0.57	5.73d ± 0.23	6.12d ± 0.32
Manganese	1.39^{e} ± 0.016	1.64^{a} ± 0.009	1.66a ± 0.05	1.28a ± 0.01	1.28a ± 0.02	1.29a ± 0.01
Iron	0.79^{e} ± 0.008	0.38^{e} ± 0.007	2.53ef ± 0.10	3.70ef ± 0.01	2.72de ± 0.12	2.59ef ± 0.11
Zinc	2.17^{e} ± 0.012	1.42^{e} ± 0.046	1.50e ± 0.02	1.79e ± 0.00	1.78de ± 0.06	1.78e ± 0.03
Copper	0.24^{e} ± 0.009	0.29^{e} ± 0.001	0.36ef ± 0.02	0.27ef ± 0.00	0.27de ± 0.00	0.27e ± 0.00
Phosphorus	234.35^{a} ± 2.775	84.08^{e} ± 1.344	120.70f ± 0.75	167.05f ± 1.70	147.11e ± 1.56	160.65f ± 0.05

*ND: below the detection limit. **Mean values followed by the same letters do not differ significantly from each other according to the Tukey test at the 95% level; $^{\alpha}$Means standard deviation of duplicate assessments.

Although sodium is essential for fluid balance and nerve function, the low amount of this mineral in rice is beneficial for people who need to control their sodium intake, such as hypertensive patients. Potassium is a crucial mineral for cellular function, blood pressure regulation and fluid balance. Red polished rice flour has a significantly higher potassium content (161.02 mg/100 g) compared to white rice (64.22 mg/100 g). Potassium also acts as an antidote to sodium, helping to reduce the negative effects of high blood pressure. A lack of potassium in the diet can lead to muscle weakness, cramps and heart problems. Magnesium is essential for muscle and nerve function, energy metabolism and maintenance of bone health. Red polished rice flour contains 80.52 mg/100 g of magnesium, while white rice flour only has 17.46 mg/100 g. This difference suggests that red rice is a better source of magnesium, a deficiency of which can result in symptoms such as cramps, fatigue and osteoporosis in the long term. Calcium, although calcium in rice is not abundant in both varieties, red polished rice flour has a slightly higher amount (6.71 mg/100 g) compared to white rice (4.39 mg/100 g). Calcium is essential for bone and dental health, as well as for muscle contraction. A lack of calcium can lead to osteoporosis and other bone problems over time. Manganese is a trace element vital for the metabolism of carbohydrates, lipids and proteins. Interestingly, white rice has a slightly higher concentration of manganese (1.64 mg/100 g) compared to red polished rice (1.39 mg/100 g). This mineral also plays a role in bone health and antioxidant metabolism. Deficiencies are rare, but can lead to growth and reproductive problems (Kothapalli, et al., 2023).

Iron is necessary for transporting oxygen in the blood and producing cellular energy. Red polished rice flour contains 0.79 mg/100g of iron, while white rice flour only has 0.38 mg/100g. Although rice is not a very rich source of iron, the red variety offers twice the content of this mineral compared to white rice. Iron deficiency can result in anemia, fatigue and impaired cognitive function.

Zinc, essential for immune function and wound healing, is also more abundant in red polished rice flour (2.17 mg/100g) than in white rice flour (1.42 mg/100g). Zinc deficiency can lead to problems such as compromised immunity, loss of appetite and stunted growth. Copper, which participates in the formation of hemoglobin and acts as an antioxidant, is present in similar quantities in both varieties of rice, with white rice flour containing slightly more (0.29 mg/100g) than red rice (0.24 mg/100g). Although the quantities are small, copper is essential for cardiovascular and neurological health (Tiwari et al. 2024).

Phosphorus is one of the most present minerals in the composition of rice, especially in polished red rice (234.35 mg/100g) compared to white rice (84.08 mg/100g). Phosphorus is essential for bone formation and energy production. Phosphorus deficiency is rare, but when it occurs, it can impair bone development and cellular function.

Interactions and Bioavailability

The minerals present in rice, although essential, can interact with each other, influencing their bioavailability. For example, phytate present in grains can inhibit the absorption of minerals such as zinc and iron. In addition, diets high in calcium can reduce the absorption of magnesium, and excess iron can impair the absorption of zinc. The bioavailability of minerals can also be influenced by the way the rice is prepared, with brown rice generally being a better option for nutrient retention due to less removal of the outer layers during processing.

Comparative Study of Mineral Composition in Raw and Processed Rice Flours

Minerals play a crucial role in human nutrition, supporting various physiological processes such as bone health, enzyme function, and nerve transmission. This study compares the mineral composition of polished red rice flour, white rice flour, and extruded white rice flour under different extrusion conditions (T2, T6, and T7). The impact of processing on the availability and concentration of essential minerals like sodium, potassium, magnesium, calcium, manganese, iron, zinc, copper, and phosphorus is analyzed, highlighting their contributions to health.

