CHILEAN JOURNAL
of AGRICULTURAL RESEARCH

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RESEARCH ARTICLE

Spelt wheat (*Triticum spelta*) and common bread wheat compared for nutritional contents and functional-technological properties

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Received: 21 July 2022; Accepted: 18 September 2022; doi: 10.4067/S0718-58392023000200146

ABSTRACT

Growing understanding of the relationship between nutrition and human health has led to an increase in the consumption of alternative crops, new cereal varieties and foods with higher nutritional values. In this study we compared nutritional contents and functional-technological properties of spelt (*Triticum spelta* L.) and bread wheat (*T. aestivum* L.) whole-meal flours, obtained from the genotypes grown at the same field trial, and their correlation with 1000 kernels weight (TKW). The average values of TKW for spelt and wheat did not significantly differ, while protein and wet gluten content were significantly higher in spelt (18.8% and 53.9% DM) than in wheat flours (12% and 27.3% DM). Although wheat flours were significantly richer in starch (66.4% compared to 62.5% DM), both spelt and wheat had similar amylose and amylopectin content. The analysis of dietary fibers showed that wheat flours had significantly higher hemicellulose and neutral detergent fiber content, as well as total sugar and sucrose. Water holding capacity were significantly higher in wheat flours. Pasting properties of flours did not differ significantly, except for peak viscosity (Vpeak) which was higher for spelt flours. The TKW of spelt genotypes was in the strongest positive correlation with amylopectin and reducing sugar, while in contrary, TKW of wheat was in the strongest positive correlation with amylose. The TKW had positive influence on dietary fibers of wheat and spelt flours (except acid detergent fiber and cellulose). Correlation between TKW and protein, starch and wet gluten was similar for both subspecies. In both subspecies reducing and total sugars content had negative impact on viscosity parameters.

Key words: Nutritional contents, spelt, technological properties, thousand kernels weight, wheat.

INTRODUCTION

Spelt (*Triticum spelta* L.) is one of the oldest wheat subspecies used in human nutrition. It was first cultivated as a bread cereal in the eighth century BC and is now gaining back its well-deserved attention (Bojnanská and Francáková, 2002; Frakolaki et al., 2018). The increasing awareness about the strong relationship between nutrition and human health is nowadays considerably changing dietary preferences of people worldwide prompting the rise of consumption of alternative crops, new grain varieties, and foods with high nutritional value. Beside superior nutritional properties, pleasant taste and aroma, spelt flour and bakery products have become increasingly popular due to their high digestibility, as well as suitability for consumers with wheat sensitivity (Koenig et al., 2015). On the other hand, previous studies (Shewry and Hey, 2015; Ribeiro et al., 2016) reported that based on chemical composition spelt do not have significant advantages in comparison to common wheat, and that baking properties of spelt flour found to be inferior than common wheat flour (Escarnot et al., 2010; Takac et al., 2021).

The main components of both spelt and wheat grain are carbohydrates, proteins and fibers. The protein content is one of the most important technological parameters of cereals grain, determining their end use through the level of gluten proteins which affect the quality of cereal-based products (Belcar et al., 2020). Gluten, calculated as a wet or dry gluten is important parameter that determines baking quality of cereals through the influence on water absorption capacity, cohesiveness, viscosity and elasticity on dough (Wieser, 2007). It is reported that spelt flour is characterized by high viscosity and plasticity, and it is less flexible in comparison to the dough from common wheat flour (Sobczyk et al., 2017). Starch, a mixture of two polymers amylose and amylopectin, is the major storage component in the starchy endosperm of cereals grain, and increases in starch content are largely responsible for the increases in grain size achieved by breeding to produce high-yielding wheat varieties (Shewry et al., 2013). Besides, it is an important determinant of the dynamic properties of dough, especially during heating (Zamaratskaia et al., 2021). Amylose, linear polysaccharide forms a colloidal dispersion in hot water whereas amylopectin branched polysaccharide is completely insoluble. Dietary fiber is one of the compounds in cereal grains related to positive health effects (Gebruers et al., 2008). The major components of dietary fiber are cell wall components, the polysaccharides hemicellulose, cellulose, β-glucan and lignin.

By reacting with free amino groups in amino acids, peptides and proteins, reducing sugars have several effects in baked goods, primary on flavor and aroma of baked products. One of the methods used by breeders, millers and bakers for predicting the functionality of wheat flour is the solvent retention capacity (SRC) test. Different types of flours are able to hold different amounts of water, and this determines their use in different food products.

Physical properties of wheat and spelt grains can be used for the prediction of their milling quality (technological value). The kernels size, reflected in 1000 kernel weight (TKW) is important parameter because the distribution of ingredients in the different parts of the kernels. Flours made of smaller kernels may have higher contents of crude fiber, minerals and other components concentrated in the bran (Geisslitz, 2019). The size of a kernel and, thus, the 1000-kernel weight is genetically determined although can vary significantly depending on the climatic and soil composition factors, as well as cropping practices (Jankovic et al., 2015). Previous papers reported high variation for cereals 1000 kernels weight, ranging from 27.7 g up to 59.4 g (Pospisil et al., 2011; Takac et al., 2021) for spelt and from 32.4 to 54.3 g for winter wheat genotypes from HEALTHGRAIN program (Gebruers et al., 2008).

In this paper we compared nutritional contents and functional-technological properties of spelt and wheat, and analyzed correlation between those traits and one of the cereals yield component, 1000 kernel weight.

