

## Article

# Investigation on Functional, Thermo-Mechanical and Bread-Making Properties of Some White and Black Rice Flours

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**Abstract:** The flour from white rice, Arborio (ARF) and Basmati (BRF) varieties, and the black rice Negro (NRF) variety, were investigated in this study in terms of proximate composition, solvent retention capacity (SRC), and thermo-mechanical properties of dough and bread quality. The flours fell into the classes with very low (NRF) and low amylose content (ARF and BRF); NRF flour had the highest contents of protein (11.16%), crude fiber (4.75%), ash (1.30%), and fats (3.42%). Correlations were obtained between  $\text{CaCl}_2$ -SRC and fiber content, and between  $\text{NaCl}$ -SRC and lactic acid-SRC and protein content. The dough prepared from BRF had a lower value of the thermo-mechanical weakening, which suggests a higher resistance of the proteins to kneading. On the other hand, NRF exhibited a higher value of thermo-mechanical weakening, suggesting a lower protein resistance. Increasing the amount of water used to prepare the dough resulted in the decrease of the rate of starch retrogradation, while the breakdown decreased for BRF and remained constant for ARF and NRF. The specific volume and texture of the bread have been improved by using a larger amount of water in the preparation of the dough. The texture was negatively correlated ( $p < 0.05$ ) with the specific volume of the bread. The best quality bread was obtained when the NRF was used.

**Keywords:** rice flours; solvent retention capacity; thermo-mechanical properties; water absorption



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## 1. Introduction

Rice is one of the most widely cultivated cereal crops. The four major categories of rice grown worldwide are Indica, Japonica, aromatic, and glutinous [1,2].

There are several criteria used for classifying the rice, and the most important criteria refer to the amylose content and the pigments content. From the point of view of the amylose content, the rice can be classified as: waxy rice (0–2%), rice with very low content (3–9%), with low content (10–19%), with intermediate content (20–25%), and with high amylose content (>25%) [3]. In terms of pigments content, there are two types of rice: unpigmented rice, which is the white rice, and pigmented rice, which can be further divided as red, black, and brown [4].

The chemical composition, functional, thermal, pasting, and rheological properties of the rice flour vary significantly with the type of rice [5]. In addition, the grinding process impacts the particle size distribution and the starch content of the rice flour, and therefore the technological behavior and suitability of the flour for preparing different types of end products [6].

The white rice flour has been extensively studied and is currently the most widely used for obtaining different types of food and beverages. Although appropriate for the diet of the celiac people, it was reported that high intake of white rice-based products might increase the glucose homeostasis disorder and type 2 diabetes [7,8]. On the other hand, the pigmented rice flour gained increasing attention in the last years because of the high nutritive value and potential health benefits associated with its consumption [5,8]. The black rice has a higher content of proteins which are well balanced in essential amino acids,

vitamins (A, E, and B complex), minerals (Fe, Mg, Cu, Zn, K, Mn, and P), and bioactive compounds compared to the white rice. The black rice is particularly rich in phenolic compounds, including anthocyanins and phenolic acids, tocopherols, and tocotrienols [8]. Because of the high level of bioactive compounds, the pigmented rice flour was reported to possess many functional properties, including antioxidant capacity, inhibiting effect on the activity of different digestive enzymes, such as  $\alpha$ -amylase and  $\alpha$ -glucosidase, and therefore the ability of lowering the risk of type 2 diabetes, dyslipidemia, obesity and/or hypertension, anticancer, and protection effects towards endothelial cells and against heart and cardiovascular diseases [8–11].

There are many available studies regarding the food applications of the white rice flour, but the information regarding the technological functionality and bread making applications of the black rice flour is scarce. In order to exploit the unique ability to prevent different chronic diseases and the health-promoting properties of the black rice flour, different food products were developed using this cereal as a minor or major ingredient. Ito and Lacerda [8] provided a nice overview on the use of the black rice for obtaining novel foods products like porridge, puddings, and other types of desserts, anthocyanins enriched bread, beverages, rice cakes, and pasta.

The objective of this paper was to provide a comparative analysis of the chemical composition, functional, and thermo-mechanical properties of flours obtained from two white rice and one black rice. In addition, the influence of water absorption on the thermo-mechanical behavior of the dough and on the quality of the bread was investigated.

## 2. Materials and Methods

### 2.1. Materials

Two commercial white rice samples, namely Basmati (BNF) and Arborio (ARF), and one black rice, Negro (NRF), produced by Riso Scotti, were procured from the local market (Galati, Romania).

The rice flours were obtained at laboratory scale by sequential milling the grains using a combination consisting of a disc mill (type WZ-2, Sadkiewicz Instruments, Bydgoszcz, Poland) followed a blade mill grinder (Bosch MKM6003, Gailingen, Germany). The final particles size of the flour samples prepared at laboratory scale level was lower than 400  $\mu\text{m}$ . Prior to analysis, all flour samples were stored at 4 °C in sealed containers to prevent any important chemical or enzyme-assisted changes.

