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Chapter 12

Rheological and Technological Quality of Minor Wheat Species and Common Wheat

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Additional information is available at the end of the chapter

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Abstract

Wheat is an important food grain source that nurtures millions of people around the world. Not only does wheat contain a large number of nutrients such as protein, wet gluten, etc., but also it has a lot of antioxidants such as dietary fibre, tocopherols, tocotrienols, etc. In a majority of cases, attention has been drawn to evaluate the grain yield and its components rather than its quality. The present investigation was carried out to evaluate the differences between minority wheat species and common wheat to determine the best rheological characteristics, technological quality as well as correlations between rheological and technological traits. The results revealed that hulled wheat species had a high protein content and wet gluten content. Einkorn and emmer were not suitable for 'classical' baking processing. But there is potential for other products, e.g. wheat rice (einkorn) or pasta (emmer). Spelt should be possible to be used in 'classical' baking industry, but the best solution is to use grain as a mixture with bread wheat. Also, this study showed a genotype variation in the antioxidant activity of einkorn, emmer, spelta and *Triticum aestivum*.

Keywords: wheat, quality, rheological properties, antioxidant capacity, organic farming

1. Introduction

Wheat is a plant grown on more land area than any other commercial crop. It is also one of the most important food grain sources for people all over the world because of the universal

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use of wheat for a wide variety of products such as bread, noodles, cakes, biscuits, etc. Wheat kernel is composed of endosperm (81–84%), bran (14–16%) and germ (2–3%) [1]. Endosperm is the inner part playing a role as storage of energy and functioning protein. Bran is the outer layer protecting the grain, and germ is the kernel's reproduction system. Whereas wheat endosperm contains mostly starch and protein, bran and germ are rich in dietary fibre, vitamins, minerals and phytochemicals playing an important role in nutrition and health benefits for humans [2]. The customers are, therefore, strongly recommended to consume whole grain foods with at least three servings per day. Recent studies have shown that regular consumption of whole-wheat grain has been found to be associated with reduced total mortality, as well as reduced risk of coronary heart disease, ischemic stroke, type 2 diabetes [3], hypertension in women and colorectal cancer [4].

Over the last few years, despite the development of organic farming throughout Europe, there are not enough varieties that have been purposely bred for organic farming [5]. Conventional bred and tested varieties which were reproduced under the organic farming conditions are grown there [6]. But there are many references from different authors [7] that reported lower baking quality of bread wheat within organic farming. On the other hand, there are many neglected wheat species which have potential to be grown in organic farming and provide high-quality grain [8].

Original cultivars and landraces (e.g. spelt wheat) are the most usual organically cultivated cereal species. Their yield rate is supposed to be lower. Therefore, they have been pushed out of the conventional farming system and replaced by common wheat species. Obsolete cultivars and landraces are also highly appreciated as valuable genetic resources because they are unique and irreplaceable genetic resources for further development of the biological and economic potential of cultural crops. The neglected cereal species have become attractive in the Czech Republic. Spelt wheat (*Triticum spelta* L.) was created by interbreeding of the Tausch's multigraft (*Aegilops tauschii* syn. *squarrosa* L.) with emmer wheat. It is a cultural hulled wheat species and has got 42 chromosomes. There are winter and spring forms of spelt wheat [9]. In 2001, a winter spelt wheat variety called Rubiota was bred in the Crop Research Institute in Prague-Ruzyne and registered. Nowadays, the largest areas of spelt wheat can be found in the Western European countries, such as Germany, Belgium, northern France and Switzerland. There are about 30,000 ha of spelt wheat areas in all of these countries and regions [10]. Spelt wheat has become more attractive in the Czech Republic too – thanks to the development of organic farming. In 2014, spelt wheat crop stands at 2058 ha in the Czech Republic, and the average yield rate attained is 2.81 t/ha. Having the origin from Turkey, *Triticum macha* Dekapr. and Menabde. has got 42 chromosomes as well. This variety ranks among hexaploid wheat species and is cultivated only in the Caucasus region and currently in Russia. It was not grown commercially in Europe or the USA either [11]. It has not been explored too much. Winter varieties are frost proof. This wheat species prefers mid-dry soil types with neutral pH. This is a late winter wheat species and plants have got long stalks. Grains stay in spikelet for a long time; they are kept there even if threshed. They are elliptical, red and mid-hard [11]. Based on foreign literature data, both hulled wheat species are attractive because of their nutritional parameters. Both species contain more proteins (13.5–19%) [12]. Wet gluten content varies from 35 to 45% (but it can be up to 48%) [13]. SDS test values are similar to common wheat values (40–60 mL). Digestible starch content in spelt wheat plants is also similar to the

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one in common wheat plants. Digestible saccharide content in spelt wheat plants is much lower than the one in common wheat plants. There are fairly less insoluble fibres in the spelt wheat plants than in the common wheat plants [12].

Our chapter is aimed at comparing the baking quality of grains of the different species with the baking quality of grains of modern common wheat. It is also partly aimed at assessing individual parameters of the dough rheology and comparing it with the results of usual grain quality measurement and assessment. The second aim of this chapter is to determine the contents of antioxidant activity (tocopherols) in varieties of einkorn (*Triticum monococcum* L.), emmer (*T. dicoccum* Schuebl [Schrank]), spelt (*T. spelta* L.) and *Triticum aestivum* L. and identify the richest sources for improving the nutritional value of bread, pasta and other wheat products.