MATERIALS AND METHODS

The experimental material consisted of 11 spelt (*Triticum spelta* L.) and 11 wheat (*T. aestivum* L.) genotypes. The spelt genotypes studied belong to either breeding lines (S452, S453, S454) or cultivars from Europe (Ostro, Nirvana) and International Maize and Wheat Improvement Center (CIMMYT), Mexico (S1, S4, S12, S13, S14, S16). Wheat genotypes were represented by modern varieties from Europe and Serbia (Brigand, Hairy, Dika PKB, Osatka, Zemunska rosa, Aurelia, NS-40s, Apache, Donska, Titan Div, ZP-Xt.88.512). All genotypes were grown in a single trial, in one replicate during season 2017/2018 at the Maize Research Institute Zemun Polje (44°51' N, 20°18' E), Serbia. The plots were 5 m^2, sown in October 2017 on slightly calcareous Chernozem. The experimental site is characterized by a moderate-continental climate. The average temperature for period March-June amounted 15.6 °C with sum of precipitation 248 mm. To provide adequate nutrition, standard cropping practices were used, and plant pathogens and pests were controlled with recommended chemical treatments. Plots were harvested in July 2018. After threshing, kernels were sieved on 2.2 mm sieve and 1000 kernels weight (TKW, g) was assessed from three samples from each plot.

The protein content was determined by the standard micro-Kjeldahl method as the total N multiplied by 5.7 (Official Gazette of SFRY, 1988). The wet gluten content was determined by washing dough obtained from spelt grain and wheat flour (10 g), with 2% NaCl solution, followed by water under conditions suitable for removing the starch and other soluble compounds from the sample (SRPS EN ISO, 2009). All results are expressed in the percent of DM.

The starch content was determined by the Ewers polarimetric method (Official Gazette of SFRY, 1988). The amylose and amylopectin content were determined by a rapid colorimetric method according to McGrance et al. (1998). All results are expressed in the percent of DM.

The content of hemicellulose, cellulose, neutral detergent fibers (NDF), acid detergent fibers (ADF), and lignin (ADL) were determined by the Van Soest detergent method modified by Mertens (1992) using the Fibertec system. The method is based on the fiber's solubility in neutral, acid, and alkali reagents. The NDF practically represents total insoluble fibers (not soluble in water), ADF mainly consists of cellulose and lignin, while ADL is pure lignin. The content of hemicellulose was obtained as a difference between NDF and ADF contents, while the cellulose content was calculated as the difference between ADF and lignin contents. All the results are given as the percent of DM.

The content of total sugars, reducing sugars and sucrose was determined by the Luff-Schoorl method (Egan et al., 1981). The Luff-Schoorl method is based on the reaction between reducing sugars and alkaline solution of copper sulphate, with a subsequent reduction of cupric copper to cuprous oxide. In the method, Cu^{2+} ions which had not been reduced are determined iodometrically. Furthermore, total sugars were then determined by converting nonreducing sugars into reducing sugars through acid hydrolysis. The percentage of sucrose was calculated as the difference between total and reducing sugars, i.e., as the difference between total inverter and natural inverter.

In order to obtain the pasting curves of the investigated whole-grain spelt and wheat flour samples, changes in the apparent viscosity of aqueous suspensions were analyzed. Suspensions containing 8% starch (total mass 500 g) were heated in a viscograph at a rate of 1.5 °C min^{-1} from 25 to 95 °C. The suspensions were then thermostated at 95 °C for 30 min, cooled to 50 °C, and held for another 10 min. The Brabender Viscograph (model PT 100, C.W. Brabender Instruments, Duisburg, Germany) was operated according to the official methods and the viscosities were expressed in Brabender units (BU) (ICC, 1992; AACC, 2000a; 2000b).

Solvent retention capacity (SRC), a test that indicates the ability of flour to retain individual diagnostic solvents (distilled water, 50% sucrose [Suc], 5% sodium carbonate [Na_2CO_3], and 5% lactic acid [LA] water solutions) based on the swelling behavior of polymer networks in flour, was determined according to the American Association of Cereal Chemists method 56-11 adapted by Haynes et al. (2009). Four solvents were individually used to determine the SRC values: water; 50% sucrose in water; 5% sodium carbonate in water; 5% lactic acid in water. In centrifuge tubes (50 mL) 5 g flour and 25 mL of an appropriate solvent were added. The mixture was vortexed vigorously for 5 s to suspend the flour. The samples were vortexed for 20 min at 1 min interval after every 5 min to allow the samples to solvate and swell. The centrifugation was done at 3000 rpm for 10 min. The supernatant was discarded and the wet pellet obtained was allowed to decant for 10 min and was weighed. The SRC values were reported as percent of the weight of flour gel after exposure to the solvent divided by the original flour weight. The combination of four SRC values indicate flour quality and functionality profile useful for predicting baking performance. To obtain SRC values of flours, four solvents are in use to produce four SRC values: water, 50% sucrose, 5% sodium carbonate and 5% lactic acid. Each flour polymer network is associated with the corresponding diagnostic solvent, sodium carbonate SRC is associated with damaged starch, sucrose SRC with flour arabinoxylan, glutenin characteristics and gluten strength with lactic acid SRC, while the water retention capacity is an indicator of the overall water holding capacity of all polymeric constituents (Duyvejonck et al., 2011).

The data were reported as a mean ± standard deviation of at least three independent replicates per each genotype. Statistical analyses were performed in Minitab version 19 Statistical Software (Minitab, State College, Pennsylvania, USA). The one-way ANOVA with Tukey's test was performed (data not shown). Differences between the means with probability $p < 0.05$ were accepted as significant. The principal component analysis (PCA) was used to visually display relationships among the observed parameters. A positive correlation between two parameters was represented by an acute angle between them, while an obtuse angle represented a negative correlation.