Sodium, raw materials, polished red rice flour contains a trace amount of sodium (0.21 mg/100g), whereas white rice flour has no detectable sodium. Processed materials, sodium is not detectable in any of the extruded white rice flours (T2, T6, T7). This consistency suggests that extrusion processing does not contribute significantly to sodium levels, making extruded products suitable for low-sodium diets.

Potassium, raw Materials, polished red rice flour contains a significantly higher amount of potassium (161.02 mg/100g) compared to white rice flour (64.22 mg/100g). Processed materials, potassium content increases substantially in all extruded samples compared to raw white rice flour, with T2 showing the highest increase (130.31 mg/100g). This is likely due to the concentration effect of the extrusion process, which reduces moisture and potentially increases mineral concentration. Health contribution, potassium is vital for maintaining normal blood pressure, muscle function, and nerve transmission. The increased potassium levels in extruded flours, particularly in T2, make them beneficial for cardiovascular health.

Magnesium, raw materials, polished red rice flour has a much higher magnesium content (80.52 mg/100g) than white rice flour (17.46 mg/100g). Processed materials, the magnesium content of extruded white rice flours improves significantly in all treatments, with T2 (57.10 mg/100g) showing the highest level among processed samples. This demonstrates that extrusion can enhance the bioavailability of magnesium. Health Contribution, magnesium is crucial for bone health, energy metabolism, and muscle function. Increased magnesium levels in extruded products can help meet daily nutritional requirements, especially for populations with low dietary magnesium intake.

Calcium, raw materials, both polished red rice and white rice flours have low calcium content, 6.71 mg/100g and 4.39 mg/100g, respectively. Processed materials, extrusion results in a slight increase in calcium content, particularly in T2 (7.87 mg/100g). However, the overall increase is minimal. Health contribution, calcium is essential for bone health and muscle function. Although the increase in calcium through extrusion is small, the inclusion of other calcium-rich ingredients may be necessary to achieve significant health benefits.

Manganese, raw materials, white rice flour contains slightly more manganese (1.64 mg/100g) than polished red rice flour (1.39 mg/100g). Processed materials, manganese content remains relatively stable across all extrusion trials, with a slight decrease compared to raw white rice flour. This stability suggests that manganese is not significantly affected by extrusion. Health contribution, manganese plays a role in bone formation, blood clotting, and reducing inflammation. The stable manganese content in extruded products is beneficial for maintaining adequate intake.

Iron, raw materials, polished red rice flour has higher iron content (0.79 mg/100g) compared to white rice flour (0.38 mg/100g). Processed materials, iron content increases significantly in extruded flours, particularly in T2 (3.70 mg/100g). This could be due to the release of bound iron during the extrusion process, enhancing its bioavailability. Health contribution, iron is crucial for oxygen transport and preventing anemia. The significant increase in iron in extruded products, especially in T2, enhances their nutritional value, making them a good option for individuals with increased iron needs.

Zinc, raw materials, polished red rice flour has a higher zinc content (2.17 mg/100g) compared to white rice flour (1.42 mg/100g). Processed Materials, the zinc content remains relatively stable in extruded samples, with slight increases seen in T2 (1.79 mg/100g). This suggests that zinc is not significantly impacted by extrusion. Health contribution, zinc is essential for immune function, DNA synthesis, and wound healing. The stable zinc levels in extruded flours ensure that the nutritional contribution remains consistent (Sun et al, 2024).

Copper, raw materials, white rice flour has slightly more copper (0.29 mg/100g) than polished red rice flour (0.24 mg/100g). Processed materials, the copper content remains relatively unchanged in all extruded flours. This indicates that extrusion has a minimal effect on copper levels. Health contribution, copper is involved in energy production and connective tissue formation. The consistent copper levels in extruded products maintain their contribution to health.

Phosphorus, raw materials, polished red rice flour has significantly higher phosphorus content (234.35 mg/100g) compared to white rice flour (84.08 mg/100g). Processed materials, phosphorus content increases substantially in extruded samples, with T2 showing the highest increase (167.05 mg/100g). This increase is likely due to the concentration effect during the reduction of moisture content in extrusion. Health contribution, phosphorus is essential for bone and teeth health and energy metabolism. The increase in phosphorus in extruded flours enhances their nutritional value, making them beneficial for overall health.

Consequently, the extrusion process generally enhances the mineral content of white rice flour, making it nutritionally superior to its raw form. The increases in potassium, magnesium, iron, and phosphorus are particularly noteworthy, as these minerals are crucial for maintaining various bodily functions. Extruded products, especially those processed under T2 conditions, offer significant health benefits compared to raw white rice flour. However, polished red rice flour remains superior in terms of mineral content, making it a valuable nutritional choice.