2. Materials, methods and results

2.1. Materials and methods

2.1.1. Baking quality and rheological properties

The used varieties were from the Gene Bank of the Crop Research Institute in Prague-Ruzyne, including *T. macha* Dekapr. and Menabde, *T. spelta* L. and control varieties of *T. aestivum* L. – variety SW Kadrilj. Varieties were sown on the organic certified research area of the University of South Bohemia in Ceske Budejovice, Czech Republic, and the University of Natural Resources and Life Sciences, Vienna, Austria, during 2014. The seeding rate was adjusted for a density of 350 germinable grains per m^2. The crop stands were treated in compliance with the European legislation (the European Council (EC) Regulation No. 834/2007 and the European Commission (EC) Regulation No. 889/2008).

Characteristics of the conditions of the University of South Bohemia in Ceske Budejovice research area: mild warm climate, soil type – pseudo gley cambisols, kind of soil – loamy sand soil and altitude of 388 m. Characteristics of the conditions of the University of Natural Resources and Life Sciences research area: located in Raasdorf, the soil was Calcaric Phaeozems (WRB) from loess with a silty loam texture, with the altitude of 156 m.

Quality analysis: The following parameters were tested after harvesting and dehulling of the grains by the International Association for Cereal Chemistry (ICC) methods: crude protein content (ICC 105/2); index of sedimentation – SDS test (ICC 151); wet gluten content (ICC 106/2), gluten index (ICC 155) and baking experiment [14]. For the detailed evaluation of baking quality, Mixolab II. System (accepted as the ICC standard method No. 173 – ICC 2006) was used, which makes possible to evaluate physical dough properties such as dough stability or weakening, and starch characteristics in one measurement (**Table 1**).

Statistical analysis: data were analysed by the Statistica 9.0 (StatSoft Inc., USA) programme. Regression and correlation analyses provided the evaluation of interdependence. The comparison of varieties and their division into statistically different categories were provided by Tukey's HSD test.

Time for C1 (min)	The time evolution of the dough. The stronger the flour, the longer the time evolution (time to reach C1)
Amplitude (Nm)	The elasticity of the dough. The higher the value, the greater the flexibility of flour
Stability (min)	Resistance against kneaded dough. The longer the duration, the more the flour is considered stronger
C2	Measured attenuation of protein due to mechanical work and temperature
C3	Measures the gelling starch
C4	It measures the stability of the hot gel
C5	Measured starch retrogradation in cooling phase
Guideline α (C1–C2)	Attenuation rate of protein in warming
Guideline β (C3–C4)	Speed starch gelatinisation
Guideline γ (C5–C4)	The rate of enzymatic degradation

Table 1. Description of Mixolab II. phases.

2.1.2. Quality of pasta

A mixture of tested wheat varieties – einkorn wheat, emmer wheat, spelt wheat and bread wheat (the SW Kadrilj cultivar) – was milled into semolina and flour. The semolina was used to make pasta and the selected baking properties of the flour were determined. A reference method was used for the determination of moisture content of flour; the Falling Number method according to Hagberg-Perten was used, as well. The amount of nitrogen in the flour was measured according to Kjeldahl; the sedimentation index was calculated on the basis of Zeleny's test, and the wet gluten quantity and quality were determined with the Glutomatic System.

Semolina pasta was prepared in the pasta machine MPF2.5, and subsequently, a cooking test was performed. The cooking test focused on the determination of the boiling properties, binding and swelling capacity as well as the amount of sediment. The sensory evaluation of the cooked pasta samples was carried out by a group of 10 evaluators.

2.1.3. Antioxidant capacity

The used varieties came from the Gene Bank of the Crop Research Institute in Prague-Ruzyne. In the precise, 3-year field experiments in 2010, 2011 and 2012, four varieties of wheat einkorn *T. monococcum* L., eight varieties of emmer (*T. dicoccum* Schuebl [Schrank]), seven varieties of spelt (*T. spelta* L.), four varieties of landraces of bread wheat (*T. aestivum* L.) and three varieties of spring wheat (*T. aestivum* L.) as control (SW Kadrilj, Vanek, Jara) were used.

Varieties were sown on the organic certified research area of the University of South Bohemia in Ceske Budejovice, Czech Republic. The seeding rate was adjusted for a density of 350 germinable grains per m^2. The crop stands were treated in compliance with the European legislation (the

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European Council (EC) Regulation No. 834/2007 and the European Commission (EC) Regulation No. 889/2008). Characteristics of the conditions of the University of South Bohemia in Ceske Budejovice research area: mild warm climate, soil type – pseudo gley cambisols, kind of soil – loamy sand soil and altitude of 388 m.