RESULTS AND DISCUSSION

Physical properties

High 1000 kernel weight, density and uniformity are grain characteristics preferred for high milling quality (Belcar et al., 2020). The average values of the 1000 kernel weight (TKW) for spelt (40.7 g) and wheat (40.2 g) did not significantly differ (Figure 1), it varied from 35.7 to 44.4 g and from 31.4 to 45.9 g in spelt and wheat, respectively. These are generally in accordance with the results obtained by Takac et al. (2021), who examined several European spelt and wheat genotypes under similar agro-ecological conditions, reporting that their TKW did not differ significantly, with average TKW for spelt 42.9 and 43.8 g for wheat genotypes. Spelt and bread wheat differ in spike morphology and threshing characteristics mainly controlled by the gene Q (Curzon et al., 2019), resulting with dense compact spike of wheat and less compact of spelt. Besides, spelt genotypes have fewer grains per spikelet comparing to wheat, which can provide more space for endosperm cells during grain differentiation phase and formation of larger grains Takac et al. (2021), which is support by negative correlation between TGW (of spelt and wheat) and all the grain number components (grains per spike, spikelets per spike, fertile spikelets per spike, grains per spikelet) reported by Xie et al. (2015).

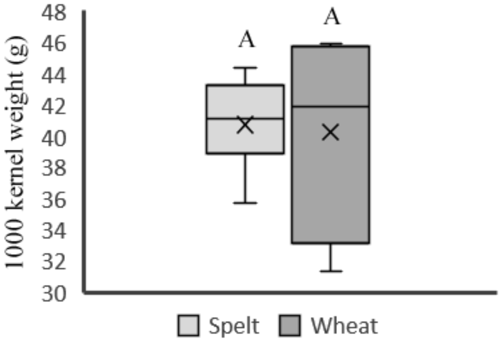

Figure 1. Variable 1000 kernel weight (TKW) of spelt and wheat genotypes. Boxes represent the interquartile range, the dot in the box represents the mean value, line in the box median value and whiskers designate minimal and maximal values. Different uppercase letters indicate significant differences between the spelt and wheat genotypes, Tukey's test ($P < 0.05$).

Chemical composition

Nutritive values of the whole-grain wheat and spelt flours were determined by analysis of protein, wet gluten, starch, amylose and amylopectin (Figure 2), dietary fibers (Figure 3) and sugars (Figure 4). Protein and wet gluten content were significantly higher in spelt comparing to whole-grain wheat flour. Total protein content of spelt flours ranged from 16.6% to 20.2% DM, on average 18.8% DM, while in the flours of wheat genotypes protein content ranged from 11.4% to 13.7% DM. with an average of 12% DM. Our results are in accordance with previously reported significantly higher protein content in spelt than in wheat flours by Frakolaki et al. (2018) and Takac et al. (2021). The wet gluten as an indicator is connected with the baking quality of flours, because gluten is a binding agent holding together the flour and other ingredients, and ultimately creating the backbone structure of the dough (Bojnanská and Francáková, 2002). Wet gluten in flours ranged from 42.2% to 66.0% DM for spelt and from 19.5% to 35.5% DM for bread wheat, with average values of 53.9% and 27.3% DM for spelt and bread wheat, respectively. Significantly higher wet gluten content in spelt than in wheat was also obtained by Belcar et al. (2020), Rachon et al. (2020), and Takac et al. (2021). Similar variability of wet gluten in spelt flour was reported by Bojnanská and Francáková (2002), ranging from 30.60% to 51.80%. Previous studies showed that higher protein content is related to the increased gliadin content which contributes to the higher extensibility of the dough, one of the traits specific to spelt wheat (Takac et al., 2021). Comparing protein and gluten content of ancient and modern wheat species Geisslitz et al. (2019) concluded that ancient species had higher protein yield efficiency, meaning that they have a better potential to use N more efficiently than modern wheats.

Average starch content, major storage component in the starchy endosperm was significantly higher in wheat (66.4% DM) than in spelt flours (62.5% DM). Similar results (66.4% and 64.2% DM) were obtained by Frakolaki et al. (2018) comparing starch of wheat and spelt flour, respectively. Kohajdová and Karovicová (2009) compared whole-meal flours and showed that wheat flour had greater starch content than spelt whole-meal flour. Starch in spelt genotypes ranged from 60.0% to 66.6% DM, while in wheat it ranged from 63.9% to 67.9% DM. Bojnanská and Francáková (2002) reported that starch content of spelt genotypes in their study ranged from 49.9% to 65.8% DM while in Skrabanja et al. (2001) study starch content of spelt whole-meal and white flour amounted 63.2% and 76.3% DM, respectively. Nikolic et al. (2021) analyzed starch content in whole-grain flour from wheat genotypes grown in the similar agroecological conditions (different year) and it ranged from 61.1% to 71.6% DM with an average 67.7% DM. In our study it was confirmed that genotypes with lower starch content will have higher grain protein content (Shewry et al., 2013).