Evaluation of the Anthocyanin Profile of Red Rice and Blackberry Retentate

Figure 3 shows the chromatogram of the methanolic extract of polished red rice. No anthocyanins were observed in this chromatogram, and even when the analyses were performed on rice samples containing red pericarp, no significant signal was observed in the anthocyanin absorption region. Initially, it was believed that, due to the characteristics of red rice, it would contain anthocyanins in its composition. However, in Figure 4, at four minutes, a peak is shown, indicating the presence of anthocyanins in the retentate (Gouvêa, 2011; Melini, et al., 2019).

This chromatogram (Figure 3.) suggests that the methanolic extract of hulled red rice contains compounds with some initial absorptivity at 520 nm, which quickly elute early in the run. The sharp spikes may correspond to phenolic compounds or pigments, such as anthocyanins, commonly found in red rice. Anthocyanins typically absorb in the visible region around 520 nm, and the sharp early peaks could reflect the rapid detection of these compounds (Wijaya & Romulo, 2021).

After the initial peaks, the signal stabilizes, indicating either that most detectable components have been eluted or that the remaining constituents do not absorb significantly at 520 nm.

Consequently, the chromatogram reflects the presence of early-eluting, likely phenolic or pigmented compounds, followed by a relatively quiet signal, suggesting most of the detectable analyses are present in the early phase of the run Fitriyah, &, Ayu, 2020; Sumczynski, 2016; Ascheri, et al., 2012; Finocchiaro, et al., 2007; Paiva et al., 2014; Santiago, et al, 2010).

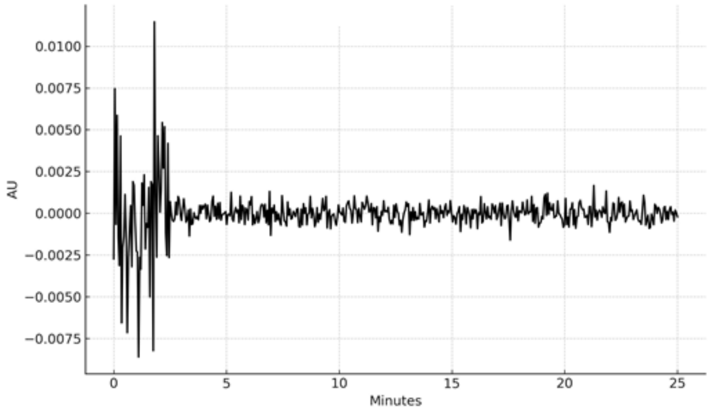

Figure 3: Chromatogram of the methanolic extract of hulled red rice at 520 nm.

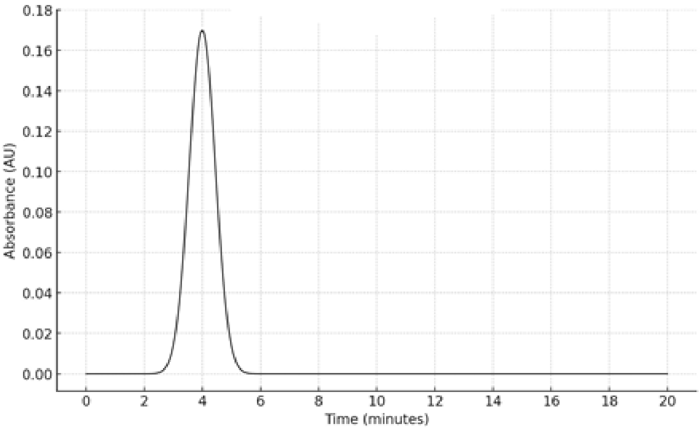

Figure 4: Chromatogram of blackberry extract.

The chromatogram of blackberry (blackberry pomace, Figure 4) shows a sharp peak at around 4 minutes, with the highest absorbance reaching approximately 0.16 AU. This sharp peak suggests the presence of a dominant compound being eluted early in the run. The lack of additional peaks after 6 minutes indicates that the majority of the compounds in the blackberry extract are eluted within the first 5 minutes. This type of chromatographic profile could be associated with specific anthocyanins or other polyphenolic compounds, which are known to be abundant in blackberries. The early elution time suggests the compound is likely hydrophilic or relatively small in size. The peak in the blackberry chromatogram is likely caused by anthocyanins, specifically cyanidin-3-glucoside and cyanidin-3-rutinoside, which are predominant anthocyanins in blackberries. Anthocyanins are water-soluble pigments responsible for the deep purple and red color of blackberries and typically elute early in chromatographic analyses due to their hydrophilic nature. Other potential compounds could include flavonoids or phenolic acids, such as gallic acid or ellagic acid, which are also abundant in blackberry extracts.

Results of Extrusion Effects and Physical Characterization of Expanded Extrudates

Color Analysis of Final Products:

According to Kramer and Twigg (1962), color is a characteristic of light measured in terms of intensity and wavelength. This arises from the presence of light at higher intensities at some wavelengths than at others. The formation of color during the extrusion process provides important information about the degree of heat treatment and is directly related to the composition of the formulation (Linko et al., 1981). Table 5, additionally shows the experimental design and instrumental color of the extrudates of the different extruded flours. Severe conditions result in darker products, with lower luminosity values and increases in the values of the ***a*** and ***b*** coordinates (Badrie and Mellowes, 1991). According to Sebio (1996), color stability is a quality characteristic for extruded foods that are normally consumed directly without further heat treatment.