The following methodology is based on the description in a paper by Lachman et al. [14]. Laboratory analysis of composed finely ground wheat samples (ca 5.0 g) were weighed into 100 mL volumetric flasks and dissolved in methanol. The flasks were filled up with methanol to a volume of 100 mL. For AOA determination, 100 μL aliquots of sample solutions were pipetted. Indirect method described by Roginsky and Lissi was used [15]. Sample containing antioxidants reacts with a solution of stable synthetic radical being converted to a colourless product (DPPH assay). Methanolic DPPH solution [absorbance (t0) 0.600 ± 0.01] was prepared and 100 μL of the sample were added. Reaction time was 20 min. Absorbency was measured at wavelength λ = 515 nm. AOA was calculated as the decrease of absorbency according to the equation (1): AOA (%) = 100−[(At20/At0) × 100] (1) where At20 is the absorbency in time 20 min and At0 is the absorbency in time 0 min. Calculated AOA was expressed in mg Trolox/kg DM. At0 and At20 were determined from the standard calibration curve ($r2 \geq 0.9945$). Calibration curves were prepared using working solutions of Trolox in methanol between 5 and 25 μg Trolox/mL (LOD = 0.601 μg Trolox/mL, LOQ = 2.000 μg Trolox/mL, RSD = 1.83%). All samples were analysed in duplicates.

2.2. Results

2.2.1. Baking quality and rheological properties

Part of our work focuses on finding any differences in the baking quality between the tested varieties. It is also aimed at evaluating correlations between the baking quality parameters determined by common methods and in every single stage of Mixolab II. **Table 2** shows the tested varieties and their average values do not differ statistically from each other in the amplitude, stability, C2–C5, Gamma directive and Falling Number (the Mixolab II. stages are explained in **Table 2**). On the other side of the coin, there were statistically significant differences in C1 stage, Alpha and Beta directives, protein content, wet gluten, gluten index and SDS test. Statistically, significant differences and correlations existed between the following stages. C1 stage had a positive correlation with gluten index and dough stability. According to **Table 2**, a control variety of *T. aestivum* L. was different from the other varieties in C1 stage, which was confirmed by a high gluten index value and more stable dough as well. A positive correlation existed between protein content and C4 + C5 stages, wet gluten content and Gamma directive. *T. macha* Dekapr. and Menabde contained the highest amount of proteins. Wet gluten had a negative correlation with C1 stage. If dough contains more wet gluten, it does not need to be worked so hard mechanically [16]. A positive correlation existed between wet gluten content and protein content. On the other hand, higher gluten index value enhanced dough to develop and had a negative correlation with protein content and wet gluten content. *T. aestivum* L. attained the highest gluten index values. SDS test had a negative correlation with Alpha directive, which relates to a starch grain size and resistance –

Species	C1	Amplitude	Stability	C2	C4	C5	Alpha
T. macha	3.08[a]	0.09[a]	7.8[a]	0.36[a]	1.1[a]	1.8[a]	−0.08[a]
T. spelta	4.45[a]	0.07[a]	8.9[a]	0.39[a]	1.2[a]	1.9[a]	−0.09[ab]
T. aestivum	6.69[b]	0.07[a]	9.8[a]	0.44[a]	1.3[a]	2.0[a]	−0.10[b]
Species	**Beta**	**Gamma**	**Protein content**	**Wet gluten**	**GI**	**SDS**	**Falling Number**
T. macha	0.45[a]	−0.05[a]	15.2[b]	36.07[b]	55.4[a]	42.75[a]	526[a]
T. spelta	0.63[b]	−0.07[a]	14.99[a]	36.9[a]	56.0[a]	43.08[a]	425[a]
T. aestivum	0.65[ab]	−0.07[a]	13.1[a]	19.3[a]	96.8[b]	49.40[b]	463[a]

Note: Values marked with the same letter are, based on Tukey's HSD test, statically significantly different at a significance level $P \geq 0.05$.

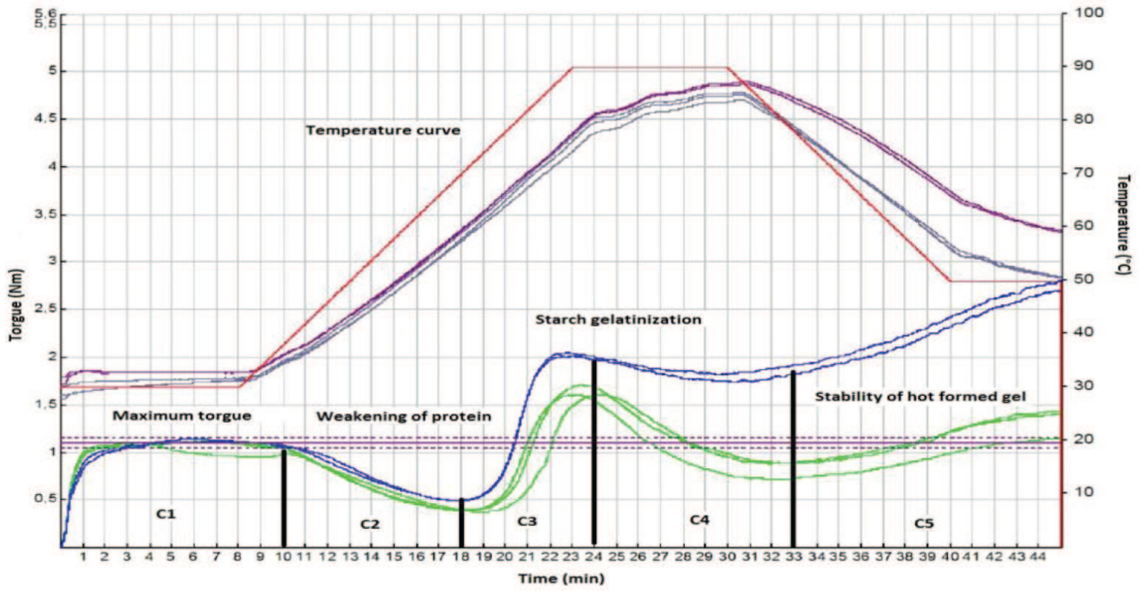
Table 2. Average values of tracked characteristic on Mixolab II. machine and basic parameters of baking quality.

