Received: 1 May 2021 | Revised: 12 July 2021 | Accepted: 5 August 2021

DOI: 10.1111/jfpp.15873

ORIGINAL ARTICLE

Journal of Food Processing and Preservation | Institute of Food Science + Technology ifst | WILEY

Rheological behavior of emmer, spelt and khorasan flours

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Funding information
European Cooperation in Science and Technology, Grant/Award Number: CA 18101; Science Fund of the Republic of Serbia, Grant/Award Number: 6062634

Abstract

A comparative evaluation of the rheological properties of ancient wheat flours (emmer, spelt, and khorasan), cultivated under the same conditions, was conducted. They were evaluated for chemical composition, wet gluten quantity, quality, aggregation, and disruption kinetics (GlutoPeak), dough proofing (Rheofermentometer), as well as mixing and thermal behavior (Mixolab). High wet gluten content of spelt flour led to formation of strong gluten network with the highest water absorption and maximum dough height during proofing in comparison to other varieties. Khorasan flour, although having very low wet gluten content, exhibited the highest dough stability both during mixing and fermentation due to high gluten index. Despite being characterized with high wet gluten, very low gluten index of emmer flour affected dough development process, resulting in the lowest dough height, and pronounced loss in dough height during fermentation as well as the lowest percentage of gas retained in the dough compared to other species.

Novelty impact statement: The results obtained in this study can be used to better understand the techno-functionality and target application in cereal based products of different ancient wheat species. Considering the obtained results, khorasan wholegrain flour can be the most suitable for bread-making process requiring longer fermentation time, while emmer flour will exhibit better performance in short-term fermentation. In general, making bread from ancient wheats will require modified baking techniques in order to satisfy the renewed consumers' demand for these products, while improving their bread-making potential.

1 | INTRODUCTION

Wheat is one of the major world agricultural products, extensively grown worldwide due to the unique dough rheological properties and the bread-baking quality of its flour (Arzani & Ashraf, 2017). According to EUROSTAT (2020), in 2019, the harvested production of cereals in the EU-27 was 299.3 million tons from which common wheat and spelt account for 131.8 million tons or 44% of total cereals production. Cultivated area of common wheat and spelt in EU in 2019 was 24.2 million ha (EUROSTAT, 2020). On the other hand, the production of the ancient wheat species, such as, diploid einkorn (*Triticum monococcum* L.), tetraploid emmer (*T. dicoccum* L.), and hexaploid spelt (*T. spelta* L.) is suppressed (Geisslitz et al., 2018). In Serbia, spelt is cultivated on the area of 157.9 ha, mostly in the northern region called Vojvodina (120.04 ha) (Vojnov et al., 2020), while emmer and khorasan are produced in a significantly smaller scale compared to spelt. The main reason behind this is low yield (Geisslitz et al., 2018), difficulties related to the processing of grains, as well as inferior technological quality (Arzani & Ashraf, 2017) compared to the common wheat. Regardless of these shortcomings, ancient wheat varieties are considered environment friendly because of its disease resistance and low fertilizer input. Moreover, considering high adaptability to the altered climatic conditions, ancient wheat represents a valuable genetic resource of interest to breeders (Boukid et al., 2018).

In recent years, increased conscience of consumers to healthy and functional foods brought ancient wheat grains back to the spotlight of scientific society. Numerous studies revealed that ancient wheat grains provide more vitamins and minerals, iron and zinc in particular, compared to common wheat (Boukid et al., 2018; Zamaratskaia et al., 2021). According to Zamaratskaia et al. (2021), spelt (50–57 mg/kg), einkorn (49 mg/kg), and emmer (49 mg/kg) contain higher levels of iron compared to modern wheat (20–38 mg/kg). It was also shown (Boukid et al., 2018) that Mg and Zn contents of einkorn (200 and 15 mg/100 g, respectively), emmer (128 and 4.8 mg/100 g, respectively) and khorasan (130 and 3.7 mg/100 g, respectively) are higher than those of common wheat (90 and 3.5 mg/100 g, respectively). Moreover, Hidalgo et al. (2006) reported that tocols in einkorn (61.80 to 115.85 μg/g), emmer (62.7 to 67.9 μg/g), and spelt (62.7 to 67.5 μg/g) were slightly higher than in durum (38.8 to 57.27 μg/g) and common (53.2 to 74.9 μg/g) wheat. Ancient grains are also good sources of proteins, lipids, fructans, and several antioxidants (Hidalgo & Brandolini, 2014; Hidalgo et al., 2013; Longin et al., 2015). Zrcková et al. (2019) have determined that total content of polyphenols was in the following order: einkorn > emmer > common wheat > spelt, while total content of phenolic acids followed the order einkorn > spelt > emmer > common wheat. There are also indices that consumption of ancient wheat flours may reduce metabolic risk factors, markers of oxidative, and inflammatory status, improve lipidic parameters (Sofi et al., 2013).