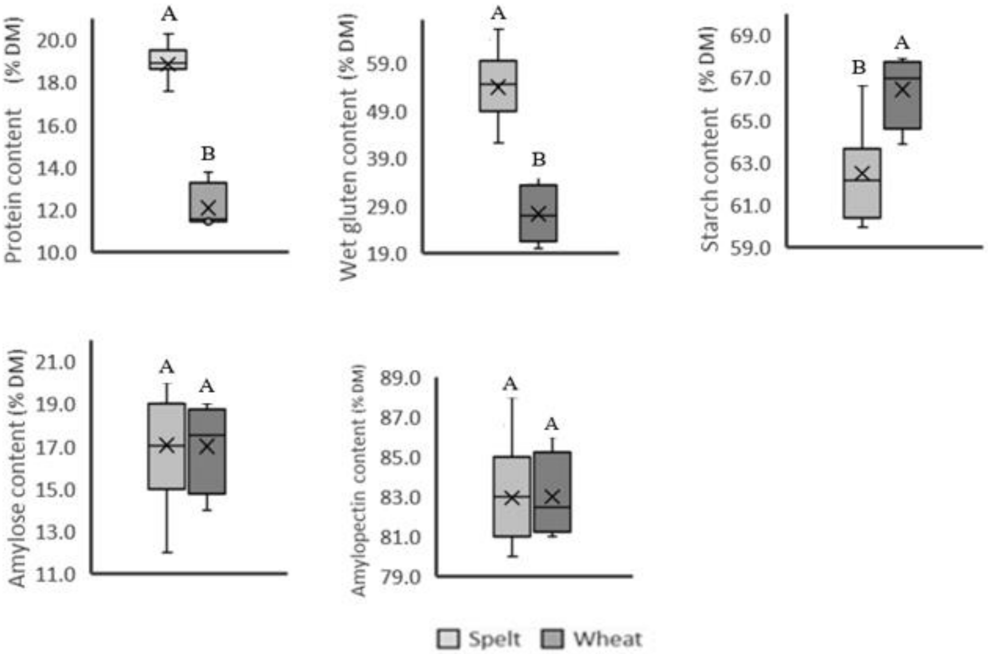

Figure 2. Protein, wet gluten, starch, amylose and amylopectin content in examined spelt and wheat genotypes/flours. Boxes represent the interquartile range, the dot in the box represents the mean value, line in the box median value and whiskers designate minimal and maximal values. Different uppercase letters indicate significant differences between the spelt and wheat genotypes, Tukey's test ($P < 0.05$).

The proportions of amylose and amylopectin in starch have a significant impact on flour processing quality, and high amylose starches are preferable for developing healthy foods as they are more slowly digested in the human gastrointestinal tract. Amylose content, the component of starch granule, ranged from 15% to 20% DM for spelt and from 14% to 19% DM for bread wheat. Average amylose content between spelt (17% DM) and wheat flours (17.1% DM) did not show significant difference. In previous studies, contradictory results were obtained. Abdel-Aal et al. (1999) reported that spelt has a lower amylose content than wheat, while Wilson et al. (2008) reported a higher average amylose content in spelt starch (31.3%) than in the hard red winter wheat (26.1%). Considering that the proportion of amylose in wheat starch generally ranges from about 18% to 35% (Tosi et al., 2018), all genotypes from this study could be characterized as a low amylose. For amylopectin content there was nonsignificant differences between the two species, for spelt flours on average amounted 83% DM, ranging from 79.8% to 88.3% DM, while for wheat flours range was from 81.3% to 86.3% DM, with an average 82.8% DM.

Fiber components are one of the most important nutritional and technological factors of the cereals grain. The content of NDF, ADF, ADL, hemicellulose and cellulose in the flours of investigated genotypes are presented in Figure 3. Between both species, significant differences were recorded for NDF and hemicellulose content. The NDF content in flour of spelt genotypes amounted on average 62.6% DM (56.5%-68.6% DM) and in wheat flours average NDF was 69.6% DM (67.0%-73.2% DM). Hemicellulose content of spelt flours, ranged from 48.0% to 59.9% DM, with an average of 54.8% DM. In wheat, hemicellulose content ranged from 60.9% to 66.9% DM, with an average 62.9% DM. The lower content of insoluble fiber NDF and hemicellulose in spelt genotypes comparing to wheat was reported by Escarnot et al. (2010; 2012). The ADF is a measure of the least digestible parts of a plant, and when it increases, the digestibility of a feed/food will decrease. Spelt genotypes had higher average values of ADF (7.87% DM), ADL (4.75% DM) and cellulose (3.12% DM) compared to wheat genotypes (6.70%, 4.53%, 2.21% DM, respectively). Higher ADF values of spelt comparing to wheat genotypes, and results reported by Zilic et al. (2011a) that grain DM digestion was positively correlated with hemicellulose and NDF ($r = 0.80$ and 0.71, respectively) indicates that wheat genotypes from this study are more favorable in terms of digestibility comparing to spelt. Escarnot et al. (2010) reported that lignin content was similar in spelt and wheat genotypes. Lower content of dietary fibers in flour from spelt genotypes compared to wheat was reported by Suchowilska et al. (2020). A similar group of four wheat genotypes was previously tested in 2010, when different values were reported by Zilic et al. (2011b); NDF, hemicellulose, ADF and ADL content were lower (28.99%, 23.24%, 4.11% and 1.45% DM, respectively), while cellulose content was higher 2.92% DM. Comparison of the results obtained from two different years suggests that those traits were highly influenced by environmental factors.

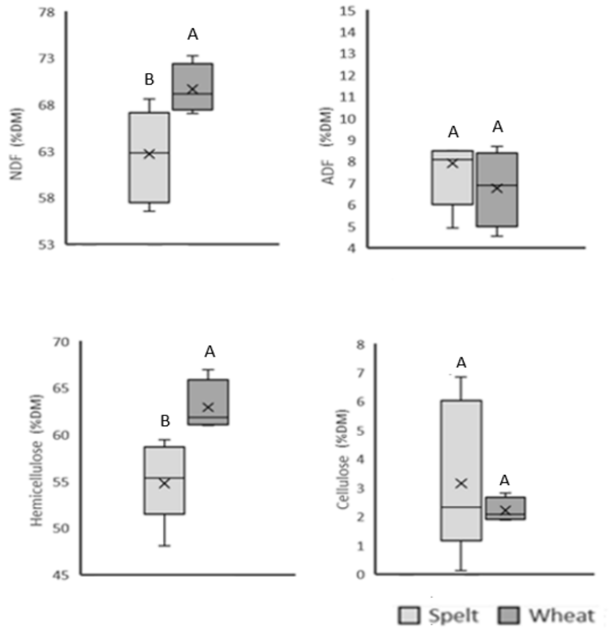

Figure 3. Dietary fiber content (neutral detergent fibers NDF, acid detergent fibers ADF, lignin ADL) in examined spelt and wheat genotypes/flours. Boxes represent the interquartile range, the dot in the box represents the mean value, line in the box median value and whiskers designate minimal and maximal values. Different uppercase letters indicate significant differences between the spelt and wheat genotypes, Tukey's test ($P < 0.05$).

