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THERMO-MECHANICAL AND BAKING PROPERTIES OF THE QUINOA-RICE COMPOSITE FLOUR

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Abstract
The increased interest of consumers for new products from ancient grains has driven the development of bakery products from quinoa. The objective of this study was to investigate the impact of quinoa flour addition to the rice flour on the thermo-mechanical properties of the dough, and on the quality of the bread. Compared to the rice flour-based dough, the quinoa flour-based one presented higher thermo-mechanical weakening of proteins. The starch stability during heating and starch retrogradation during the cooling phase were lower in the case of quinoa flour compared to rice flour. The quinoa flour addition to the rice flour improved starch retrogradation properties. Thus, the torque value from the Mixolab curve, indicating starch retrogradation decreased from 1.716 Nm to 0.979 Nm when replacing 50% of rice flour with quinoa flour. The bread prepared with composite flour has higher specific volume and lower crumb firmness, compared to the rice flour-based bread. These results highlight the possibility of using quinoa flour to prepare high quality gluten-free bakery products.

Keywords: quinoa, rice, dough, rheology, gluten free bread

Introduction

Quinoa is a pseudocereal that became more and more popular among consumers due to its nutritional composition. The nutritional potential and the possible contribution of quinoa to global food security were recognized by FAO, whcih declared 2013 as “The International Year of Quinoa” (FAO, 2013).

In the last 10 years, the world production of quinoa increases from 74,353 tonnes to 161,415 tonnes, the most important producers being Peru and Bolivia (FAO, 2021). In 2019, the European import of quinoa was about 28,000 tonnes, France being the main European importer, followed by Germany, Netherlands, United Kingdom,

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Spain and Poland (CBI, 2021). The high interest of European consumers for quinoa resides in their concern for new and authentic products, including the ancient grain (CBI, 2021). Therefore, the producers are interested to use quinoa for obtaining composite flours with rice or pulses flour, to be used for preparing different kinds of cereal products, such as bakery products and breakfast cereals.

Quinoa is a valuable source of high-quality proteins (Vidueiros *et al*., 2015; Xu *et al*., 2019). Moreover, quinoa has a high content of unsaturated fatty acids, vitamins, minerals, dietary fibers and polyphenols (Ahmed *et al*., 2019; Pellegrini *et al*., 2018; Pereira *et al*., 2019; Vidueiros *et al*., 2015; Xu *et al*., 2019). Recent studies showed that the baking products obtained from composite flours that include quinoa flour have a low glycemic index (Xu *et al*., 2019).

Besides all these properties, quinoa is a gluten-free grain, which can be therefore included in the diet of people with celiac disease (Jan *et al*., 2018).

This study focused on evaluating the impact of quinoa flour addition to the rice flour, on the rheological properties of the dough, and the bread-making potential. Thus, after analyzing the chemical composition of quinoa and rice flour, the thermo-mechanical properties of composite dough and the physical-chemical properties of the resulting bread were studied.

Materials and Methods

Materials

The quinoa white flour (Planteea, Bucharest, Romania) and whole rice flour (Solaris Plant SRL, Bucharest, Romania) were purchased from the Galati market (Romania).

Proximate compositions

The proximate compositions of quinoa white flour (QF) and whole rice flour (RF) were determined using the following methods: SR ISO 712:2005 for moisture content, SR ISO 2171/2002 for ash content, semimicro-Kjeldahl for protein content (Raypa Trade, R Espinar, SL, Barcelona, Spain), Soxhlet for fat content (SER-148; VELP Scientifica, Usmate Velate (MB), Italy), specific digestion and filtration processes using the Fibretherm Analyser for crude fiber content (C. Gerhardt GmbH & Co. KG, Germany). Finally, the starch content of the rice and quinoa flours was determined by subtracting from one hundred the amount of all components assessed through analytical methods.