Despite knowledge about health positive effects and consumers' interest toward ancient wheat grains, commercially available products based on these cereals are still quite rare. Low technological quality of dough produced with ancient wheat flours, in terms of its strength, stability, development time and extensibility, are among the main reasons behind shifting away from ancient grains (Cappelli et al., 2018; Sobczyk et al., 2017).

In order to convert ancient grains into food products with acceptable techno-functional properties, dough's rheological behavior has to be considered. Available literature data, dedicated exclusively to evaluation of technological usefulness of ancient wheat, are commonly focused on quantity and quality of gluten as well as on rheological parameters of individual variety determined by using farinograph, extensograph, and alveograph (Akman & Karaduman, 2021; Cappelli et al., 2018; Sobczyk et al., 2017). Taking into account that conventional bread making process is designed for common and modern wheat, further research, focused on the evaluation of rheological properties, is needed in order to optimize technological processing and formulations to fit compositional and morphological characteristics of ancient wheat varieties. Therefore, the aim of the present work was to perform comparative evaluation of the rheological properties of ancient wheat species (emmer, spelt, and khorasan), cultivated under the same conditions, in terms of gluten aggregation and disruption kinetics, dough proofing, as well as mixing and thermal behavior.

2 | MATERIALS AND METHODS

2.1 | Raw materials preparation

Emmer, spelt, and khorasan were kindly provided by small local producer from Vojvodina region (Poljoprivredno gazdinstvo Jevtić, Serbia). The crops were grown in the year 2018/2019 at the agricultural farm in Bačko Gradište (45°32′N, 20°2′E). Planting took place on October 2018, while crops were harvested in the first decade of July. Crops were stored for six months before analysis. Prior to analysis, hulled crops were dehulled by Heger large scale friction dehuller (Herrenberg, Germany). Milling was carried out using a large scale stone mill Osttiroler Getreidemühlen (Dölsach, Austria).

2.2 | Physico-chemical characterization of flours

Moisture and ash content were determined according to ISO 712:2012 and ISO 2,171:2012, respectively. For the determination of the starch and total fiber content, ISO 10,520:1997 and AOAC 985.29 were used. Protein content was assessed by the Kjeldahl method (ISO 20,483:2013), using a nitrogen to protein conversion factor of 5.7. Wet gluten quantity and quality, expresses as gluten index values, were determined using ISO 21415–2:2015.

2.3 | Rheological characterization of flours

2.3.1 | Mixolab analysis

Emmer, spelt, and khorasan flour water absorption and response to mixing and temperature constraint were measured by Mixolab device (Chopin Technologies, France) according to ICC standard No. 173. The obtained parameters from the recorded curve were: water absorption (WA, %), dough development time (DDT, min); dough stability (min); dough elasticity (amplitude, Nm), the minimum torque value at the beginning of heating (C2, Nm); peak torque or the maximum torque produced during the heating stage (C3, Nm); cooking stability (C4–C3, Nm) and setback as a measure of starch retrogradation (C5–C4, Nm).

2.3.2 | GlutoPeak analysis

Gluten aggregation properties of flour samples were determined using a GlutoPeak (Brabender, Germany). Briefly, flour and demineralized water were mixed in equal amounts (9 + 9 g) and subjected to intensive mixing at 2,750 rpm and 36°C for 10 min. Peak maximum time (s) and maximum torque (GPU) were extracted from GlutoPeak curve.