The presence of sugar in the dough affects the porosity, structure and appearance of breadcrumbs (Vujic et al., 2013). Previous study on limited number of samples, by Escarnot et al. (2012), reported that sugar content in spelt was more variable than in wheat samples, and there was no difference in free sugars concentration between spelt and modern wheat (Zörb et al., 2007). In our study wheat genotypes had significantly higher content of total sugars and sucrose (Figure 4). Total sugars content for spelt flours ranged from 0.72 to 3.12 mg g^{-1} DM, with an average 1.57 mg g^{-1} DM. For wheat genotypes average value was 2.52 mg g^{-1} DM, ranging from 1.92 to 3.0 mg g^{-1} DM. In the group of spelt flours sucrose ranged from 0.5 to 2.28 mg g^{-1} DM, with an average 1.23 mg g^{-1} DM. Range of sucrose content for wheat flours was 1.64 to 2.67 mg g^{-1} DM, with an average 2.12 mg g^{-1} DM. The reducing sugars content did not differ significantly in spelt and wheat flours (0.266 and 0.583 mg g^{-1} DM, respectively). Comparing whole grain flour from different species wheat, durum, rye, barley, oat and maize for a sugar content, Zilic et al. (2017) reported that wheat genotypes had the lowest percentage of total sugars and sucrose content of all examined genotypes. Comparing whole-meal spelt and wheat flour, Kohajdová and Karovicová (2009) reported that sucrose content in wheat was for 11% higher than in spelt flour.

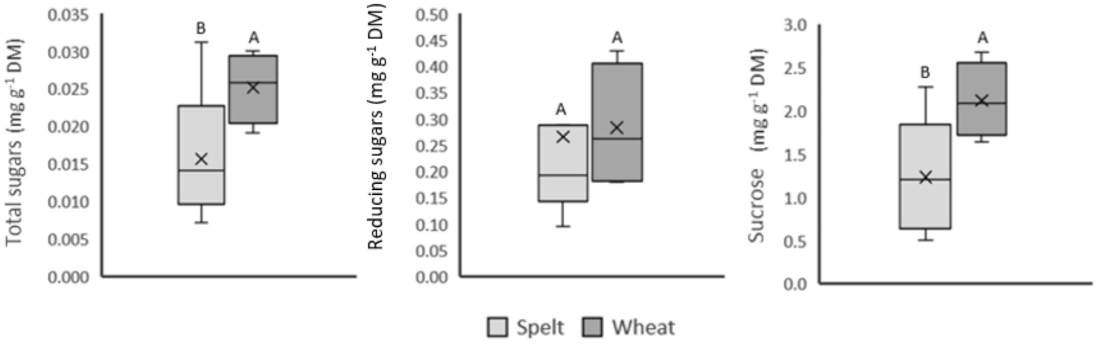

Figure 4. Sugar content (mg g^{-1} DM) in examined spelt and wheat genotypes/flours. Boxes represent the interquartile range, the dot in the box represents the mean value, line in the box median value and whiskers designate minimal and maximal values. Different uppercase letters indicate significant differences between the spelt and wheat genotypes, Tukey's test ($P < 0.05$).

Baking functionality

The solvent retention capacity (SRC) method could be used to predict bread loaf volume based on functional polymeric components in flour (Duyvejonck et al., 2012) and to determine end-product functionality. The pattern of flour SRC values for the four diagnostic SRC solvents (water, lactic acid, sodium carbonate and sucrose solutions), rather than any single individual SRC value, has been shown to be critical to various successful end-use applications (Kweon et al., 2011). Between two species, significant differences were recorded for water SRC and sodium carbonate SRC (Figure 5). Water SRC values describe the overall water holding capacity and are lower compared to the other SRC values (Vukic et al., 2020), which is in accordance with our results. For the spelt genotypes water SRC values ranged from 60.5% to 67.1% with an average 63.5%, while for wheat genotypes average water SRC was 74.7%, ranging from 72.6% to 78.0%. The sodium carbonate SRC values are related to the damaged starch content of the flour, and in our study, wheat flours had significantly higher average content of this component (84.0%), ranging from 79.9% to 88.7%, than spelt flours with an average 71.1%, ranging from 66.4% to 76.7%. The sucrose SRC values refer to the arabinoxylan content of the flour sample, and in our study, wheat genotypes (with average sucrose SRC values 96.9%) had slightly higher arabinoxylan content comparing with spelt genotypes (92.8%). Study by Aghagholizadeh et al. (2019) reported that lactic acid SRC values can be used to indicate the quantity and quality of the glutenin fractions present in flour and bread. Higher, but nonsignificant lactic acid SRC values were observed for wheat flours, ranging from 68.0% up to 81.3%, with an average 76.5%, comparing to spelt genotypes where lactic acid SRC ranged from 64.7% to 73.3%, averaging 68.9%.

Pasting properties

Pasting properties of flours were investigated with viscograph and depend on different chemical components of grains as well as their interactions. Starch granules are not soluble in water at room temperature, but it becomes disorganized during thermal treatments. Pasting curves indicate the capacity of starch to retain water and swell when suspension is heated from 25 to 95 °C and their shape depends on amylose to amylopectin ratio, protein and fat compounds. The pasting properties and pasting curves, in reference to the two wheat species spelt and common wheat are shown in Figures 6 and 7.