Manoharkumar et al. (1978) described the importance of extrusion operating conditions in the loss of color of corn grits. Many reactions occur during this extrusion process, and the most common are coloring reactions and non-enzymatic degradation of the flour pigment. Table 6 shows the minimum and maximum values of the color difference, which varied from 11.96 (T1: 358.58 rpm; 128.79 °C) to 19.16 (T6: 700 rpm; 150 °C). It can be seen that the greatest color difference is related to high screw rotation and temperature values, therefore non-enzymatic darkening may have occurred due to the reaction of proteins with dextrinized starch during the extrusion process. The regression model of the color difference is represented by the following linear equation (equation 3):

$$\Delta E = 14.68 + 1.98\, X_1 + 1.58\, X_2 \qquad \text{Equation 3}$$

The regression model for color difference was $R^2 = 85.86\%$, therefore explaining the tendency of the equation in terms of its reproducibility. The tendency of the screw rotation and temperature variables had a linear and positive influence on the color difference results, with rotation having the greatest influence.

Table 6: Decoded levels of the experiment's independent variables, and color results of expanded extrudates.

Trial	X_1	X_2	L	*a*	*b*	ΔE
1	358.58	128.79	$70.57^{b} \pm 0.52^{\alpha}$	$5.60^{f} \pm 0.13$	$11.38^{d} \pm 0.14$	$11.96^{h} \pm 0.52$
2	641.42	128.79	$69.12^{def} \pm 0.47$	$6.33^{de} \pm 0.06$	$13.15^{c} \pm 0.12$	$14.20^{ef} \pm 0.34$
3	358.58	171.21	$69.34^{cdf} \pm 0.41$	$6.25^{e} \pm 0.14$	$12.82^{c} \pm 0.31$	$13.84^{ef} \pm 0.35$
4	641.42	171.21	$66.09^{i} \pm 0.36$	$7.40^{ab} \pm 0.12$	$14.97^{a} \pm 0.25$	$17.90^{b} \pm 0.18$
5	300	150	$70.21^{bcd} \pm 0.48$	$5.82^{f} \pm 0.05$	$11.64^{d} \pm 0.21$	$12.44^{gh} \pm 0.37$
6	700	150	$64.78^{j} \pm 0.13$	$7.76^{a} \pm 0.16$	$15.10^{a} \pm 0.40$	$19.16^{a} \pm 0.20$
7	500	120	$70.52^{bc} \pm 0.43$	$5.85^{f} \pm 0.07$	$11.48^{d} \pm 0.26$	$12.13^{h} \pm 0.24$
8	500	180	$66.95^{hi} \pm 0.36$	$7.32^{b} \pm 0.21$	$14.85^{ab} \pm 0.34$	$17.12^{bc} \pm 0.56$
9	500	150	$67.74^{gh} \pm 0.60$	$6.88^{c} \pm 0.10$	$14.16^{b} \pm 0.31$	$15.99^{cd} \pm 0.60$
10	500	150	$68.57^{efg} \pm 0.17$	$6.56^{cde} \pm 0.20$	$13.27^{c} \pm 0.53$	$14.79^{e} \pm 0.49$
11	500	150	$69.73^{bcd} \pm 0.86$	$6.23^{e} \pm 0.15$	$12.61^{c} \pm 0.35$	$13.42^{fg} \pm 0.74$
12	500	150	$68.88^{efg} \pm 0.39$	$6.42^{de} \pm 0.13$	$12.92^{c} \pm 0.35$	$14.32^{ef} \pm 0.57$
13	500	150	$68.42^{fg} \pm 0.43$	$6.64^{cd} \pm 0.25$	$13.22^{c} \pm 0.38$	$14.90^{de} \pm 0.43$
RPRRF*	-	-	$80.81^{a} \pm 0.32$	$2.13^{g} \pm 0.09$	$6.25^{e} \pm 0.09$	-

X_1=Screw speed (rpm); X^2 = Temperature (°C); $\pm\alpha = \pm 1.414$ *RPRRF= Raw polished red rice flour. $^{\alpha}$Means followed by the same letters do not differ significantly from each other by the Tukey test at the 95% level.