the bigger and the better quality the grains are (prime ones), the more they swell and the less resistant they are to higher temperatures [10].

Statistically non-significant differences and correlations existed in the following stages. C2–C2 stage had a positive correlation with C3–C5 stages and Beta and Gamma directive and Falling Number. This indicates that the baking technology must be adapted to its properties. C3 – the so-called amylase peak – indicates a different composition of starch and size fractions of starch grains [10]. Samples originating from Vienna research locality contained a higher amount of small starch grains (second ones) which are bound tightly to the protein matrix, and they gelatinise in higher temperatures. On the contrary, samples originating from the Ceske Budejovice research locality contained a higher amount of good-quality big starch grains (prime ones) which gelatinise in lower temperatures. A positive correlation existed with C4 and C5, Falling Number and Beta and Gamma directives. C4 – less stable dough – needs to be baked longer at lower temperature. They do not need to be worked so hard mechanically [16]. This parameter had a strong correlation with C2. In C5, starch gets cooler, starch structure changes and starch gets harder. Retrogradation had a positive correlation with Falling Number. For amplitude, stability and Gamma directive, see **Table 2**. Falling Number had a strong correlation with stability, C2–C5 stages, Beta and Gamma directives and protein content. It is one of the most significant features determining flour baking quality [10].

Triticum macha Dekapr. and Menabde: there were significant differences in the protein-weakening stage (C2) (see **Figure 1**). These were caused by an increasing temperature and mechanical processing of dough. Large differences between two of our localities existed since the starch gelatinisation stage (C3). Samples originating from Vienna research locality attained the amylase peak at the same stage as samples of the control common wheat. Values, enzymatic activity and stability were lower in Ceske Budejovice. Such differences were kept until C5 stage – retrogradation – solidification. *Triticum spelta* L: There were enormous differences since C2 stage as well. Since C3 stage, samples originating from Vienna research locality attained the amylase peak. Those samples from Vienna kept the same or similar test results in C4 stage too.

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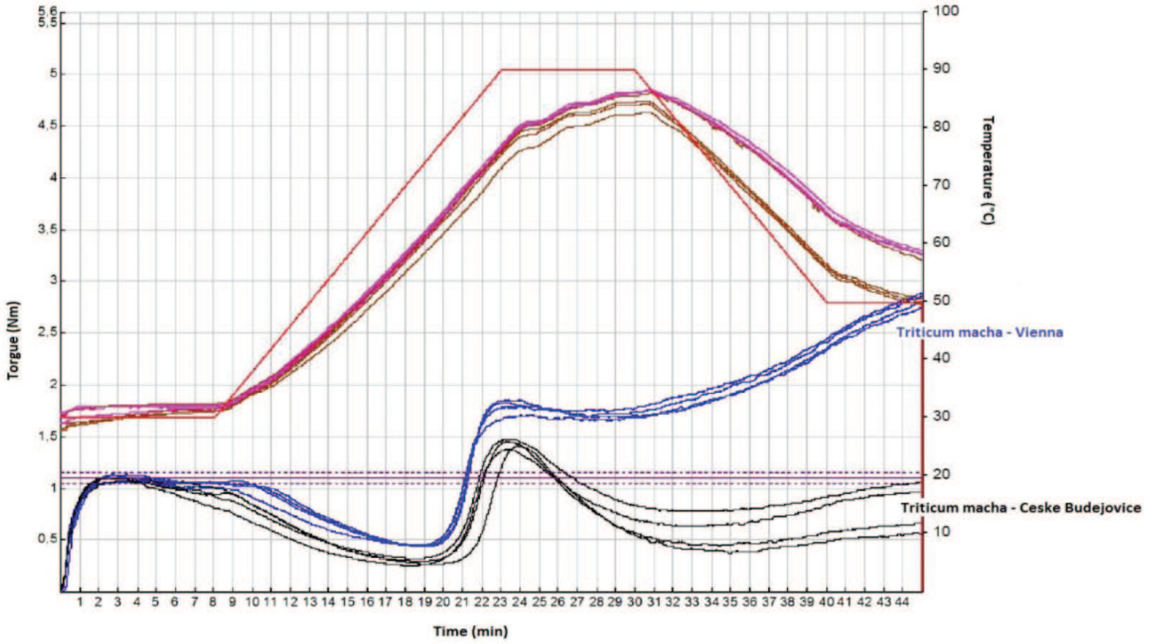


serie testy	Hyd (%)	Work basis	Vyhlazená křivka	teplota sáčku	teplota mísiče
Mendel net 2 SW Kadrilj bez F	63,0	b14			
Mendel net 3 SW Kadrilj a CB 2014	61,6	b14			
Mendel net 4 SW Kadrilj b CB 2014	61,6	b14			
Mendel net 47 SWKadrilj a Vídeň 2014	62,8	b14			
Mendel net 48 SWKadrilj b Vídeň 2014	62,3	b14			