### 2.2. Physico-Chemical Characteristics of Rice Flours

The chemical composition of flours was determined as follows: moisture content using the SR ISO 712:2005 method [12], protein content through semimicro-Kjeldahl method using a nitrogen-to-protein conversion factor of 5.95 (Raypa Trade, R Espinar, SL, Barcelona, Spain), fat content by extraction with ether (Soxhlet extractor, SER-148; VELP Scientifica, Usmate Velate, Italy), crude fiber using the Fibretherm Analyser (C. Gerhardt GmbH & Co. KG, Königswinter, Germany), and ash content using the SR ISO 2171:2002 [12]. The starch content was estimated by subtracting from one hundred grams the percentage of all other chemical components determined experimentally.

Amylose/Amylopectin Assay Kit (Megazyme International Ireland Ltd., Wicklow, Ireland) was used to determine the amylose content, while the damaged starch content was quantified by using the Starch Damage Assay Procedure (Megazyme International Ireland Ltd., Wicklow, Ireland), following the AACC Method 76-31.01 [13].

Fineness module was assessed by sieving the flour samples through 400, 315, 160, and 125  $\mu\text{m}$  mesh [14].

### 2.3. Functional Properties of Rice Flours

The solvent retention capacity (SRC) profile, showing the ability of the flour samples to retain various solvents, such as water (W-SRC), 5% sodium carbonate (SC-SRC), 50% sucrose (Su-SRC), and 5% lactic acid (LA-SRC) upon centrifugation for 15 min at 1000  $\times$  g,

was determined in agreement with the AACC Method 56-11.02 [13]. In a similar manner, the retention of the 1 M CaCl<sub>2</sub> (Ca-SRC) and 1% NaCl (Na-SRC) solvents was tested [15]. The SRC values were determined as the amount of solvent retained by 100 g of flour samples and were reported at moisture basis (14%).

#### 2.4. The Thermo-Mechanical Properties of Rice Flours

The Mixolab device (Chopin Technology, Villeneuve La Garenne, France) was used to prepare doughs and study the thermo-mechanical properties of rice flours. The consistency of the dough was measured while running the protocol proposed by Xie et al. [16]: total weight of the dough 90 g; mixing rate of 120 rpm; temperature of 30 °C for the first plateau of 8 min; temperature increase by 4 °C/min up to 90 °C, corresponding to the second plateau of 7 min; temperature decrease by 4 °C/min down to 50 °C, corresponding to the third plateau of 10 min. Two sets of experiments were performed using different levels of water absorption (WA): (i) WA1 of 65% for all rice flours, (ii) WA2 required to reach the C1 consistency of 1.1 Nm in case of each studied sample.

The Mixolab torque parameters registered while subjecting the dough to dual mixing and thermal constraints are: the maximum C1 torque achieved during initial mixing (used to determine the water absorption), dough consistency after 8 min of mixing at 30 °C (CS), C2, which is an indicator of protein weakening at thermal treatment, C3, associated with starch gelatinization, C4, related to paste stability at high temperature, and C5, which provides information on starch retrogradation during the cooling phase. For each investigated sample, the starch behavior was further determined by calculating the starch gelatinization rate (C3-C2), breakdown torque (C3-C4), and starch retrogradation rate (C5-C4). The speed of starch gelatinization was determined as  $\beta$  slope of curve connecting the C2 and C3 torques [17]. Additionally, the thermo-mechanical weakening (TMW) was calculated as:  $TMW = (CS - C2)/C1 \times 100$  [18].

#### 2.5. Bread-Making Procedure and Bread Characterization

The doughs were prepared according through the one stage method described by Pătrașcu et al. [19]. The following ingredients were added to 100 g whole flour to prepare the dough: 1.5% salt, 2% sugar, 6% lecithin, 3% compressed baker's yeast (Pakmaya, Rompak SRL, Pascani, Romania), and water in agreement with the WA determined for each type of rice flour by means of Mixolab. After mixing all ingredients well for 3 min using a Philips kitchen machine HR7915 (Shanghai, China) at the highest speed, the dough was incubated at 30 °C for 90 min, followed by molding and final leavening for additional 50 min. The leavened samples were baked at 190 °C for 30 min.

The rice flour-based bread samples were characterized by determining the specific volume, crumb firmness, and color. Prior to analysis, the breads samples were tempered to room temperature for 60 min.

The rapeseed displacement method (SR 91:2007) [12] was used to determine the specific volume of the bread samples. Crumb texture was estimated by measuring the firmness in three different points of two slices taken from the center of the bread samples, using the MLFTA apparatus (Guss, Strand, South Africa) and a probe with a diameter of 7.9 mm. The set-up used for measuring the crumb firmness was as follows: bread slice penetration speed of 5 mm/s, penetration wide of 25 mm, and trigger threshold force of 20 g.

The crumb color measurements were performed using the Chroma Meter CR-410 (Konica Minolta Inc., Ramsey, NJ, USA) and the standard illuminant C. Three measurements were performed in the CIE Lab color space.

#### 2.6. Statistical Analysis

The experiments were carried out in duplicate, and average data are reported together with standard deviation. The Minitab 19 software (Minitab Inc., State College, PA, USA) and the one-way ANOVA with a 95% confidence interval were used to assess the differ-

ences between different samples. The normality and variance equality conditions were first checked.