The thermo-mechanical properties

The Mixolab device (Chopin Technology, Villeneuve La Garenne, France) was used to measure the thermo-mechanical properties of quinoa white flour, whole rice flour and the blends consisting of whole rice flour and quinoa white flour in the ratio of 25:75 (75RF+25QF) and 50:50 (50RF+50QF). In order to obtain the dough, a water absorption (WA) of 66.4% was used. The protocol of Xie et al. (2011) was considered for preparing 90 g of dough per batch and monitoring its thermo-mechanical behavior while subjecting it to the dual constraint of kidding and heating: initial mixing for 8 min at 120 rpm and constant temperature of 30°C rate, followed by heating by 4°C/min up to 90°C when a second temperature plateau of 7 min was allowed; the dough was afterward cooled down to 50°C, at gradient temperature of 4°C/min; a third temperature plateau of 10 min was allowed at 50°C. The main torque values registered in the Mixolab curves associated with proteins and starch performance in the dough matrix are: C2 provides information on the thermal-dependent protein weakening, while C3, C4 and C5 are associated wtih starch behavior at gelatinization, hot gel stability and retrogradation behavior during the cooling phase, respectively (Dubat and Boinot, 2012; Svec and Hruskova, 2015). In order to gather more insights into the starch related dough behavior during heating and cooling, additional parameters were calculated starting from the Mixolab torques values, as follows: breakdown (C3-C4), starch retrogradation (C5-C4). Moreover, the consistency of the dough after 8 min of mixing at 30ºC (CS) was measured and was used to determine the thermo-mechanical weakening of proteins as TMWP = (CS-C2)/C1 (Villanueva *et al*., 2018; Svec and Hruskova, 2015; Gujral *et al*., 2018).

Bread-making procedure and bread characterization

In order to perform the baking test, the one-stage method was used to obtain the dough, in agreement with Pătraşcu *et al*. (2017). The following ingredients were mixed to obtain the dough: 100 g whole rice flour or flour mixture, 1.5 g salt, 2 g sugar, 6 g lecithin, 3 g compressed baker's yeast (Pakmaya, Rompak SRL, Pascani, Romania) and 66.4 ml water.

After baking for 30 min at 190ºC using the oven (Micro 4T, Mondial Forni, Italy), the bread samples were allowed to cool down and equilibrate to room temperature and were further used for analysis.

The SR 91:2007 method based on the rapeseed displacement was used to determine the specific volume of the bread samples. The firmness of the crumb was measured using the MLFTA apparatus (Guss, Strand, South Africa). Three distinct measurements were carried out by penetrating for 25 mm the center of two different bread slices, using a test speed of 5 mm/s, a probe with a diameter of 7.9 mm and a trigger threshold force of 1.96 N.

Statistical analysis

The results are presented as mean ± standard deviation values of triplicate measurements. The significant differences among results were assessed using the Minitab19 (Minitab Inc., PA, USA) software and the One-way ANOVA. The post-hoc analysis using the Tukey method at a confidence of 95% was employed when appropriate ($p < 0.05$).

Results and discussion

Proximate compositions

The proximate composition of quinoa and rice flours is shown in Table 1. As can be seen, the protein content of quinoa flour is more than double compared to rice flour. Different studies indicate that quinoa flour is a source of high-quality protein, rich in lysine and histidine (Ahmed *et al*., 2019; Jancurova *et al*., 2009; Pellegrini *et al*., 2018). Beyond the qualitative and quantitative aspects regarding the protein, both quinoa and rice flours have low prolamin contents, being listed as natural gluten-free flours (Jan *et al*., 2018).

Table 1. Proximate compositions of quinoa and rice flours (% d.w.).

Component	Quinoa flour	Rice flour
Moisture, %	9.67±0.08	11.27±0.06
Protein, %	13.08±0.07	6.32±0.08
Fat, %	5.72±0.07	2.15±0.05
Ash, %	2.61±0.01	1.51±0.02
Crude fiber, %	5.97±0.16	6.53±0.15
Starch, %	62.95±0.17	72.22±0.16

Quinoa flour has higher fat and ash contents compared to rice flour (Table 1). Previous studies indicated that quinoa seeds have high contents of fat, including essential fatty acids, and minerals, such as calcium, iron and magnesium (Ahmed *et al*., 2019; Pereira *et al*., 2019). On the other hand, the rice flour had higher crude fiber and starch contents compared to the quinoa flour (Table 1). These results can be explained by the fact that the rice flour used in the present experiment is wholemeal flour. In the case of quinoa, in addition to the ecotype, variety and growth conditions (Jancurova *et al*., 2009; Pereira *et al*., 2019; Vidueiros *et al*., 2015) which are usually recognized as major factors influencing the composition of the grains, the amount of different nutrients in the flour also depends on the particular preliminary treatments, *e.g.* dehulling, washing and drying, applied to seeds prior to grinding (Stikic *et al*., 2012; Miranda *et al*., 2010).