Figure 1. Rheological properties of control variety of *Triticum aestivum* L. - SW Kadrilj

There were large differences in stability between samples originating from Ceske Budejovice locality. In the last C5 stage, spelt wheat varieties attained higher average values than *T. macha* varieties. *T. aestivum* L. (control variety) – SW Kadrilj: larger differences between common wheat varieties arose during the test, since C3 stage (see **Figure 2**). These were the largest differences during the enzymatic degradation (C4 stage). It meant a very different enzymatic activity in every single sample. It was reflected in the retrogradation of starch as well (C5).

Such differences between Vienna and Ceske Budejovice research samples were caused by different conditions in every research locality (climate, weather changes, soil quality, agro-technology and quality of harvested material and post-harvest arrangements). There are



serie testy	Hyd (%)	Work basis	Vyhlazená ivka	teplota sto	teplota mixéra
Mendel net 23 Macha 1a CB 2014	62,0	b14			
Mendel net 24 Macha 1b CB 2014	62,0	b14			
Mendel net 25 Mach 2a CB 2014	64,8	b14			
Mendel net 26 Mach 2b CB 2014	65,8	b14			
Mendel net 27 Mach 1 a Vídeň 2014	64,0	b14			
Mendel net 29 Mach 2 a Vídeň 2014	66,5	b14			
Mendel net 28 Mach1 b Vídeň 2014	66,3	b14			
Mendel net 30 Mach 2 b Vídeň 2014	63,6	b14			

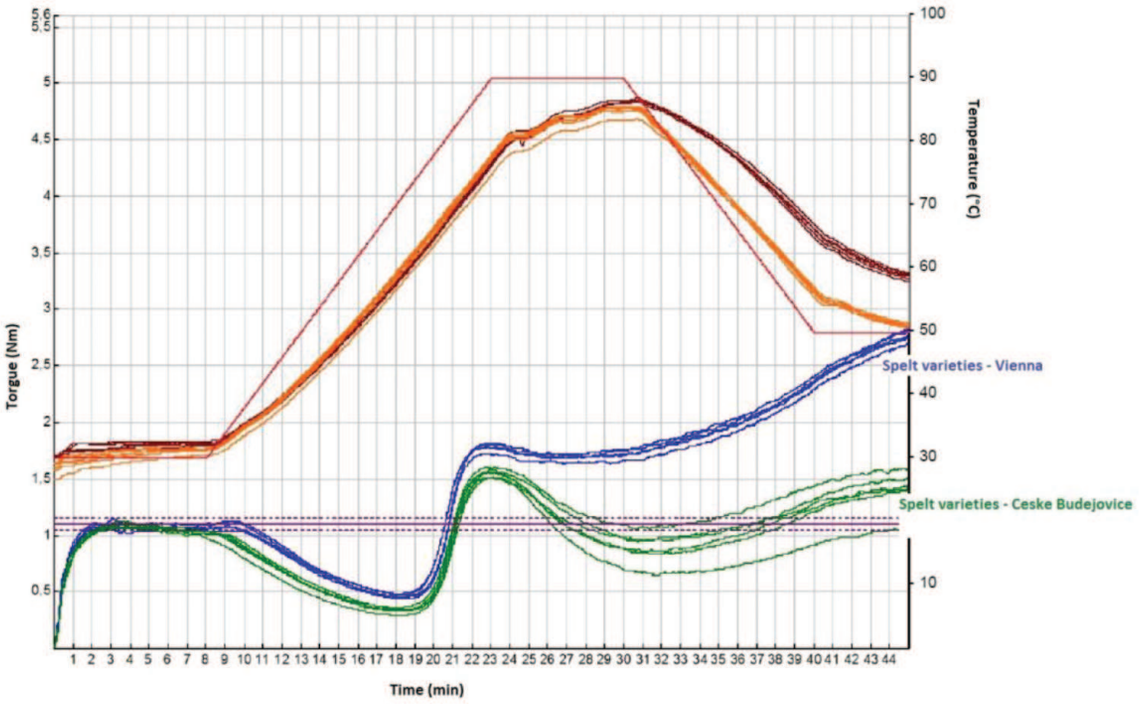
Figure 2. Rheological properties of control variety of *Triticum macha* Dekapr and Menabde

more precipitations and irregular rains in Ceske Budejovice. Rain occurs during the harvest period too. Water percentage in dry matter is a significant factor influencing Falling Number and behaviour of proteins in grains. On the other side of the coin, there are minimum precipitations in Vienna, and almost no rain occurs during the harvest period. However, there is a good-quality soil in Vienna and the total amount of nutrients in the soil is balanced (**Figure 3**).