### 3. Results and Discussion

#### 3.1. Physico-Chemical Characteristics of the Rice Flours

The chemical composition of the three rice flours is presented in Table 1. The ash, protein, fat, and fiber contents of NRF were 1.30%, 11.16%, 3.42%, and 4.75%, respectively, much higher than BRF and ARF. At the same time, BRF has higher contents of protein and fiber compared the ARF. Black rice flours usually have higher contents of protein, fiber, ash, and fat compared to the white rice flours [2,8], but differences also appear between Indica and Japonica varieties, Indica being reported to have a higher content of proteins [1]. Based on the amylose content, the investigated flour samples can be classified, according to Kumar and Khush [3], as follows: NRF (6.87% amylose) as rice flour with very low amylose content (3–9%), while BRF and ARF (amylose content of 17.40% and 11.17%, respectively) are rice flours with low amylose content (10–19%). The firmness module varied within quite large limits, from 1.99, in the case of NRF, to 2.10 and 2.15 for BRF and ARF, respectively. NRF had a higher percentage of particles smaller than 160  $\mu\text{m}$  (15.57%), followed by BRF (with 8.57%) and ARF (with 5.83%).

**Table 1.** Physico-chemical characteristics of rice flours.

Component	Flour Samples		
	ARF	BRF	NRF
Moisture, %	12.78 $\pm$ 0.11 <sup>a</sup>	12.15 $\pm$ 0.15 <sup>b</sup>	12.21 $\pm$ 0.09 <sup>b</sup>
Ash, %	0.46 $\pm$ 0.01 <sup>b</sup>	0.46 $\pm$ 0.01 <sup>b</sup>	1.30 $\pm$ 0.03 <sup>a</sup>
Protein, %	7.73 $\pm$ 0.11 <sup>c</sup>	9.99 $\pm$ 0.10 <sup>b</sup>	11.16 $\pm$ 0.05 <sup>a</sup>
Fat, %	1.47 $\pm$ 0.03 <sup>b</sup>	1.45 $\pm$ 0.03 <sup>b</sup>	3.42 $\pm$ 0.07 <sup>a</sup>
Crude fiber, %	2.06 $\pm$ 0.05 <sup>b</sup>	1.46 $\pm$ 0.03 <sup>c</sup>	4.75 $\pm$ 0.05 <sup>a</sup>
Starch, %	88.28 $\pm$ 0.63 <sup>a</sup>	86.64 $\pm$ 0.56 <sup>b</sup>	79.37 $\pm$ 0.23 <sup>c</sup>
Starch damage, %	9.71 $\pm$ 0.10 <sup>a</sup>	5.34 $\pm$ 0.05 <sup>c</sup>	6.26 $\pm$ 0.05 <sup>b</sup>
Amylose, %	17.40 $\pm$ 0.17 <sup>a</sup>	11.17 $\pm$ 0.11 <sup>b</sup>	6.87 $\pm$ 0.16 <sup>c</sup>
Fineness module	2.15 $\pm$ 0.05 <sup>a</sup>	2.10 $\pm$ 0.10 <sup>a</sup>	1.99 $\pm$ 0.04 <sup>a</sup>

ARF—Arborio rice flour; BRF—Basmati rice flour; NRF—Negro rice flour. Mean values on the same row not sharing a superscript letter are significantly different ( $p < 0.05$ ).

#### 3.2. Functional Properties of Rice Flours

In order to gather information on the contribution of the main macromolecular compounds of the rice flour to the functionality of the samples, the solvent retention capacity profiles were determined, and the results are shown in Table 2.

The values of Ca-SRC varied significantly with the investigated samples ( $p < 0.05$ ). The highest values of Ca-SRC were registered for NRF. In a previous study performed on oat, Niu et al. [15] showed that Ca-SRC is correlated with  $\beta$ -glucan content and reported no relationship with protein and starch contents. On the other hand, Phuwadolpaisarn [20] characterized different rice cultivars grown in various locations of Thailand and reported a significant negative correlation between the  $\beta$ -glucan and amylose contents. They indicated that rice contains between 0.11 and 0.88%  $\beta$ -glucans, similar to other cereal grains, the  $\beta$ -glucan being mainly located in the starchy endosperm, subaleurone, and aleurone cell walls. No assessment of the  $\beta$ -glucan content was performed in the present study, but a significant negative correlation was found between amylose content and Ca-SRC ( $R^2$  of 0.9939 and  $p < 0.05$ ; Table S1).