The thermo-mechanical properties

The thermo-mechanical properties of quinoa and rice flours and of the two composite flours used in the study (75RF+25QF and 50RF+50QF) are shown in Figure 1. Analyzing the Mixolab curves registered for quinoa and rice flours, one can easily notice the distinct thermo-mechanical behavior of the two samples. Upon water addition to WA of 66.4%, a rapid increase of the torque to 2.11 Nm (C1) was registered, whereas after 8 minutes of kneading at a constant temperature of 30°C the torque of the quinoa flour dough decreases to 1.05 Nm (Table 2). A different behavior was registered for rice in this zone of the Mixolab curve, in which case the maximum torque (C1) of 1.17 Nm was preserved even after 8 min of kneading. These results give an indication about the better stability of the dough obtained from rice flour compared to quinoa flour. The stability of the rice flour dough was 8.1 min, while in the case of quinoa flour dough the stability was 1.1 min.

The minimum torque C2 of quinoa flour dough (0.49 Nm) was reached more quickly (15.73 min) and at a lower temperature (51.1°C), compared to the rice flour dough when the C2 of 0.73 Nm was registered at 53.3°C after 16.88 min.

The rheological behavior of the quinoa flour dough during kneading at 30°C for 8 min and afterward upon subjecting it to the dual constraints including gradual heating up to 51.1°C, can be due to the proteins. Higher protein weakening was noticed in the case of quinoa compared to rice flour (Figure 1). In addition, the greater thermo-mechanical weakening of quinoa proteins is confirmed by the TMWP value of 26.54% obtained for quinoa flour dough, which is significantly lower compared to 37.61% obtained in the case of rice flour dough.

Table 2. Mixolab parameters of quinoa flour (QF), rice flour (RF) and composite flours (75RF+25QF and 50RF+50QF).

Parameters	RF	75RF+25QF	50RF+50QF	QF
WA, %	66.4	66.4	66.4	66.4
C1, Nm	1.17±0.02^{b*}	0.65±0.01^{d}	0.80±0.02^{c}	2.11±0.01^{a}
CS, Nm	1.17±0.03^{a}	0.52±0.02^{c}	0.53±0.02^{c}	1.05±0.01^{b}
Stability, min	8.10±0.10^{a}	4.30±0.10^{b}	2.60±0.10^{c}	1.10±0.10^{d}
C2, Nm	0.73±0.03^{a}	0.28±0.02^{c}	0.24±0.03^{c}	0.49±0.01^{b}
Time for C2, min	16.88	16.55	15.57	15.73
Temperature at C2, °C	53.3	52.3	50.7	51.1
TMWP, %	37.61±2.16^{a}	36.92±1.36^{a}	36.25±2.21^{a}	26.54±0.13^{b}
C3, Nm	2.56±0.02^{a}	2.46±0.03^{b}	2.24±0.03^{c}	1.75±0.01^{d}
C3’, Nm	-	-	-	1.44±0.03
Time for C3, min	23.75	23.32	23.07	19.48
Time for C3’, min	-	-	-	23.25
Temperature at C3, °C	78.9	79.2	79.9	65.4
Temperature at C3’, °C	-	-	-	79.7
C4, Nm	2.28±0.03^{a}	1.92±0.02^{b}	1.76±0.02^{c}	1.12±0.01^{d}
Time for C4, min	30.2	31.73	32.68	31.6
Temperature at C4, °C	87.7	88.4	88.3	87.3
C5, Nm	4.13±0.02^{a}	3.11±0.02^{b}	2.75±0.02^{c}	2.07±0.02^{d}
C3-C4, Nm	0.28±0.02^{d}	0.54±0.03^{b}	0.48±0.02^{c}	0.63±0.02^{a}
C5-C4, Nm	1.85±0.02^{a}	1.19±0.03^{b}	0.99±0.01^{c}	0.95±0.01^{c}

*Average values on the same line not sharing a superscript letter are significantly different

The main thermo-mechanical parameters of composite flours dough are presented in Table 2. Typical Mixolab curves were registered for both tested composite flours (Figure 1), but C1 values were lower than 1.1 Nm – 0.65 Nm in the case of the composite flour with 25% QF, and 0.80 Nm in the case of the composite flour with 50% QF (Table 2). However, the 75RF+25QF and 50RF+50QF composite flours had similar CS torque values, registered after 8 min of kneading at 30ºC. The addition of quinoa flour decreased dough stability and increase TMWP compared to the rice flour. Anyway, compared to the quinoa flour dough, the behavior of the composite flour doughs during kneading and heating was improved. In particular, the C2 value decreases to 0.28 Nm in the case of the 75RF+25QF dough and to 0.24 Nm in the case of the 50RF+50QF dough.