2.2.1.1. Quality of bread

The results of determination of baking quality are summarised in **Table 3**. It is evident that the lowest protein content was measured in bread wheat flour. This fact is also confirmed

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serie testy	Hyd (%)	Work basis	Vyhlazená ivka	teplota sto	teplota mkčina
Mendel net 11 SP6 a CB	62,7	b14			
Mendel net 12 SP6 b CB	62,7	b14			
Mendel net 14 SP7 b CB	63,5	b14			
Mendel net 13 SP7 a CB	63,5	b14			
Mendel net 16 SP8 b CB	61,8	b14			
Mendel net 15 SP8 a CB	61,8	b14			
Mendel net 57 SP8_8_1 Vídeň	64,3	b14			
Mendel net 56 SP8_3_4 Vídeň	65,0	b14			
Mendel net 34 SP6_3_2 Vídeň	62,0	b14			
Mendel net 35 SP6_7_6 Vídeň	62,8	b14			
Mendel net 37SP7_2_3 Vídeň	63,7	b14			
Mendel net 38 SP7_6_1 Vídeň	62,2	b14			

Figure 3. Rheological properties of *Triticum spelta* L. varieties.

by the classification in a statistically different group ($P < 0.05$). Similarly, the lowest protein content was detected in white spelt flour. The observed result is consistent with the data published in the literature, where the protein content is normally referred above the limit

Kind of flour	Protein content (%)	Zeleny's test (mL)	Gluten index	Wet gluten content (%)	Falling Number (s)	Bread volume (cm^3)
Spelt – whole grain flour	12.77[a]	10.0[a]	57[a]	40.7[ab]	441[b]	1500[a]
Spelt – white flour	14.93[c]	11.0[a]	55[a]	42.4[b]	560[d]	1725[c]
Bread wheat – whole grain flour	9.98[b]	10.0[a]	52[a]	40.4[ab]	406[a]	2190[d]
Bread wheat – white flour	12.70[a]	14.0[b]	83[b]	30.8[a]	496[c]	1610[b]

Note: Values marked with the same letter are, based on Tukey's HSD test, statistically significantly different at a significance level $P \geq 0.05$.

Table 3. Selected parameters of baking quality (mean of two replications).

of 15%. The amount of wet gluten in the samples was in optimum quantity excluding white bread wheat flour that showed a statistically significant difference from white spelt flour. The values resulting from the Zeleny's test were generally low. Only bread wheat reached higher values. Low values of sedimentation are general problems of hulled wheat, which are due to the genetic background to some extent. The gluten index was determined to assess the gluten quality. As expected, the highest amount of gluten was found in bread wheat flour (also confirmed by Tukey's HSD test). However, the value of gluten index in whole-wheat bread flour was surprisingly low. A partial explanation was found based on the correlation analysis (**Table 4**), because the flour had low Zeleny's values. The correlation between these values and the values of gluten index was statistically significant (r = 0.89). Flour of both wheat varieties showed high values of the Falling Number – an indicator of damage to the starch grains due to the pre-harvest sprouting. The values are very high (exceed the standard). Such a high Falling Number may have negative effects on loaf volume, as well as the sensory evaluation of bread crumb.

Parameter		Mean ± SD	1	2	3	4	5
Protein content (%)	(1)	12.6 ± 1.9					
Zeleny's test (mL)	(2)	11.3 ± 1.8	0.23^{ns}				
Gluten index	(3)	62.0 ± 14.0	0.12^{ns}	0.89^{*}			
Wet gluten content (%)	(4)	38.5 ± 5.2	0.11^{ns}	-0.88^{ns}	-0.89^{*}		
Falling Number (s)	(5)	475.8 ± 62.3	0.92^{*}	0.42^{ns}	0.24^{ns}	-0.04^{ns}	
Bread volume (cm^3)		1756.3 ± 280.9	-0.69^{*}	-0.34^{ns}	-0.42^{ns}	0.25^{ns}	-0.44^{ns}

Note: $^{*}P < 0.05$; ^{ns}, non-significant.

Table 4. The results of correlation analysis (mean of a`ll flour kinds).

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The most objective parameter of the baking quality is a determination of the loaf volume. In the present case, a modified methodology was used, and hence the values are for guidance only. Whole-wheat bread showed the highest values. Conversely, the lowest values were found in whole-wheat spelt flour. The results do not fully correspond with the values regarding the gluten index and Zeleny's test (**Table 3**). Correlation analysis results (**Table 4**) indicate a negative correlation (r = −0.69) between the bread volume and protein content. A possible explanation is the fact that spelt is generally higher in protein, but it is of lower baking quality than bread wheat (**Figure 4**).

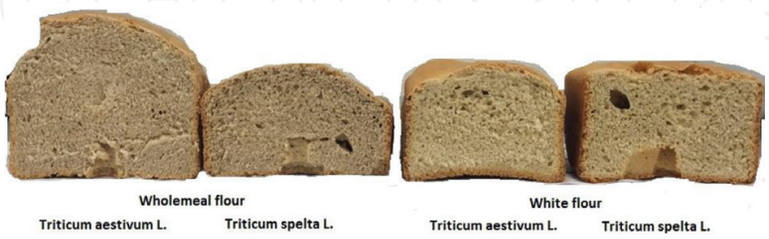


Figure 4. The result of the baking test. A cross-section of bread, in order from left to right: a bread of whole-wheat flour, finely ground flour, whole-wheat spelt flour, finely ground flour, bread wheat flour and spelt flour.