Table 7 show results of extrusion effects and physical characterization of extrudates. Extrusion cooking is a transformative process that greatly enhances the functional properties of starch, particularly in terms of water absorption and solubility. These properties are vital for producing a wide range of extruded food products with desirable textures, mouthfeel, and ease of preparation. The ability to manipulate these properties through extrusion technology offers significant advantages for developing innovative food products, particularly in the instant foods and snack industries. By understanding the changes that occur during extrusion, food technologists can better control the quality and functionality of extruded starch in various applications, leading to products that meet both consumer demands and nutritional standards. Starch is a biopolymer composed of amylose and amylopectin. In its native form, starch granules exhibit semi-crystalline structures, composed of alternating amorphous and crystalline regions. The functional properties of starch are highly dependent on its granular structure and the amylose-to-amylopectin ratio. Native starch has a limited capacity to absorb cold water, as the crystalline structure restricts water penetration and gelatinization. The two primary functional properties of starch that are of great interest to the food industry are water absorption index (WAI) and water solubility index (WSI). These properties determine how starch behaves in aqueous environments, influencing product texture, viscosity, and mouthfeel. Table 6 shows that the WSI varied from 14.30% to 24%, with the highest value in treatment 7 obtained at 500 rpm and 120 °C temperature. The control flour presented a similar value (18.21%) compared to the 3 best treatments regarding the highest WSI (T2 = 19%, T6 = 22.10%, T7 = 24%). According to the general objective of this work, the selection of the 3 best treatments was made based on the highest WSI. The regression model for the WSI presented an R^2 = 65.80%, lower than 70%, therefore no predictive model was generated. However, the trend of the variables was positive linear, with the variable screw rotation having more influence in relation to the variable temperature. After extrusion, the starch exhibits a higher water absorption capacity. This is because the heat and shear forces disrupt the crystalline regions, allowing water molecules to penetrate and bind with the exposed hydroxyl groups of amylose and amylopectin (da Silva, et. Al, 2023). Increased water absorption improves the functionality of starch in products where hydration is necessary, such as soups, sauces, and certain snacks. Extruded starch also shows increased solubility in water. During extrusion, amylose and amylopectin are fragmented, reducing their molecular size and increasing the number of solubilized molecules (Ribeiro-Fi; lho, et al., 2024; Padma, et. al, 2018). This results in higher water solubility, making extruded starch ideal for instant products, where rapid rehydration and dispersion in water are essential. Consequently, the functional properties in food applications in extruded food products, the functional properties of starch determine the texture, mouthfeel, and appearance. For expanded products, as snacks, in puffed snacks, the ability of starch to absorb water during extrusion and trap air as it expands during puffing leads to the desirable light, airy texture. For instant foods, extruded starch with high solubility is a key ingredient in instant beverages. It helps to thicken the mixture rapidly when reconstituted with hot water, without forming clumps. While extrusion significantly enhances the functional properties of starch, there are challenges in controlling the degree of gelatinization and the balance between water absorption and solubility. Excessive extrusion can lead to starch degradation, resulting in undesirable textures or overly soluble products that lose structure during cooking. To overcome this, food technologists modify starches through pre-treatments, adding other ingredients such as proteins or fibers to adjust the final product's functional characteristics.

The radial expansion index is probably the most important physical characterization test for extruded products. This index can be used to predict at first glance how drastic or mild the extrusion process was. In addition, it can be verified whether a given raw material, when extruded, has an appropriate composition for the preparation of the desired final product (Ascheri, 2024; Ascheri, 2023).

Table 7: Results of extrusion effects and physical characterization of expanded extrudates.

Trial	Flow rate (kg/h)	Torque kN.m (kJ)	SME (kJ/Kg)	REI	LEI	VEI	Density (ρ_e) g.cm^3	WSI (%)	WAI (g gel. g^{-1})
1	α10.15^{a}	3.41^{a}	909.46^{ef}	4.61^{abc}	1.25^{cd}	5.68^{e}	0.24^{a}	16.63^{abc}	6.14^{abc}
2	10.35^{a}	2.53^{efg}	1174.73^{c}	3.51^{defg}	2.02^{b}	6.99^{de}	0.19^{b}	19.00^{abc}	5.52^{def}
3	9.82^{a}	2.36^{g}	650.74^{g}	4.29^{abcde}	2.07^{b}	8.72^{abc}	0.16^{cde}	14.43^{bc}	6.39^{ab}
4	10.30^{a}	2.8^{cd}	1328.52^{b}	2.23^{h}	3.58^{a}	7.96^{bcd}	0.17^{bcd}	18.77^{abc}	5.26^{fg}
5	9.53^{a}	2.87^{cd}	697.27^{g}	4.74^{ab}	1.24^{cd}	5.82^{e}	0.23^{a}	14.30^{c}	6.59^{a}
6	9.62^{a}	3.2^{ab}	1752.96^{a}	3.03^{g}	3.16^{a}	9.09^{ab}	0.15^{de}	22.10^{ab}	5.21^{fg}
7	10.10^{a}	2.67^{def}	990.66^{de}	5.03^{a}	1.16^{d}	5.83^{e}	0.23^{a}	24.00^{a}	5.82^{cde}
8	9.87^{a}	2.78^{cde}	1056.66^{d}	2.36^{h}	3.28^{a}	7.74^{cd}	0.18^{bcd}	15.81^{bc}	5.99^{bcd}
9	10.22^{a}	2.44^{fg}	898.86^{f}	2.88^{gh}	3.49^{a}	9.93^{a}	0.14^{e}	18.96^{abc}	5.65^{cdef}
10	10.30^{a}	2.49^{fg}	905.67^{ef}	3.51^{efg}	2.19^{b}	7.57^{cd}	0.18^{bcd}	16.33^{abc}	5.83^{cde}
11	10.62^{a}	2.45^{fg}	862.98^{f}	3.39^{fg}	2.27^{b}	7.62^{cd}	0.78^{cde}	15.99^{bc}	5.78^{cde}
12	10.11^{a}	2.38^{g}	881.53^{f}	3.73^{cdefg}	2.07^{b}	7.48^{cd}	0.18^{bcd}	16.62^{abc}	5.82^{cde}
13	9.92^{a}	3.06^{bc}	1155.99^{c}	3.96^{bcdefg}	2.20^{b}	8.66^{abc}	0.16^{cde}	16.88^{abc}	5.38^{efg}
Controle*	10.41^{a}	2.44^{fg}	881.65^{f}	4.37^{abcd}	1.75^{bc}	7.55^{cd}	0.18^{bc}	18.21^{abc}	4.91^{g}