**Table 2.** The solvent retention capacity (SRC) profile of the rice flours.

SRC	Flour Samples		
	ARF	BRF	NRF
W-SRC, %	115.49 ± 0.50 <sup>b</sup>	105.85 ± 0.30 <sup>c</sup>	124.51 ± 0.36 <sup>a</sup>
Ca-SRC, %	103.65 ± 0.41 <sup>c</sup>	110.84 ± 0.30 <sup>b</sup>	134.33 ± 0.25 <sup>a</sup>
Na-SRC, %	93.03 ± 0.26 <sup>c</sup>	101.66 ± 0.35 <sup>b</sup>	105.27 ± 0.23 <sup>a</sup>
SC-SRC, %	104.10 ± 0.36 <sup>a</sup>	84.89 ± 0.35 <sup>c</sup>	90.18 ± 0.17 <sup>b</sup>
LA-SRC, %	79.27 ± 0.15 <sup>c</sup>	95.33 ± 0.25 <sup>b</sup>	106.01 ± 0.34 <sup>a</sup>
Su-SRC, %	88.36 ± 0.23 <sup>b</sup>	82.53 ± 0.21 <sup>c</sup>	124.57 ± 0.35 <sup>a</sup>

ARF—Arborio rice flour; BRF—Basmati rice flour; NRF—Negro rice flour; W-SRC—water retention capacity; Ca-SRC—CaCl<sub>2</sub> solvent retention capacity; Na-SRC—NaCl solvent retention capacity; SC-SRC—sodium carbonate solvent retention capacity; LA-SRC—lactic acid solvent retention capacity; Su-SRC—sucrose solvent retention capacity. Mean values on the same row not sharing a superscript letter are significantly different ( $p < 0.05$ ).

Na-SRC and LA-SRC are associated with protein (glutenin) characteristics [15]. NRF had higher Na-SRC and LA-SRC values compared to BRF and ARF. In fact, both Na-SRC and LA-SRC were significantly correlated with the protein content ( $R^2$  of 0.9974 and 0.9957, respectively, and  $p < 0.05$ ; Table S1).

SC-SRC is associated with starch damage and varied between 84.89% (BRF) and 104.1% (ARF). Cappa et al. [21] reported slightly higher SC-SRC values of 116.6% for rice flour, while Mariotti et al. [22] reported SC-SRC values of 88.9% and 127.4% for two different commercial gluten free bread mixtures. The SC-SRC results were positively correlated with the damaged starch content ( $R^2$  of 0.9953 and  $p < 0.05$ ; Table S1). Among the investigated rice flours, the ARF presented the highest starch damage, followed by NRF and BRF (Table 1).

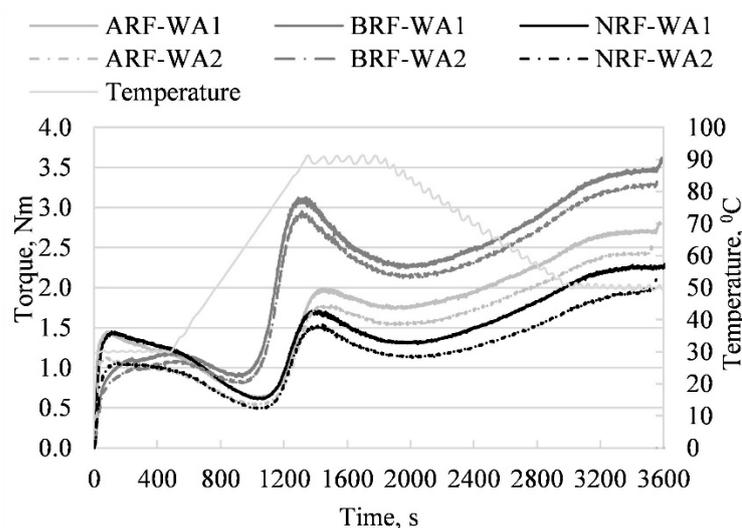
Su-SRC provides indications on the characteristics of the pentosans found in the flour samples (AACC Method 56-11.02) [13]. The non-starchy polysaccharides of the white rice contain arabinose, xylose, mannose, galactose, and glucose units [23], while the non-starchy polysaccharides found in the black rice are mainly made of arabinose, xylose, rhamnose, fucose, and ribose units [24]. The arabinoxylans from rice grain have different arabinose/xylose ratio, Japonica and Indica of 0.84–0.68, and 1.19–1.06, respectively, the lower values of the range being found in the milled rice, while higher ones are found in the brown rice [23]. On the other hand, Kang et al. [25] reported, for four different black rice cultivars (Heukgwangbyeo, Heuknambyeo, Heukjinjubyeo, and Josaengheukchal), a much higher value of the arabinose/xylose ratio (in the 7.62–22.14 range) than in Japonica (arabinose/xylose ratio of 0.84) and Indica (arabinose/xylose ratio of 1.19) varieties investigated by Lai et al. [23]. These differences in the monosaccharide units were found in the composition of the pentosans from different rice varieties, as well as in the ratio between the monosaccharides, which might explain the variation in the ability of the flours to retain the sucrose solution. According to the results shown in Table 2, NRF presented a significantly higher value of the Su-SRC compared to ARF and BRF flours ( $p < 0.05$ ). In fact, a significant positive correlation was found between crude fiber content and Su-SRC values ( $R^2$  of 0.9981 and  $p < 0.05$ ; Table S1).