Respondents rated the bread made of whole-wheat, finely ground flour that is the best within the sensory evaluation. The main reason was its high volume. Eight out of 10 respondents described this bread visually appealing. Taste, of course, is a very important indicator of the quality of bread. For all breads, the taste was evaluated as pleasant and less intense. In overall assessment, the bread made of whole-wheat, finely ground flour and bread wheat flour received the highest rating. On the contrary, spelt bread gained only an average rating in the overall evaluation.

2.2.1.2. Quality of pasta

The resulting values of baking properties of flour, which may also affect the quality of pasta, were analysed using the correlation analysis. **Tables 5** and **6** show the results of Tukey's HSD test at a level of significance ($P \geq 0.05$). The tables also present the assessment of cooked pasta.

Species	Protein content (%)	Zeleny's test (mL)	Gluten index	Wet gluten content (%)	Falling Number (s)
Einkorn	15.59^{b}	8.50^{a}	25.8^{a}	36.45^{b}	387^{a}
Emmer	16.04^{d}	13.00^{a}	45.9^{b}	38.40^{c}	470^{c}
Spelt	15.74^{c}	21.0^{b}	76.0^{c}	42.26^{d}	403^{a}
SW Kadrilj – bread wheat	12.79^{a}	34.0^{c}	86.1^{d}	30.88^{a}	187^{b}

Note: Values marked with the same letter are, based on Tukey's HSD test, statistically significantly different at a significance level $P \geq 0.05$.

Table 5. Selected parameters of baking quality of different wheat species.

Species	Firmness	Binding capacity	Swelling capacity	Sediment	Increase of volume	Increase of weight
Einkorn	13[a]	105[a]	2.48[a]	180[c]	120.5[c]	105[a]
Emmer	10[b]	100[c]	2.28[a]	110[b]	102[a]	100[c]
Spelt	13[a]	108[a]	2.41[a]	79.5[a]	105.0[a]	108[a]
SW Kadrilj – bread wheat	11[c]	95[b]	2.20[a]	80.0[a]	94.5[b]	95[b]

Note: Values marked with the same letter are, based on Tukey's HSD test, statistically significantly different at a significance level $P \geq 0.05$.

Table 6. Selected parameters of quality of different wheat species.

According to CSN 46 1100-2 (the Czech Republic's standard quality), an amount of N-substances in wheat for food use should reach 10.8–13.7%, which corresponds with the sample of bread wheat flour. The fact that hulled wheat is higher in protein has been confirmed within this study. The tested wheat varieties contained 16% of N-substances. Generally, the sedimentation index was low in hulled wheat samples. It may be therefore stated that these varieties are not, in contrast to bread wheat, suitable for baking purpose. On the other hand, these values do not affect the quality of pasta to a great extent. By contrast, gluten index and the amount of sediment have an impact on it. In this case, negative correlation indicates that increased gluten index decreases an amount of sediment with 99.9% probability, when cooking pasta. Gluten index of einkorn wheat is very low, which consequently resulted in the relatively large amount of sediment. The interesting information shown by this statistical method is the dependence of wet gluten on the amount of water bound by pasta during boiling. The amount of water absorbed by pasta thus increases due to the higher wet gluten content together with the weight of pasta. Spelt showed the highest values of wet gluten and thereby the highest binding; conversely, the lowest amounts were found in bread wheat. The Falling Number method did not prove any evidence showing a connection with the quality of pasta.

The sensory evaluation included tasting and filling out a questionnaire. Colour, surface (smooth, rough and floury), edges (sharp and rough), texture (compact and cracked) and firmness (strong, fragile, crumbly and translucent) of uncooked pasta had been evaluated. In consequence, colour, hardness (undercooked, al dente and overcooked), shape (appropriate and deviation of shape), flavour (excellent, good, fair and poor with foreign taste), odour (pleasant and unpleasant) and surface (sticky, slightly sticky and dry) of cooked pasta had been evaluated. Based on the data gained from the questionnaires, it may be assumed that the pasta production of hulled wheat was assessed positively by the respondents on the whole (**Figure 5**).

2.2.2. Antioxidant activity of different wheat species

Whole grain phytochemicals have an antioxidant activity, the ability to scavenge free radicals that may oxidise biologically relevant molecules [17]. Due to this, whole-wheat foods could

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Figure 5. Differences in pasta colour.

contribute to the health benefits of people such as reducing the risk of heart disease, diabetes type 2, cancer, etc. In the present study, there were highly significant differences ($p < 0.05$) among 26 varieties for antioxidant activity (**Figure 6** and **Table 7**).