SME: Specific mechanical energy. REI: Radial Expansion Index; LEI: Longitudinal Expansion Index; VEI: Volumetric Expansion Index; *Control based on white rice flour; WSI: water solubility index. WAI: water absorption index. $^{\alpha}$Means followed by the same letters do not differ significantly from each other by the Tukey test at the 95% level.

Expansion is understood as the process that occurs as part of extrusion cooking. In this case, air compartments or gas cells are created in the product, thus decreasing the apparent density of the product. Some of these air compartments are open, allowing air to move freely from one cell to another. Other compartments are closed, thus preventing air movement between the pores. The expansion of extrudates depends on the development of these air compartments or bubbles, which are created when water vapor expands as the extrudates leaves the matrix (ALI et al., 1996). Table 6 shows the results regarding the radial expansion index, which varied from 2.23 to 5.03. It is believed that there was total denaturation of the starch structure in treatment 4 (641.42 rpm, 171.21 °C). The mechanical stress caused low molecular weight structures that do not allow the expected degree of expansion. The best expansion index found was in treatment 7 (500 rpm, 120 °C). It is believed that these extrusion conditions are favorable for achieving good expansion results. The same effect was observed by Meng et al., (2010). The authors evaluated the effects of screw rotation on chickpea-based snacks and found that increasing screw speed increased the expansion index values of these products. Similarly, Ding et al., (2005) found that screw speed was fundamental and significant in the expansion results of rice-based extrudates.

The regression model for the radial expansion index (REI) is represented by the following linear equation (equation 4):

$$REI = 3.49 - 0.70\, X_1 - 0.67\, X_2 \qquad \text{Equation 4}$$

It can be seen in the equation that the independent variables, screw rotation represented by (X_1) and temperature represented by (X_2), negatively affected the radial expansion index results in similar proportions. With reference to $R^2 = 80.77\%$, it explains the tendency of the equation regarding its reproducibility. The results of the longitudinal and volumetric indexes varied between (1.16 and 3.58); (5.68 993) respectively (Table 6).

Apparent Density (APD) of Extrudates:

The apparent density is generally related to the REI. Extrudates with high radial expansion rates tend to have lower apparent density, since the formation of internal air bubbles in the material structure increases the volume of the extrudates and consequently reduces its weight, thus increasing crunchiness. The apparent density is an important measure in the development of snacks at an industrial level. By checking the weight and volume of the extrudates, it is possible to plan, for example, the size of the packages, the type of material to be used in their manufacture, the space occupied by the product within each batch to be sent for transportation, among others. In Table 6, it can be seen that the minimum value of the apparent density was 0.14 g/cm3 and the maximum value was 0.78 g/cm3. According to the application of the Tukey test, there were no major differences between the treatments. These results were probably due to the high starch content present in red rice, producing low-density expanded products.

Specific Mechanical Energy (SME):

Specific mechanical energy can be defined as the amount of energy required to process the material inside the extruder and out of it. This will depend on the motor power and the total amount of material processed in a given time. Motor power is the product of torque, which is proportional to the distance of force application, and screw speed (Shevkani, 2014). Table 6 shows the minimum and maximum values of specific mechanical energy, which ranged from 650.74 kJ/kg (T3: 358.58 rpm; 171.21 °C) to 1728.96 kJ/kg (T6: 700 rpm; 150 °C). The control (SME) can also be observed; high values mean greater screw rotation, consequently greater friction and energy expenditure. The regression model of SME is represented by the following linear equation (equation 5):

$$SME = 941.02 + 304.52\,X_1 \qquad \text{Equation 5}$$

The regression model of SME was, $R^2 = 74.08\%$, therefore explaining the tendency of the equation in terms of its reproducibility. However, the tendency of the screw rotation variable was linear positive, however it is observed that the temperature variable did not affect the results of SME.