2.3.3 | Rheofermentometer analysis

The dough development and the gas volume produced by the yeast activity were measured with a Rheofermentometer (Chopin Technologies, France). Each dough was prepared in a Farinograph mixing bowl by mixing 300 g flour, 6 g salt, 3.6 g dry yeast, and water in an amount necessary to achieve consistency of 400 BU for a 5 min. The Rheofermentometer test was performed on 315 g portion of the dough and carried out at 28°C for 4 hr. In contrast to the classic method, the

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weight of dough was reduced to 200 g due to the structure weakness of this kind of wheat varieties compared to modern ones. From dough development curve: maximum dough height (Hm; mm), time to reach maximum height (T1, min), and loss in dough height expressed as percentage, (Vol. loss = (Hm−h)/Hm; %) were determined; while from gas release curve: time of maximum gas formation, (T′1, min), maximum gaseous release height (H′m, mm), time when the porosity of the dough developed and gas starts to escape from the dough (Tx, min), total CO_2 production (Vt, ml), total CO_2 retention (Vr, ml), and CO_2 retention coefficient (Vr/Vt, %) were determined.

2.4 | Statistical analysis

All data are reported as average plus/minus standard deviation of three individual measurements. Statistical analysis of the data and significant differences at the significant level 0.05 for all variables were analyzed by one-way ANOVA procedure, followed by Tukey's multiple comparison tests, using Statistica 10.

3 | RESULTS AND DISCUSSION

Morphological properties of emmer, spelt, and khorasan grain and flour are presented in Figure 1. All wheats were characterized with thin and long grains of elliptical shape. Emmer wheat kernel had lower amount of yellow tone compared to spelt and khorasan. Unlike emmer and spelt, khorasan was characterized with glassy and translucent kernels. Upon milling, khorasan produced the wholegrain flour with the highest content of yellow pigment.

3.1 | Chemical composition of ancient wheat flours

Since nutritional composition of cereals is closely associated with cultivation area, climatic conditions, and agronomic practices (Hidalgo & Brandolini, 2017; Miranda et al., 2011), emmer, spelt, and khorasan were grown in the same field, under the same conditions (fertilization, irrigation), and processed in the flour using the same cleaning and grinding technology. According to results summarized in Table 1, the total starch content of ancient wheat varieties investigated in this study ranged from 67.37% to 71.37% db (dry basis), while total dietary fiber content ranged from 9.58% to 10.10% db, respectively. Spelt provided the lowest starch content in comparison to emmer and khorasan which is in agreement with results of Boukid et al. (2018). However, in contrast to Boukid et al. (2018), three different wheat varieties contained comparable amounts of total dietary fiber, which implies sample variability in terms of genotype by environment and genotype by processing (dehulling and milling) interactions. In general, ancient wheat varieties are characterized with lower starch and fiber content than modern varieties as reported by Boukid et al. (2018) and Ranhotra et al. (1996).

Regarding the protein quantity and quality, emmer and spelt flour showed higher protein and wet gluten content than the khorasan flour. However, khorasan flour was characterized with the highest gluten index value. According to the results of Bojnanska and Francakova (2002), Boukid et al. (2018), and Sumczynski et al. (2015), ancient wheat varieties protein content is generally higher to that of common wheat. Higher protein content described in ancient wheat varieties in comparison to modern is mostly influenced with increased participation of the prolamin alleles from aleurone layer in the kernel of the former (Bojnanska & Francakova, 2002; Rodríguez-Quijano et al. 2010). Bojnanská and Francáková (2002) found from 30.6% to 51.8% of wet gluten in the five spelt cultivars, which is in agreement with results reported in this study. However, ancient wheat varieties are characterized with weak gluten structure which is evident from gluten index values determined in this study and confirmed by RP-HPLC results from Pruska-Kedzior et al. (2008) which have shown that spelt flour has much higher gliadins/glutenins ratio compared to modern wheat.