Finally, the ability of the flour samples to bind and retain water (W-SRC) depends on all flour constituents (AACC Method 56–11.02) [13]. The W-SRC values varied between 105.85% (BRF) and 124.51% (NRF) (Table 2), in agreement with the results of 116.55% reported by Cappa et al. [21] for rice flour.

### 3.3. The Thermo-Mechanical Properties of Rice Flours

The Mixolab curves showing the thermo-mechanical behavior of the investigated rice flour samples are presented in Figure 1. Analyzing the Mixolab curves, one can observe that NRF and ARF behaved similarly when subjected to mechanical and thermal constraints. Thus, during mixing at 30 °C, the consistency of the two doughs increased

up to 1.43–1.44 Nm quite suddenly, within 1.45–1.97 min at WA1 of 65%, and within 1.28–2.48 min at WA2 of 69.7–70.3% (Table 3). However, the stability of NRF dough is 6.1 min, higher compared to that of ARF (4.5 min), at the same WA1 (65%). In the case of WA2 necessary to obtain the maximum consistency of  $1.1 \pm 0.5$  Nm, the situation is maintained, the NRF dough being more stable than the ARF. When a smaller amount of water was used in the dough system (WA1 of 65%), after 8 min of mixing the NRF dough consistency was 1.24 Nm, significantly higher than that of ARF (1.17 Nm) ( $p < 0.05$ ). On the other hand, when a larger amount of water was used to prepare the dough, the CS values of ARF and NRF were extremely close, 0.96–0.97 Nm. When compared to the ARF and NRF doughs, the dough from BRF flour reached a significantly lower consistency at WA1 of 65% ( $p < 0.05$ ), the dough development being slower (C1 achieved after 8.3 min of mixing), and the stability of the dough significantly higher (9.1 min) ( $p < 0.05$ ). Even slower BRF dough development was observed when the WA2 of 66% was used to obtain the maximum consistency of  $1.1 \pm 0.5$  Nm. The BRF dough had a high stability in this case as well, the consistency remaining within the limit of  $1.1 \pm 0.5$  Nm even after 8 min.



**Figure 1.** Mixolab curves of the dough samples prepared with the Arborio (ARF), Basmati (BRF), and Negro (NRF) rice flours at different water absorption (WA) levels: WA1 of 65% and WA2 necessary to obtain the maximum consistency of 1.1 Nm.

In agreement with the observations of Hadnadev et al. [18], the differences in the behavior of NRF dough, on the one hand, and ARF and BRF, on the other hand, can be attributed to the differences in the protein and fiber contents (Table 1), but also to the quality of the proteins. Rice proteins are mainly composed of glutenins and are rich in high molecular weight protein fractions [25]. Liu et al. [26] showed that the proteins in black rice contain a higher amount of glutenins (82.75%), compared to white rice (60%). In addition, there are important differences in other protein fractions: albumin, globulin and prolamins account for 12.61%, 3.41%, and 1.24%, respectively, in the black rice, and for 5%, 10%, and 25%, respectively, in the white rice. Regarding fibers, Kosik et al. [27] showed that the main components of dietary fiber in rice are non-starch polysaccharides in the cell walls, formed by four major fractions: 25% arabinoxylans, 20% glucans, 23% cellulose, and 27% pectin. In addition, Lai et al. [23] showed that the composition of the non-starch polysaccharides is different in the long grain rice compared to the short grain rice, pectic substances being found in a higher percentage of 47.3–62.7% in the short grain rice compared to 42.7–36.3% in the long grain.

**Table 3.** Mixolab parameters of the dough samples prepared with the Arborio (ARF), Basmati (BRF), and Negro (NRF) rice flours at different water absorption (WA) levels: WA1 of 65% and WA2 necessary to obtain the maximum consistency of 1.1 Nm.