The peak viscosity (Vpeak) indicates the maximum consistency obtained when the flour is heated in excess water and spelt genotypes showed significantly higher values comparing to wheat. Peak viscosities were all detected in the time range between 25 and 27 min during the heating of the flour-water suspensions. The range of a Vpeak for spelt genotypes was from 370 to 970 BU, 698 BU on average, while for wheat genotypes those values were from 170 to 560 BU, 346 BU on average. The highest peak temperature (92.3 °C) was obtained in the group of spelt and the lowest (84.7 °C) in the group of wheat genotypes. Spelt and wheat genotypes did not differ significantly for the breakdown and final viscosity parameters. All tested genotypes showed an increase in total setback and final viscosities compared to the Vpeak. The final viscosity for spelt genotypes ranged from 460 to 1200 BU, averaged 849 BU, and for wheat from 230 to 850 BU, averaged 539 BU. Similar results were obtained by Wilson et al. (2008), where starches of five spelt genotypes had higher pasting peaks and final viscosity than red winter wheat. The shape of a pasting curve of cereals starches depends on among others, amylose and amylopectin ratio, but the protein composition and the size fraction of a material could also affect pasting viscosity and properties (Wilson et al., 2008; Galkowska et al., 2014).

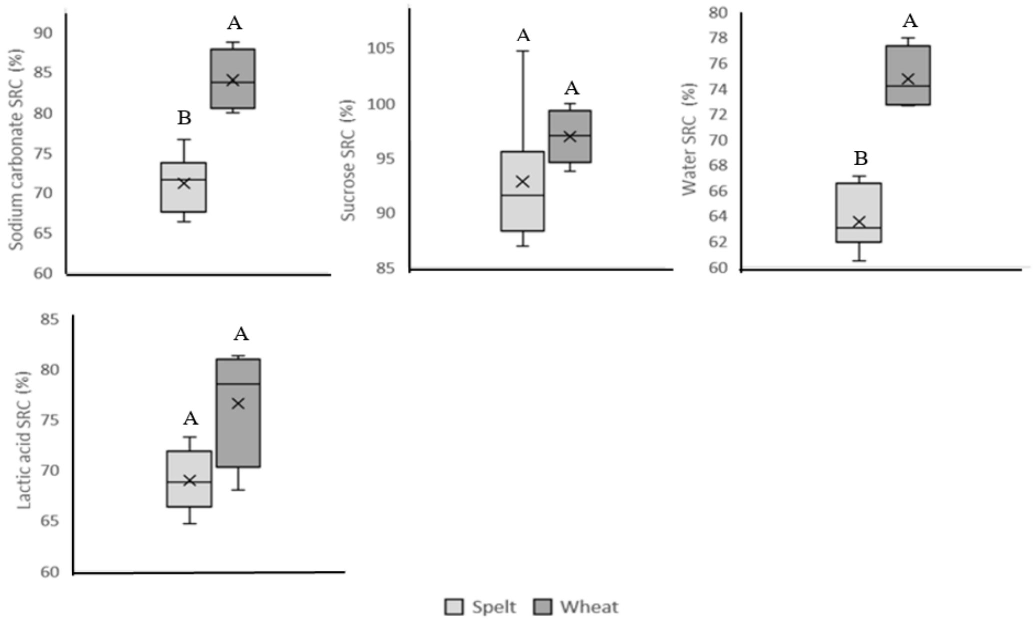

Figure 5. Solvent retention capacities (SRC) of examined spelt and wheat genotypes/flours. Boxes represent the interquartile range, the dot in the box represents the mean value, line in the box median value and whiskers designate minimal and maximal values. Different uppercase letters indicate significant differences between the spelt and wheat genotypes, Tukey's test ($P < 0.05$).

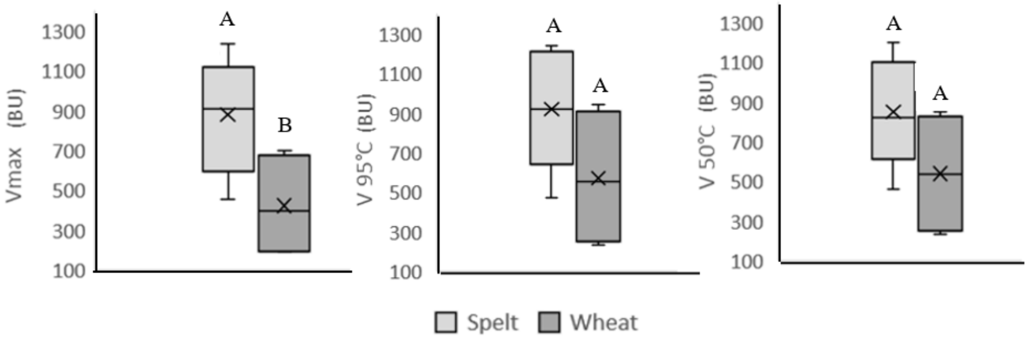

Figure 6. Pasting properties (Vmax, V95°C, V50°C) of examined spelt and wheat genotypes/flours. Boxes represent the interquartile range, the dot in the box represents the mean value, line in the box median value and whiskers designate minimal and maximal values. Different uppercase letters indicate significant differences between the spelt and wheat genotypes, Tukey's test ($P < 0.05$).

Principal component analysis

The relationships among studied nutritional, functionally-technological properties and 1000 kernels weight (TKW), separated for the group of spelt and wheat genotypes are shown on genotype by trait biplots (Figure 8). The kernel weight is one of the main yield components, so we analyzed correlation between this trait and flour quality parameters for each species separately.