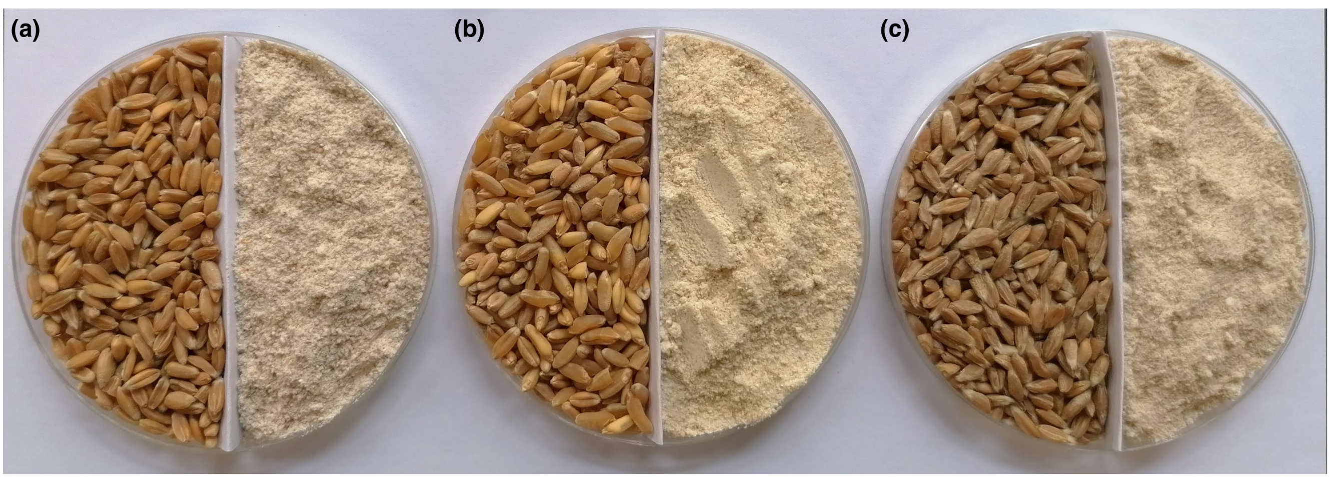

FIGURE 1 Spelt (a), khorasan (b), and emmer (c) grains and wholegrain flours cultivated in Vojvodina region

TABLE 1 Flour characteristics of some ancient wheat varieties cultivated in Vojvodina region

	Emmer	Spelt	Khorasan
Moisture (%)	11.31 ± 0.11[b]	10.80 ± 0.07[a]	10.70 ± 0.06[a]
Ash (%db)	1.87 ± 0.04[b]	1.98 ± 0.06[b]	1.50 ± 0.07[a]
Total starch (%db)	71.37 ± 0.32[b]	67.34 ± 0.34[a]	70.27 ± 0.35[b]
Total fiber (%db)	9.58 ± 0.28[a]	10.10 ± 0.42[b]	9.85 ± 0.31[ab]
Protein (%db)	15.99 ± 0.30[b]	15.87 ± 0.37[b]	11.49 ± 0.43[a]
Wet gluten (%)	29.5 ± 0.42[b]	39.0 ± 0.14[c]	17.5 ± 0.15[a]
Gluten index (%)	11.0 ± 1.41[a]	49.5 ± 2.12[b]	64.0 ± 2.83[c]

Note: The mean values ± standard deviation in the same row are not significantly different ($p > .05$) if they are followed by the same letters in the superscript.

Abbreviation: db, dry basis.