Properties	Flour Samples					
	ARF-WA1	ARF-WA2	BRF-WA1	BRF-WA2	NRF-WA1	NRF-WA2
WA, %	65.00	70.30	65.00	66.00	65.00	69.70
C1, Nm	1.44 ± 0.10 <sup>aA</sup>	1.12 ± 0.10 <sup>bX</sup>	1.18 ± 0.01 <sup>aB</sup>	1.08 ± 0.01 <sup>bY</sup>	1.43 ± 0.01 <sup>aA</sup>	1.05 ± 0.01 <sup>bZ</sup>
Time C1, min	1.45 ± 0.02 <sup>aC</sup>	1.28 ± 0.01 <sup>bZ</sup>	8.30 ± 0.03 <sup>bA</sup>	8.68 ± 0.01 <sup>aX</sup>	1.97 ± 0.01 <sup>bB</sup>	2.48 ± 0.01 <sup>aY</sup>
S, min	4.50 ± 0.10 <sup>bC</sup>	6.10 ± 0.10 <sup>aZ</sup>	9.10 ± 0.01 <sup>aA</sup>	8.60 ± 0.01 <sup>bX</sup>	6.10 ± 0.10 <sup>bB</sup>	8.30 ± 0.10 <sup>aY</sup>
CS, Nm	1.17 ± 0.02 <sup>aB</sup>	0.96 ± 0.01 <sup>bY</sup>	1.17 ± 0.01 <sup>aB</sup>	1.07 ± 0.02 <sup>bX</sup>	1.24 ± 0.01 <sup>aA</sup>	0.97 ± 0.01 <sup>bY</sup>
C2, Nm	0.63 ± 0.02 <sup>aB</sup>	0.54 ± 0.01 <sup>bY</sup>	0.90 ± 0.02 <sup>aA</sup>	0.82 ± 0.01 <sup>bX</sup>	0.62 ± 0.01 <sup>aB</sup>	0.49 ± 0.02 <sup>bZ</sup>
TMW, %	37.46 ± 0.27 <sup>aB</sup>	37.14 ± 0.78 <sup>aY</sup>	22.81 ± 0.81 <sup>aC</sup>	23.15 ± 1.04 <sup>aZ</sup>	43.37 ± 1.10 <sup>aA</sup>	45.58 ± 2.12 <sup>aX</sup>
C3, Nm	1.97 ± 0.02 <sup>aB</sup>	1.77 ± 0.01 <sup>bY</sup>	3.09 ± 0.03 <sup>aA</sup>	2.91 ± 0.01 <sup>bX</sup>	1.70 ± 0.02 <sup>aC</sup>	1.51 ± 0.01 <sup>bZ</sup>
TC3, °C	80.50 ± 0.10 <sup>bA</sup>	82.30 ± 0.10 <sup>aX</sup>	77.80 ± 0.10 <sup>aC</sup>	74.50 ± 0.10 <sup>bZ</sup>	79.90 ± 0.10 <sup>aB</sup>	78.80 ± 0.10 <sup>bY</sup>
C4, Nm	1.75 ± 0.01 <sup>aB</sup>	1.55 ± 0.02 <sup>bY</sup>	2.27 ± 0.02 <sup>aA</sup>	2.14 ± 0.01 <sup>bX</sup>	1.31 ± 0.01 <sup>aC</sup>	1.14 ± 0.01 <sup>bZ</sup>
C5, Nm	2.77 ± 0.02 <sup>aB</sup>	2.47 ± 0.01 <sup>bY</sup>	3.54 ± 0.01 <sup>aA</sup>	3.33 ± 0.01 <sup>aX</sup>	2.26 ± 0.02 <sup>aC</sup>	2.01 ± 0.01 <sup>bZ</sup>
C3-C2, Nm	1.36 ± 0.03 <sup>aB</sup>	1.23 ± 0.01 <sup>bY</sup>	2.19 ± 0.04 <sup>aA</sup>	2.09 ± 0.01 <sup>bX</sup>	1.08 ± 0.03 <sup>aC</sup>	1.02 ± 0.02 <sup>bZ</sup>
C3-C4, Nm	0.22 ± 0.01 <sup>aC</sup>	0.22 ± 0.03 <sup>aZ</sup>	0.82 ± 0.04 <sup>aA</sup>	0.77 ± 0.02 <sup>aX</sup>	0.39 ± 0.03 <sup>aB</sup>	0.37 ± 0.02 <sup>aY</sup>
C5-C4, Nm	1.03 ± 0.03 <sup>aB</sup>	0.92 ± 0.01 <sup>bY</sup>	1.27 ± 0.01 <sup>aA</sup>	1.19 ± 0.02 <sup>bX</sup>	0.95 ± 0.02 <sup>aC</sup>	0.88 ± 0.01 <sup>bZ</sup>
Beta, Nm/min	0.38 ± 0.01 <sup>aB</sup>	0.38 ± 0.01 <sup>aY</sup>	0.65 ± 0.01 <sup>aA</sup>	0.60 ± 0.02 <sup>bX</sup>	0.37 ± 0.01 <sup>aB</sup>	0.34 ± 0.01 <sup>bZ</sup>

For each type of flour, mean values on the same row, not sharing a lowercase superscript letter, are significantly different ( $p < 0.05$ ). For each WA level, mean values on the same row, not sharing an uppercase superscript letter, are significantly different ( $p < 0.05$ ).

The high stability of the BRF dough can be explained by the low fiber content. On the other hand, an explanation for the higher value of the water absorption capacity, for which the consistency of  $1.1 \pm 0.5$  Nm is obtained in the case of ARF, compared to BRF, could be the higher content of damaged starch, which exhibits significantly higher water absorption than the native one [28]. A decrease of dough consistency (C2) was further registered in the Mixolab curves when the dough was subjected to a dual constraint of kneading and temperature. As can be seen from Table 3, the ARF and NRF doughs, at WA1 of 65%, registered close C2 values of 0.62–0.63 Nm, while in the case of BRF dough, a significantly higher C2 of 0.90 Nm ( $p < 0.05$ ) was found, a fact also confirmed by the lower value of TMW, which suggests a higher resistance of BRF proteins during kneading and heating. In the case of NRF dough, TMW value was significantly higher compared to both BRF and ARF ( $p < 0.05$ ), regardless of the amount of water used to prepare the dough. This behavior suggests that the NRF proteins, even if they are found in higher quantities than in BRF and ARF, had a lower resistance to kneading and heating.