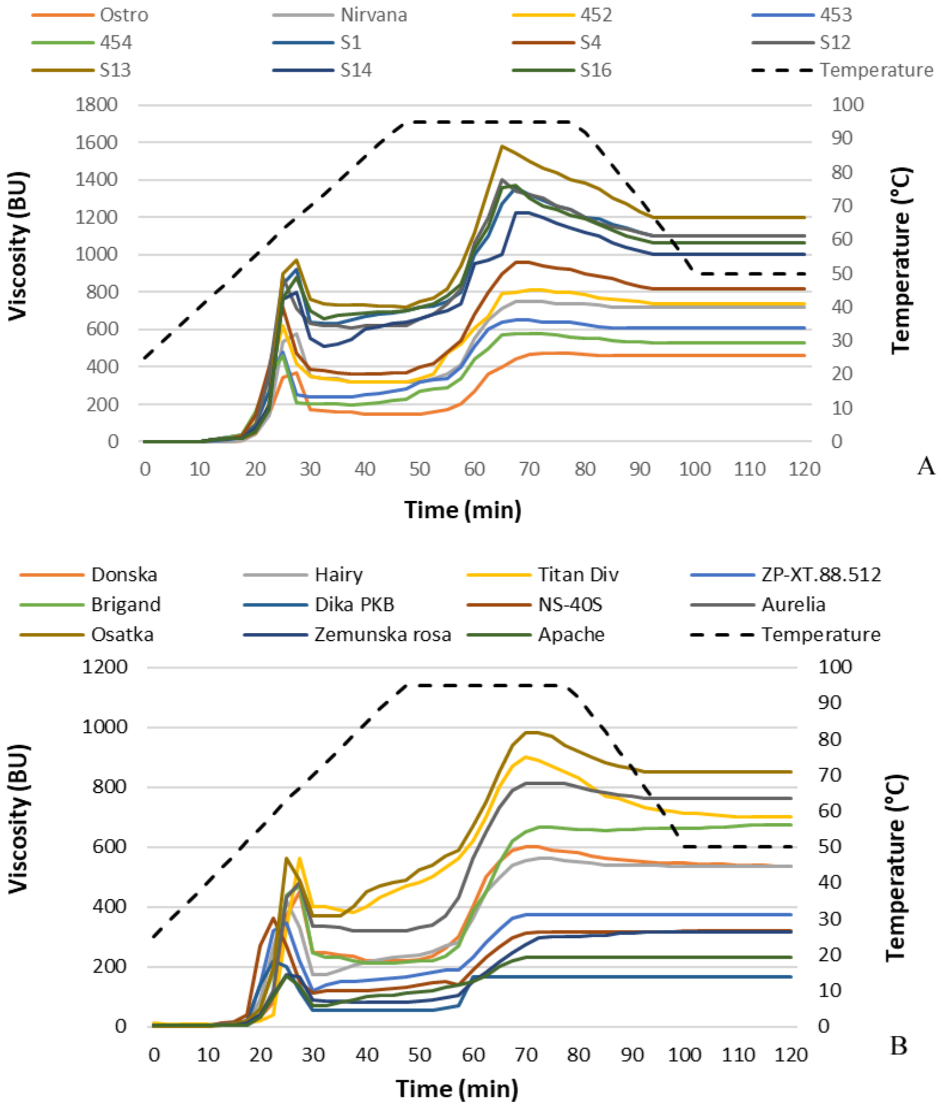

Figure 7. The pasting curves, in reference to the group of spelt (a) and wheat (b) genotypes.

For the group of spelt genotypes (Figure 8a) the PC1 accounted for 30.4%, and PC2 for 21.7% of total variation. Kernel weight of spelt genotypes was in the strongest positive correlation with amylopectin and reducing sugar. Besides, spelt kernel weight had positive effect on dietary fibers (except ADF) and cellulose, sugar content (total sugar and sucrose), wet gluten and protein content. The SRC values were in strong correlation with protein and amylose content. Strong correlation between SRC and dietary fiber constituents indicate that presence of bran in the whole grain flours has influence on their baking functionality. Maximum (peak) viscosity was very strongly correlated with cellulose and amylose. Viscosity parameters were in positive correlation with SRC. On viscosity parameters the strongest negative influence had reducing sugars and amylopectin, and based on the results from PC analysis smaller (lighter) kernels would show higher viscosity parameters.