Pasting Viscosity (RVA)

Paste viscosity depends of the degree of starch gelatinization and the rate of molecular fragmentation and solubilization. The degree of cooking of a product can be verified by determining the viscosity of a sample suspension that is subjected to controlled shear and a temperature regime imposing intercalated cycles of low, high and low temperature (Ascheri, 2024). The viscosity curves performed in the RVA are represented in Figure 5, in which the treatments with the best results for the objectives of the work were considered, in terms of solubility.

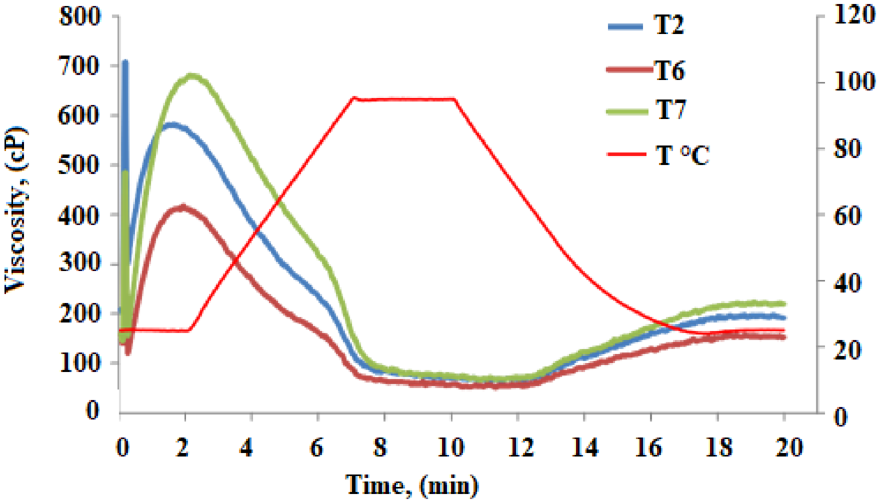

Figure 5: Paste viscosity profiles of the best treatments T2 (641.42 rpm /128.79 °C), T6 (700 rpm /150 °C) and T7 (500 rpm /120 °C).

The Figure 5 illustrates the Rapid ViscoAnalyzer (RVA) results for three different extrusion conditions: T2 (641.42 rpm / 128.79 °C), T6 (700 rpm / 150 °C), and T7 (500 rpm / 120 °C). The primary objective was to optimize the solubility and fluidity of the extrudates for use in beverages containing blackberry. Each curve represents the viscosity changes of the extrudates samples over time as they were subjected to a controlled heating and cooling cycle.

Analysis of RVA Curves:

The initial (0 - 3 minutes) rise in viscosity for all treatments (T2, T6, and T7) is indicative of starch granule swelling and initial gelatinization. Among the treatments, T7 (green line) shows the highest peak viscosity, suggesting a more extensive starch gelatinization at the initial stage. This can be attributed to the lower extrusion temperature (120 °C), which might have preserved more native starch granules, resulting in a more pronounced swelling during RVA analysis. - T6 (red line) has the lowest initial viscosity, which might indicate more pre-gelatinized starch due to the high extrusion temperature (150 °C), resulting in less water absorption and swelling capacity during RVA analysis.

The peak viscosity (4 - 6 minutes) values are highest for T7, followed by T2 and T6. This peak is a critical indicator of the maximum viscosity the sample achieves during heating, often correlating with water-binding capacity and the ability of the starch to gelatinize. T7's higher peak viscosity suggests a better potential for forming a viscous solution, making it a suitable candidate for beverages requiring a thicker consistency. The lower peak for T6 may indicate that the starch has undergone more extensive breakdown during extrusion, resulting in lower viscosity during RVA testing. Breakdown viscosity (6 - 10 minutes) reflects the stability of the starch paste during heating. All treatments show a significant decrease in viscosity after the peak, with T6 experiencing the most considerable drop. This could be due to the more extensive breakdown of the starch structure at higher extrusion temperatures. T2 and T7, with less breakdown, suggest that the starch structure remains more intact, providing better stability, which is desirable for certain beverage applications. The final viscosity (10 - 20 minutes), observed after cooling, indicates the reformation of the starch network. T2 shows the highest final viscosity, followed closely by T7, indicating good retrogradation properties, which could be beneficial for forming a stable suspension in beverages. T6, with the lowest final viscosity, suggests that the starch has been extensively degraded, resulting in lower reformation of the network, which may impact the suspension stability in a beverage matrix.

Optimal Treatment for Beverages:

The trial T7 (500 rpm / 120 °C), exhibits a high peak and final viscosity with moderate breakdown, indicating that it provides good initial thickening and stability upon cooling. This treatment would be ideal for creating beverages with a thicker consistency, which is desirable for smoothie-like drinks or where a fuller mouthfeel is required. T2 (641.42 rpm/128.79 °C): Demonstrates a balanced performance with high final viscosity, indicating a good potential for reformation and suspension stability in beverages. This could be advantageous in products where a smooth and uniform texture is essential. T6 (700 rpm/150 °C): Shows the least viscosity throughout the process, indicating a lower thickening potential and reduced stability. This might be more suitable for clear, thinner beverages where minimal thickening is required.