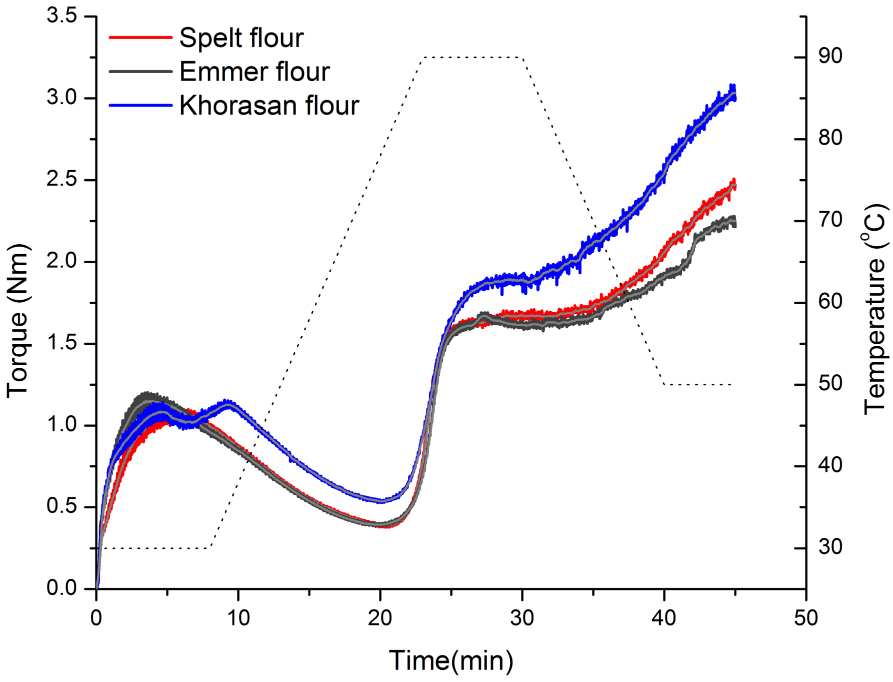

FIGURE 2 Mixolab profiles of some ancient wheat varieties cultivated in Vojvodina region

TABLE 2 Mixolab parameters of some ancient wheat varieties cultivated in Vojvodina region

	Emmer	Spelt	Khorasan
Water absorption (%)	62.2 ± 0.44[b]	62.6 ± 0.25[b]	60.0 ± 0.37[a]
Dough development time, DDT (min)	3.48 ± 0.20[a]	6.33 ± 0.27[c]	4.53 ± 0.17[b]
Dough stability (min)	8.33 ± 0.40[a]	8.20 ± 0.21[a]	11.97 ± 0.45[b]
Dough elasticity (Nm)	0.10 ± 0.02[b]	0.05 ± 0.01[a]	0.09 ± 0.02[b]
C2 torque (Nm)	0.394 ± 0.013[a]	0.388 ± 0.011[a]	0.536 ± 0.010[b]
C3 torque (Nm)	1.670 ± 0.023[a]	1.663 ± 0.020[a]	1.891 ± 0.009[b]
C3-C4 (Nm)	0.064 ± 0.003[c]	0.000 ± 0.000[a]	0.002 ± 0.000[b]
C5-C4 (Nm)	0.639 ± 0.034[a]	0.800 ± 0.049[b]	1.141 ± 0.058[c]

Note: The mean values ± standard deviation in the same row are not significantly different ($p > .05$) if they are followed by the same letters in the superscript.

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3.2 | Rheological properties of ancient wheat flours

3.2.1 | Mixolab profiles of ancient wheat flours

The effect of ancient wheat species on the Mixolab measurements is presented in Figure 2 and summarized in Table 2. Water absorption values ranged from 60% to 62.6%, for khorasan and spelt, respectively. The high wet gluten content in spelt and emmer flour and slightly higher dietary fiber content in the spelt wholegrain flour account for the high water absorption values (Frakolaki et al., 2018). Comparing spelt and emmer flour Mixolab profiles (Figure 2), similarity in behavior could be noticed in terms of water absorption, dough stability, dough weakening upon mixing, and heating, indicating that these properties were influenced with high wet gluten content of these flours. However, these two flours significantly differ in gluten index values which reflected in dough development time (DDT) and elasticity parameters, where spelt flour exhibited almost twice higher DDT than emmer flour, while emmer flour was two times more elastic than spelt flour. On the contrary, khorasan flour was characterized with two peaks during dough development and grater dough stability, an indication of the resistance to mechanical stress (Frakolaki et al., 2018). Since higher stability values in combination with high C2 value (dough weakening upon mixing and heating) suggest stronger doughs (Rosell et al., 2001), khorasan wholemeal flour was characterized with the highest strength despite very low wet gluten values. In addition, although having similar starch content to emmer flour, khorasan exhibited higher starch gelatinization and retrogradation rate which could be ascribed to differences in starch/protein interactions during thermal treatment. Moreover, differences in starch pasting profiles could also be related to differences in starch granule size and amylose/amylopectin ratio.