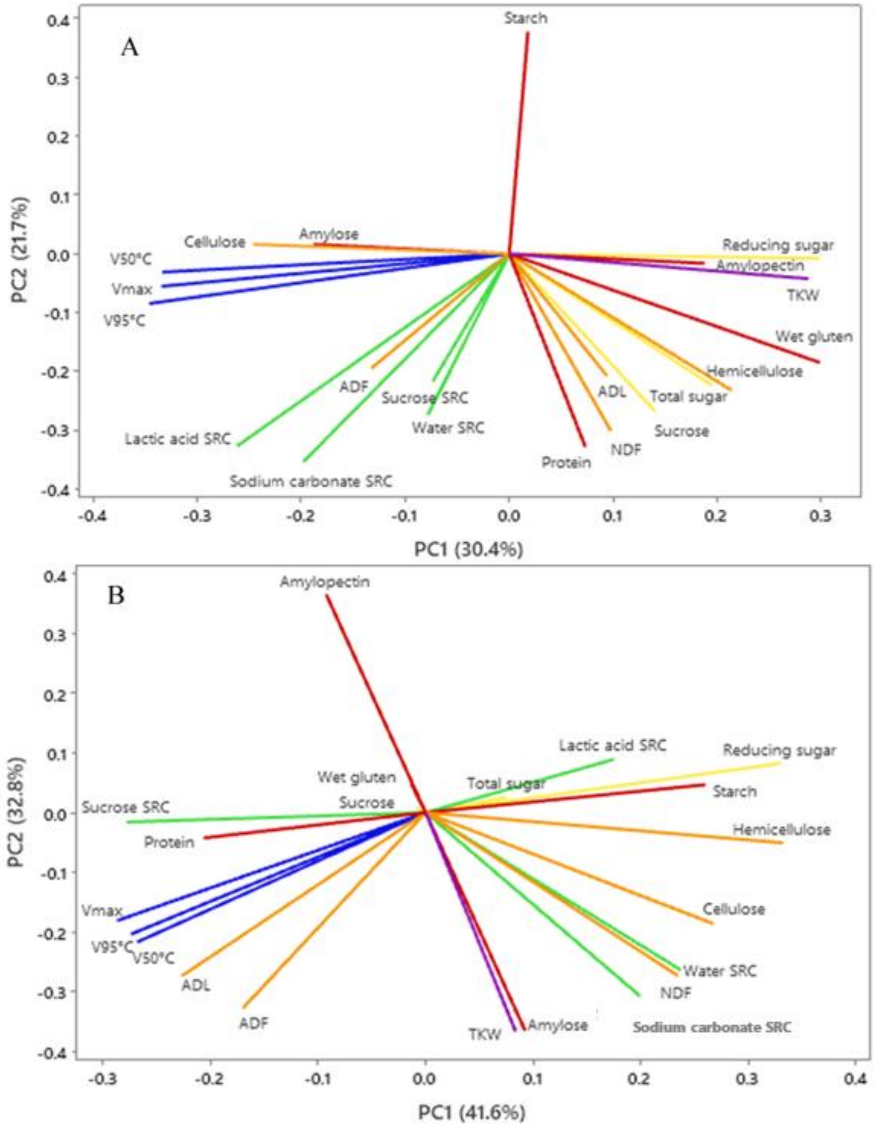

Figure 8. Principal component analysis biplot of all investigated traits for spelt (A) and wheat (B) genotypes. Different colors represent different groups of traits: physical properties (1000 kernel weight, TKW), chemical composition (protein, wet gluten, starch, amylose, amylopectin), dietary fibers (neutral detergent fibers NDF, acid detergent fibers ADF, lignin ADL, cellulose, hemicellulose) sugars content (total sugar, reducing sugar, sucrose), solvent retention capacities (water SRC, sucrose SRC, sodium carbonate SRC, lactic acid SRC) and pasting properties (Vmax, V95°C, V50°C) of whole-grain flours.

For the group of wheat genotypes (Figure 8b) the PC1 accounted for 41.6% and PC2 for 32.8% of total variation, and analysis showed different results. In contrary to spelt genotypes, TKW of wheat was in the strongest positive correlation with amylose and in the strongest negative with amylopectin. All dietary fibers had positive influence on TKW. Correlation between TKW and protein, starch and wet gluten was similar for both subspecies. No correlation was observed between sugars and TKW of wheat genotypes, while in spelt genotypes they had positive correlation. While water SRC, lactic acid SRC and sodium carbonate SRC were in positive correlation, sucrose SRC was on opposite side of PC biplot. The inverse relationship between lactic acid SRC and sucrose SRC was reported by Kweon et al. (2011). Katyal et al. (2017) showed that higher protein content caused higher Vpeak, which is in accordance with our results. Beside of a protein content, strong influence on a viscosity parameter had dietary fibers ADL and ADF and sucrose SRC. In both sub-species reducing and total sugars content had negative impact on viscosity parameters. Previous study by Zeng et al. (1997) found a reverse relationship between wheat amylose content and the Vpeak, while Majzoobi et al. (2011) reported a weak and negative relationship between peak and breakdown viscosities and its total amylose content, which is in accordance with our results.

CONCLUSIONS

In this study we compared nutritional contents and functional-technological properties of spelt and bread wheat whole-meal flours, obtained from the genotypes grown at the same field trial, and their correlation with 1000 kernel weight (TKW). The average values of TKW for spelt and wheat did not significantly differ, while protein and wet gluten content were significantly higher in spelt than in wheat flours. Although wheat flours were significantly richer in starch, both spelt and wheat had similar amylose and amylopectin content. Wheat flours had significantly higher hemicellulose and NDF content, as well as total sugar and sucrose. Water holding capacity were significantly higher in wheat flours. Pasting properties of flours did not differ significantly. The TKW of spelt genotypes was in the strongest positive correlation with amylopectin and reducing sugar, while in contrary, TKW of wheat was in the strongest positive correlation with amylose. The TKW had positive influence on dietary fibers of wheat and spelt flours. Correlation between TKW and protein, starch and wet gluten was similar for both subspecies. In both subspecies reducing and total sugars content had negative impact on viscosity parameters. Due to increased interest in spelt cultivation, there is a need for further validation of our results through multi environmental filed trials with more varieties within spelt and wheat species.

Author contributions

Conceptualization: S.Ž., D.D., V.K. Methodology: S.Ž., V.N., V.K., D.D. Validation: M.S., D.M. Formal analysis: V.N., M.S., V.K. Investigation: V.N., M.S., V.K. Resources: V.N., M.S., V.K., D.D., S.Ž. Writing-original draft: V.K. Writing-review & editing: V.K. Visualization: V.K., V.N. Supervision: D.D., S.Ž. All co-authors reviewed the final version and approved the manuscript before submission.

Acknowledgements

This study was supported by the Ministry of Education, Science and Technological Development of the Republic of Serbia (grant number TR31069).

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