Practical Implications for Beverage Formulation. - In beverage formulations, achieving the right balance between solubility and viscosity is crucial. Higher solubility ensures that the extrudates disperses well in the liquid medium, while the viscosity must be controlled to prevent excessive thickening, which can lead to undesirable textures. Trial T7 appears to offer the best compromise between these parameters, providing sufficient viscosity for a smooth and creamy texture without excessive thickening. Overall, careful consideration of extrusion parameters such as screw speed, temperature, and feed rate is necessary to tailor the functional properties of the extrudates for specific applications in beverage formulations. Future research could explore the impact of other variables, such as feed moisture content and screw configuration, on the solubility and viscosity of extrudates for a broader range of applications.

Beverage Formulation Sensory Evaluation

Considering the three best selected treatments (T2, T6, T7), treatment T6 (700 rpm/150 °C) was chosen because it has the best water solubility index (ISA: 22.10%) and low initial paste viscosity at 25°C (339.00 cP), favorable conditions for the formulation of an easy-to-reconstitute beverage based on polished red rice flour and retentate blackberry powder.

Sample Selection for Triangular Test and Selection of Tasters

Seven samples of easily reconstituted powdered beverages in milk, strawberry or red fruit flavor, with and without rice flour in their composition, were purchased from a local market. Among them, the samples that had cereal flour in their composition (four samples) were selected. These samples were selected by trained panelists and prepared according to the recommendations on the packaging. Once ready, they were tasted by five tasters, randomly selected, in order to elect the most palatable samples considering the following criteria: sweetness, cereal flavor, homogeneity and consistency. After the analysis, two commercial samples were chosen (**AA**) according whit Table 8, **B** is a beverage with rice and retentate), which would be considered for the triangular test. The tasters recruited were between 19 and 35 years old, and were consumers or had already consumed this type of product. They were not lactose intolerant or allergic to milk proteins, not gluten intolerant or allergic and not diabetic. For the balancing of the triangular test, two (02) Blocks were considered: each block in three stages, as shown in Table 8.

Table 8: Sample balancing for the triangular test.

BLOCK 1			**BLOCK 2**		
1ª STAGE	2ª STAGE	3ª STAGE	1ª STAGE	2ª STAGE	3ª STAGE
AAB	BAA	BAB	ABB	ABA	BBA

Tested Formulations

Preparation method: 30g of the formula for 200 ml of cold whole milk.

FORMULATION 1	
Ingredients	**%**
Extruded Red Rice flour	**45**
Sugar	**23**
Skimmed milk powder	**20**
Maltodextrin	**10**
Blackberry retentate	**2**
Flavoring	**3**

FORMULATION 2	
Ingredients	**%**

Extruded Red Rice flour	**35**
Sugar	**20**
Oatmeal	**10**
Maltodextrin	**10**
Blackberry retentate	**5**
Flavoring	**3**

FORMULATION 3	
Ingredients	**%**
Extruded Red Rice flour	**35**
Sugar	**23**
Whole milk powder	**25**
Maltodextrin	**5**
Blackberry retentate	**2**
Flavoring	**3**

FORMULATION 4	
Ingredients	**%**
Extruded Red Rice flour	**35**
Sugar	**23**
Whole milk powder	**17**
Maltodextrin	**10**
Oatmeal	**10**
Blackberry retentate	**5**
Flavoring	**3**

FINAL FORMULA 5	
Ingredients	**%**
Extruded Red Rice flour	**30**
Sugar	**27**
Whole milk powder	**17**
Maltodextrin	**12**
Oatmeal	**9**
Blackberry retentate	**5**
Flavoring	**3**

The final formulation of the drink for 200mL in whole milk after characterization by the team of tasters was as follows: Extruded polished red rice flour 30%, Sugar 27%, Milk powder 17%, Maltodextrin 12%, Oat flour 9%, Flavoring 3%, Blackberry retentate powder 5%.

CONCLUSIONS

Although it may seem obvious, it is worth mentioning that the extruded samples of both red and white rice had the same degree of extrudability. That is, the ease of working with the granulometries, parameter conditions and equipment configuration during the extrusion process. From the composition point of view, it can be seen that both the raw material and the red rice extrudates had better nutritional quality than white rice. Another interesting conclusion was that the red rice variety studied did not present positive results regarding the presence of anthocyanins. Unlike the blackberry retentate, which had significant values and deserves attention as an ingredient for its use in food formulation. The conditions established by the group of trained tasters were able to define an adequate formulation for the combination of pre-gelatinized red rice flour and percentages of blackberry, among other ingredients, in such a way as to produce a drink that is acceptable to the consumer. From a nutritional point of view, it can be considered a reasonably valuable drink, given the presence of carbohydrates, proteins, minerals and antioxidant components due to the contribution of blackberry retentate.

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