3.2.2 | GlutoPeak profiles of ancient wheat flours

In order to further examine gluten network development and breakdown upon subjecting ancient wheat flour/water slurry to continuous mechanical stress (Rakita et al., 2018), GlutoPeak test was employed (Table 3). Khorasan flour required longer time for gluten aggregation (peak maximum time) than spelt flour due to higher ratio of quality-related protein fractions (e.g., glutenin and glutenin macro-polymer) expressed as higher gluten index (Marti et al., 2015). However, spelt flour exhibited higher maximum torque, which is correlated to wet gluten content (Rakita et al., 2018). On the contrary, emmer flour was unable to form gluten aggregation peak under the conditions used during GlutoPeak test (Figure 3). This was probably related to low glutenin content in emmer flour and high gliadin to glutenin ratio, resulting in diminished rheological performance in comparison to spelt and khorasan varieties.

3.2.3 | Gas production and dough development of ancient wheat flours

The properties of dough obtained from ancient wheat varieties during fermentation were measured by the Rheofermentometer, which provided information about dough development, gas production, and gas holding capacity (Rosell et al., 2001; Table 3). All ancient

TABLE 3 GlutoPeak and Rheofermentometer parameters of some ancient wheat varieties cultivated in Vojvodina region

		Emmer	Spelt	Khorasan
GlutoPeak test	Maximum torque (GPU)	n.d.	44.5 ± 0.71^b	28.5 ± 0.71^a
	Peak maximum time (s)	n.d.	120.5 ± 0.71^a	175.5 ± 4.95^b
Rheofermentometer dough development curve	Maximum dough height, Hm (mm)	18.4 ± 0.3^a	27.0 ± 0.4^c	21.3 ± 0.4^b
	Time to reach maximum height, T1 (min)	84 ± 2^a	114 ± 3^c	94 ± 3^b
	Loss in dough height at the end of the test, Vol. loss (%)	100 ± 4^b	90.3 ± 4^b	12.7 ± 1^a
Rheofermentometer gas release curve	Time of maximum gas formation, T′1 (min)	183 ± 2^c	147 ± 2^a	169 ± 3^b
	Maximum gaseous release height, H′m (mm)	61.9 ± 2^b	58.3 ± 3^b	50.0 ± 2^a
	Time at which gas starts to escape from the dough, Tx (min)	66 ± 2^a	73 ± 3^b	84 ± 2^c
	Total gas production, Vt (ml)	1864 ± 12^c	1648 ± 10^b	1508 ± 11^a
	Total gas retention, Vr (ml)	$1{,}271 \pm 8^c$	$1{,}220 \pm 6^b$	$1{,}158 \pm 6^a$
	Gas retention coefficient, Vr/Vt (%)	68.1 ± 2^a	74.0 ± 1^b	76.8 ± 1^b

Note: The mean values ± standard deviation in the same row are not significantly different ($p > .05$) if they are followed by the same letters in the superscript.

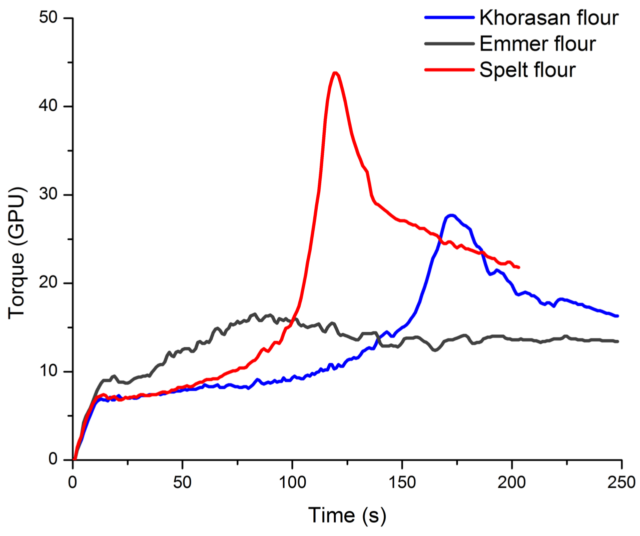

FIGURE 3 GlutoPeak profiles of some ancient wheat varieties cultivated in Vojvodina region