The dough consistency increased with the temperature, registering a maximum C3 value at 75–83 °C due to starch gelatinization. Regardless of the WA, BRF exhibited the highest C3 value, of 3.09 Nm at WA1 of 65%, and of 2.91 Nm at WA2 necessary to obtain the maximum consistency of  $1.1 \pm 0.5$  Nm. Among the three investigated rice flours, BRF exhibited not only the highest C3 value, but also the highest values for breakdown (C3-C4) and starch retrogradation rate (C5-C4). The high values of (C3-C4) highlight the measure of the degree of stability and disintegration of starch granules on heating, being in direct relation with the stability of the starch paste [29], which means a lower stability. On the other hand, the high values of (C5-C4) highlight the low resistance to retrogradation [29]. These results can be attributed to the lower amylose content of BRF flour, which has been shown to be directly related to high viscosity on gelatinization and high stability on heating,

and inversely related to gelatinization temperature [30,31]. In addition, as can be seen from Figure 1, the BRF starch gelatinization occurred in a shorter time, at a higher rate. BRF had the highest beta slope values among the three investigated flours (Table 3).

Among the three investigated flour samples, ARF flour registered the highest gelatinization temperature of 80.5 °C for WA1 of 65%, as well as for WA2 necessary to obtain the maximum consistency of  $1.1 \pm 0.5$  Nm (TC3 of 82.3 °C), and these results can be attributed to the high amylose content [32]. Moreover, Cai et al. [32] showed that the gelatinization temperature also depends on the structure of amylopectin, the short, branched chain of amylopectin, and the intensity of the lamellar peak being negatively correlated with gelatinization temperatures. On the other hand, BRF recorded the lowest values of gelatinization temperature among the analyzed samples. The higher content of damaged starch also has a certain contribution. When comparing the rheological behavior of some flours with different content of damaged starch, Dubat and Boinot [17] showed that the increase of the content of damaged starch was accompanied by the decrease of C3, C4, and C5, but also (C3-C4) and (C5-C4).

NRF flour recorded the lowest values of C3, C4, C5, and C5-C4 (Table 3), while the gelatinization temperature was significantly lower than of ARF, but significantly higher than of BRF ( $p < 0.005$ ). Among all investigated samples NRF had the lowest amylose content (Table 2). In the case of NRF samples, starch gelatinization occurred earlier than in the case of ARF, but later than in the case of BRF. When analyzing the pasting properties of black rice, Sompong et al. [2] highlighted that, at low amylose contents, starch gelatinization is obtained faster because amylopectin is predominant, and allows a lighter swelling of starch granules. In addition, the authors showed that low values of amylose content result in low values of peak viscosity, breakdown, and starch retrogradation. However, Sompong et al. [2] reported that the black rice with high amylose content had a gelatinization temperature of 73.2 °C, higher compared to the 63.8–64.1 °C range registered for the black rice with low amylose content. An explanation for these results could be the different morphologies of starch granules as identified by Kang et al. [25] in the case of black rice samples. The authors explained it by the differences in the biological and physiological origin of rice, in addition to the variation in amylose content, which plays an important role in controlling the size and shape of starch granules.

The amount of water used to prepare the dough influences the consistency values measured during heating and cooling phases of the Mixolab test. In the case of all dough samples, the maximum C3 consistency was lower by 0.18–0.21 Nm when more water was used for dough preparation. Moreover, in case of BRF and NRF samples the C3 was reached at significantly lower temperature values when the WA increased ( $p < 0.05$ ), while for ARF the temperature associated to C3 increased from 80.50 to 82.30 °C ( $p < 0.05$ ). Similarly, the C4 and C5 decrease was also recorded. However, the breakdown (C3-C4) did not change for ARF and NRF samples, while a slight decrease from 0.82 to 0.77 Nm was noticed in the case of BRF. Slight changes of the beta slope were found, regardless of the amount of water in the system. When the amount of water in the dough was higher, the starch retrogradation rate (C5-C4) decreased, which indicates lower degree of starch recrystallization on cooling and limited rearrangements of the amylose molecules coming out of the swollen starch granules during cooling [29]. From the perspective of obtaining bakery products, these results create the premises for obtaining products with better properties. Dubat and Boinot [17] studied the effect of incorporating 5–50% cassava flour in the wheat flour at different WA levels: WA necessary to obtain the dough consistency of  $1.1 \pm 0.05$  Nm out of flour mixtures vs. WA necessary to obtain the consistency of  $1.1 \pm 0.05$  Nm for wheat flour. They observed a rapid increase in cassava containing dough consistency when kneading at 30 °C, but also a decrease in C2, C3, C4, and C5, including (C5-C4); only the (C3-C4) increased. Moreover, Dubat and Boinot [17] compared the rheological behavior of gluten free flours at different absorption capacities, and noted a maximum value of C3 consistency, but also a higher (C3-C2) at low WA. Marco and Rosell [33] reported the decrease of the C2, C3, C4, C5, and (C5-C4) values when raising the water absorption capacity of rice flour from 65 to 95%.

### 3.4. Bread Characterization

The properties of the bread samples prepared with the three types of rice flour used in the study are presented in Table 4.