The C3 torque which is associated with starch gelatinization was registered at a much lower temperature of 65.4°C in the case of QF, compared to the RF sample, in which case the C3 was reached at a temperature of 78.9°C. An interesting rebound phenomenon was noticed at 79.7°C in the case of QF samples, at about the same time as C3 corresponding to the RF dough. The additions of increasing amounts of QF to RF resulted in a gradual decrease in the C3 value. This behavior of QF during heating can be due to the starch properties, in particular to the amylopectin, which has high amounts of short chains as well as super-long chains (Li and Zhu, 2018). The distribution of the individual unit chains of amylopectin was reported to exert a high influence on the quinoa starch rheological properties (Li and Zhu, 2018).

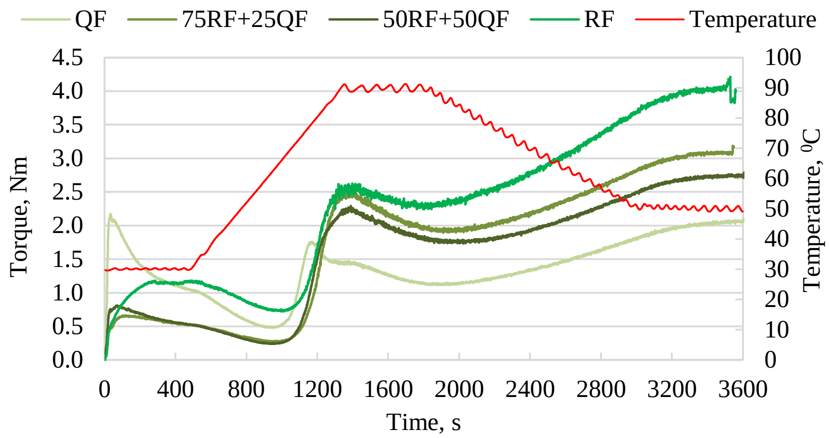

Figure 1. Thermo-mechanical properties of quinoa (QF), rice flour (RF) and composite flours (75RF+25QF and 50RF+50QF).

The starch stability during heating (C4) was lower in the case of QF compared to RF. Increasing (C3-C4) values were obtained with the increase of the QF within the flour mixture, and this can be explained by the more intense amylase activity of QF (Aprodu and Banu, 2021). Starch retrogradation during the cooling phase was much lower for QF (C5 of 2.07 Nm), compared to the RF (C5 of 4.13 Nm). In these conditions, (C5-C4) value decreased with QF addition from 1.85 Nm, corresponding to the RF sample, to 0.99 Nm corresponding to the 50RF+50QF sample, which means that QF addition improved starch retrogradation properties.

Breads characterization

The quality characteristics of the bread samples are presented in Table 3. The bread samples prepared with composite flours including different amounts of QF had significantly higher specific volumes compared to the bread sample prepared with rice flour. Moreover, the crumb firmness decreased with the increase of QF within the flour mixture. These observations are in good agreement with the literature. A previous study by Elgeti et al. (2014) showed that the dough prepared with quinoa flour has a much higher ability to retain the fermentation gas compared to rice flour. This property of the quinoa flour-based dough is due to the presence of some surface-active components (e.g. peptides, polar lipids) involved in the stabilization of the bubbles gas resulted during fermentation.

Table 3. Physical properties of bread samples prepared with rice flour (RF) alone or in admixture with 25% or 50% quinoa flour (QF).

Properties	Breads prepared with		
	RF	75RF+25QF	50RF+50QF
Specific volume, cm^3/100 g	293.54±0.62[c]	301.56±0.89[b]	313.39±0.70[a]
Crumb firmness, g force	1249.71±1.46[a]	951.43±1.01[b]	797.23±0.80[c]

*Average values on the same line not sharing a superscript letter are significantly different.

When studying the quality of bread samples prepared from different gluten-free flours, Banu and Aprodu (2020) observed that the quinoa flour bread had higher specific volume and lower crumb firmness compared to the bread prepared with rice, sorghum and millet flours.

Conclusions

Thermo-mechanical evaluation of quinoa dough evidenced that quinoa flour presents high protein weakening during kneading and heating, but starch stability during heating and starch retrogradation during the cooling phase is improved when quinoa flour is used for obtaining composite rice flour. The rice flour substitution with quinoa flour improves the specific volume and crumb firmness of bread. Quinoa flour provides to be a good source of flour for preparing bakery gluten-free products.

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