wheats reached a maximum dough height for less than 2 hr, where spelt needed the longest time to develop the maximum dough height (T1). It also had the highest maximum dough height (Hm), which is in agreement with high maximum torque measured by GlutoPeak. Loss in dough height was greatly reduced in khorasan flour compared to spelt and emmer. Since this parameter is related to dough stability, these results indicate that khorasan is characterized with improved dough stability during fermentation, which would require longer fermentation during breadmaking. This is in agreement with the results of Mixolab and GlutoPeak tests which have shown that khorasan flour exhibited the highest dough stability and required longer time for gluten aggregation during mixing.

Regarding the gas behavior (Table 3), the time of maximum gas formation (T′1) and maximum gaseous release height (H′m) was the highest for emmer flour dough which is in accordance with increased elasticity as measured by Mixolab. The time at which gas starts to escape from the doughs (Tx), that is, the moment in which the structure is no longer able to retain the CO_2 (Marti, Bottega, et al., 2015; Rosell et al., 2001) and the relation between gas production and retention (percentage of gas retained in the dough) was the highest for khorasan flour. Since, this parameter is related to dough ability to be stretched in thin membranes and associated to quality of the protein network (Bloksma & Bushuk, 1988), these results support the results of Mixolab test that khorasan flour is characterized with the highest dough strength. Although emmer had the lowest gas retention value, this variety was able to produce (Vt) and retain (Vr) the highest amount of gas.

4 | CONCLUSION

In order to sustain the suitability of some ancient wheat varieties (emmer, spelt and khorasan) for specific bakery applications, their rheological properties were assessed. It was shown that rheological properties depend largely on gluten quantity and quality. Emmer flour, which exhibited high wet gluten and low gluten index values, produced elastic dough structure, able to stretch, produce, and retain the highest amount of gas upon fermentation, but also to collapse fast and loose its structure which resulted in the highest amount of carbon dioxide released into the environment in comparison to spelt and khorasan. On the contrary, khorasan flour, characterized with low wet gluten and relatively high gluten index values, yielded stable dough with good resistance to stresses imparted during mixing and proofing and the highest ability to retain the CO_2 compared to spelt and emmer flour.

ACKNOWLEDGMENTS

This research was supported by the Science Fund of the Republic of Serbia, PROMIS, grant No 6062634, acronym ReTRA. This work is based upon the work from COST Action 18101 SOURDOMICS—Sourdough biotechnology network toward novel, healthier, and sustainable food and bioprocesses, where: the authors are members of the working group 1 (WG1); M. Rakszegi is the leader of WG1; E. Bartkiené is the Vice-Chair and leader of WG6; and J. M. Rocha is the Chair and Grant Holder Scientific Representative of this COST Action. SOURDOMICS is supported by COST (European Cooperation in Science and Technology). COST is a funding agency for research and innovation networks. COST Actions help connect research initiatives across Europe and enable scientists to grow their ideas by sharing them with their peers – thus boosting their research, career, and innovation.

CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest with respect to the research, authorship and/or publication of this article.

ETHICAL STATEMENT

This research did not involve any human or animal ethics issues to be considered.

AUTHOR CONTRIBUTIONS

Conceptualization; Formal analysis; Funding acquisition; Investigation; Project administration; Writing-review & editing: Miroslav Hadnadjev. *Conceptualization; Formal analysis; Methodology*: Jelena Tomic. *Data curation; Formal analysis; Visualization*: Dubravka Škrobot. *Formal analysis; Supervision; Writing-original draft; Writing-review & editing*: Tamara R. Dapcevic Hadnadev.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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How to cite this article: Hadnađev, M., Tomić, J., Škrobot, D., & Dapčević-Hadnađev, T. (2022). Rheological behavior of emmer, spelt and khorasan flours. *Journal of Food Processing and Preservation*, *46*, e15873. https://doi.org/10.1111/jfpp.15873