**Table 4.** Properties of bread samples prepared with the Arborio (ARF), Basmati (BRF), and Negro (NRF) rice flours at different water absorption (WA) levels: WA1 of 65% and WA2 necessary to obtain the maximum consistency of 1.1 Nm.

Properties	Samples					
	ARF		BRF		NRF	
	WA1	WA2	WA1	WA2	WA1	WA2
Specific volume, g/cm <sup>3</sup>	193.82 ± 1.60 <sup>aA</sup>	196.89 ± 1.84 <sup>aX</sup>	181.53 ± 1.50 <sup>aB</sup>	183.36 ± 1.52 <sup>aY</sup>	195.51 ± 1.33 <sup>bA</sup>	199.76 ± 1.65 <sup>aX</sup>
Firmness, g force	1444.5 ± 42.0 <sup>aB</sup>	1302.1 ± 20.3 <sup>bY</sup>	1845.4 ± 45 <sup>aA</sup>	1573.9 ± 29.6 <sup>bX</sup>	1308.0 ± 35.4 <sup>aC</sup>	1219.9 ± 26.5 <sup>bZ</sup>
L*	60.61 ± 0.01 <sup>bB</sup>	61.04 ± 0.11 <sup>aY</sup>	60.96 ± 0.05 <sup>bA</sup>	61.45 ± 0.11 <sup>aX</sup>	14.26 ± 0.06 <sup>bC</sup>	14.50 ± 0.02 <sup>aZ</sup>
a*	1.64 ± 0.01 <sup>bB</sup>	1.68 ± 0.01 <sup>aY</sup>	1.43 ± 0.01 <sup>bC</sup>	1.58 ± 0.01 <sup>aZ</sup>	5.51 ± 0.01 <sup>bA</sup>	5.95 ± 0.01 <sup>aX</sup>
b*	11.30 ± 0.01 <sup>bA</sup>	12.36 ± 0.01 <sup>aX</sup>	10.58 ± 0.04 <sup>bB</sup>	10.85 ± 0.01 <sup>aY</sup>	-1.53 ± 0.01 <sup>bC</sup>	-1.38 ± 0.01 <sup>aZ</sup>

For each type of flour, mean values on the same row, not sharing a lowercase superscript letter, are significantly different ( $p < 0.05$ ). For each WA level, mean values on the same row, not sharing an uppercase superscript letter, are significantly different ( $p < 0.05$ ).

Regardless of the amount of water used for preparing the dough, the highest values of the specific volume were obtained for NRF breads, followed by ARF and BRF samples. The specific volume increased when the doughs were prepared with higher water amounts. Marco and Rosell [33] noted the importance of using a higher amount of water in the dough preparation and mentioned the plasticizing effect of water in the preparation of the bread from gluten free and low protein flours. The positive effects of the higher amount of water in the dough on the specific volume of the bread and crumb texture were also highlighted by de la Hera et al. [34]. In agreement with the observations of de la Hera et al. [34], our results indicated that the crumb texture was also improved by using a higher amount of water in the preparation of the dough. The crumb firmness decreases from 1308.0 to 1219.9 g force in the case of NRF samples, from 1444.5 to 1302.1 g force in case of ARF, and from 1845.4 to 1573.9 g force in the case of BRF. The crumb texture was negatively correlated with the specific volume of the bread ( $R^2$  of 0.9965 and  $p < 0.05$ ). Therefore, our results comply with de la Hera et al. [34], who explained that in case of a small volume bread samples the crumb is denser, and the pores are more compact.

The lightness ( $L^*$ ) parameter was much higher in the case of ARF and BRF breads compared to NRF. The black rice has high amounts of anthocyanins [8] that confer a dark purple color to the bread. The crumb of the ARF and BRF bread samples had positive  $b^*$  values, while in the case of NRF-based samples negative  $b^*$  values were registered, suggesting the prevalence of the blue shade over the yellow one. The  $a^*$  parameter had significantly higher values in the case of NRF compared to ARF and BRF bread samples, indicating the predominance of the green shades. The slight increase of the  $L^*$ ,  $a^*$ , and  $b^*$  parameters was observed when more water was used to prepare the dough.

## 4. Conclusions

The functional and thermo-mechanical properties of the rice flours are influenced by the chemical composition. The amylose, damaged starch, fiber, and protein contents influenced the retention capacity of different solvents. The investigation of the thermo-mechanical behavior of dough also showed differences regarding the protein quality. Thus, BRF presented higher values of the thermo-mechanical weakening, suggesting a higher resistance of the proteins during heating, while the proteins from NRF had a lower resistance. The amount of water used to prepare the dough influenced its behavior during heating and cooling. Thus, C3, C4, C5, and (C5-C4) decreased with the increase of the water absorption. A positive effect of the use of a larger amount of water for dough preparation

was noticed on the specific volume of the bread and the texture of the crumb. The best quality bread was obtained using NRF.

**Supplementary Materials:** The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/app12094544/s1>, Table S1: Correlations between solvent retention capacity and main chemical components found in the rice flours.

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