Mean antioxidant activity among varieties ranged from 225.45 mg Trolox/kg DW to 400.83 mg Trolox/kg DW. This demonstrates a broad range of antioxidant content in wheat species. There were eight groups in which the means were not significantly different from one

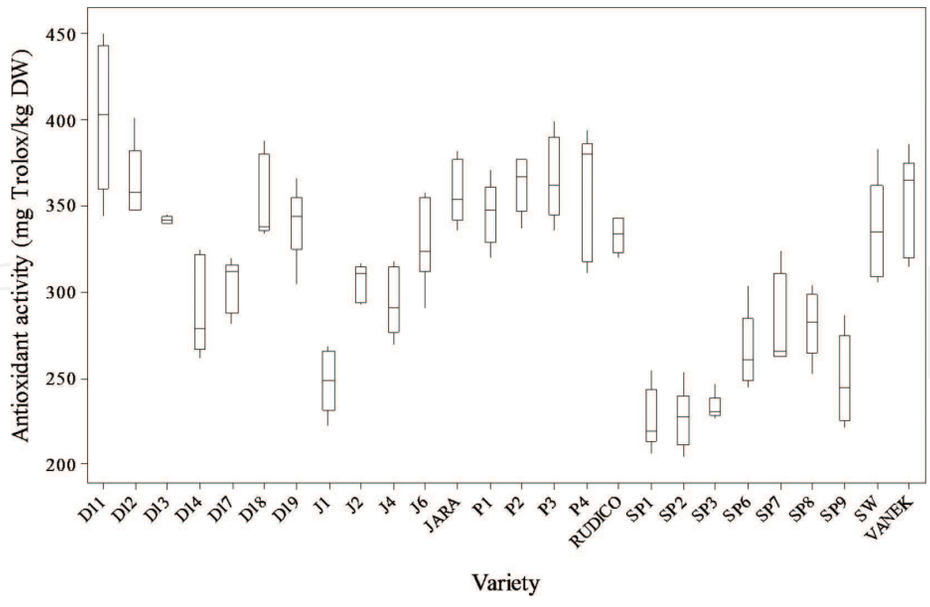


Figure 6. Antioxidant activity content of wheat varieties. Values expressed as mg Trolox/kg DM. D11 – Weisser Sommer; D12 – May-Emmer; D13 – *T. dicoccum*; D14 – *T. dicoccum*; D17 – *T. dicoccum*; D18 – *T. dicoccum*; D19 – *T. dicoccum*; J1 – *T.*; J2 – *T. monococcum*; J4 – *T. monococcum;* J6 – *T. monococcum*; P1 – *T. aestivum*; P2 – *T. aestivum*; P3 – *T. aestivum*; P4 – *T. aestivum*; SP1 – *T. spelta*; SP2 – *T. spelta*; SP3 – *T. spelta*; SP6 – *T. spelta*; SP7 – *T. spelta*; SP8 – *T. spelta*; SP9 – *T. spelta*; SW – SW Kadrilj.

Variety	D11*	D12*	D13*	D14*	D17*	D18*
AOA (mg Trolox/kg DM)	400.83^{a}	364.15^{ab}	341.60^{bc}	288.36$^{e–g}$	304.56$^{c–f}$	351.62^{b}
Variety	D19*	RUDICO*	J1**	J2**	J4**	J6**
AOA (mg Trolox/kg DM)	339.92^{bc}	332.90$^{b–d}$	247.42^{gh}	306.16$^{c–f}$	293.23^{df}	327.73$^{b–e}$
Variety	P1***	P2***	P3***	P4***	SP1****	SP2****
AOA (mg Trolox/kg DM)	345.88^{bc}	362.25^{ab}	365.26^{ab}	360.95^{ab}	225.45^{h}	226.55^{h}
Variety	SP3****	SP6****	SP7****	SP8****	SP9****	JARA
AOA (mg Trolox/kg DM)	232.63^{h}	265.56$^{f–h}$	280.63^{fg}	281.10^{fg}	248.82^{gh}	357.36^{ab}
Variety	SW	VÁNEK				
AOA (mg Trolox/kg DM)	336.98$^{b–d}$	353.70^{b}				

Values marked with different small letters are significantly different at $P \leq 0.05$.

*Emmer varieties.

**Einkorn varieties.

***Landrace of *T. aestivum*.

****Spelt varieties.

Table 7. Content of antioxidant activity in different wheat grains.

another. Having 400.83 mg Trolox/kg DW, D11 variety belonged to the lead group and was significantly different from all other varieties except P3, D12, P2, P4 and JARA. In contrast, the varieties containing the lowest content of antioxidant were SP6, SP9, J1, SP3, SP2 and SP1 with 266.57 mg Trolox/kg DW, 248.82 mg Trolox/kg DW, 247.42 mg Trolox/kg DW, 232.63 mg Trolox/kg DW, 226.55 mg Trolox/kg DW and 225.45 mg Trolox/kg DW, respectively.

The findings of Lachman et al. [14] showed that the antioxidant activity content of seven varieties ranged between 134.0 and 197.5 mg Trolox/kg DW. In this study, our results are approximately two times higher than these ones. This means that the varieties in our experiment are potential for breeding new wheat varieties, as well as essential sources of functional food ingredients.

It is known that antioxidant activity content can be influenced by stress factors of the weather conditions during the vegetation period and genotype effects. Comparing the data of four species collected from 2010 to 2012 (**Figure 7**) show that there is a decrease in the mean of antioxidant during the 3-year period by 23.26 mg Trolox/kg DW. These differences are, however, not statistically significant.

The cultivated diploid (einkorn), tetraploid (durum wheat), hexaploid (bread wheat) and other varieties possess antioxidant activity due to their content of hydrophilic (phenolics, selenium) and lipophilic (carotenoids, tocopherols) antioxidants (**Figure 8**) [18].

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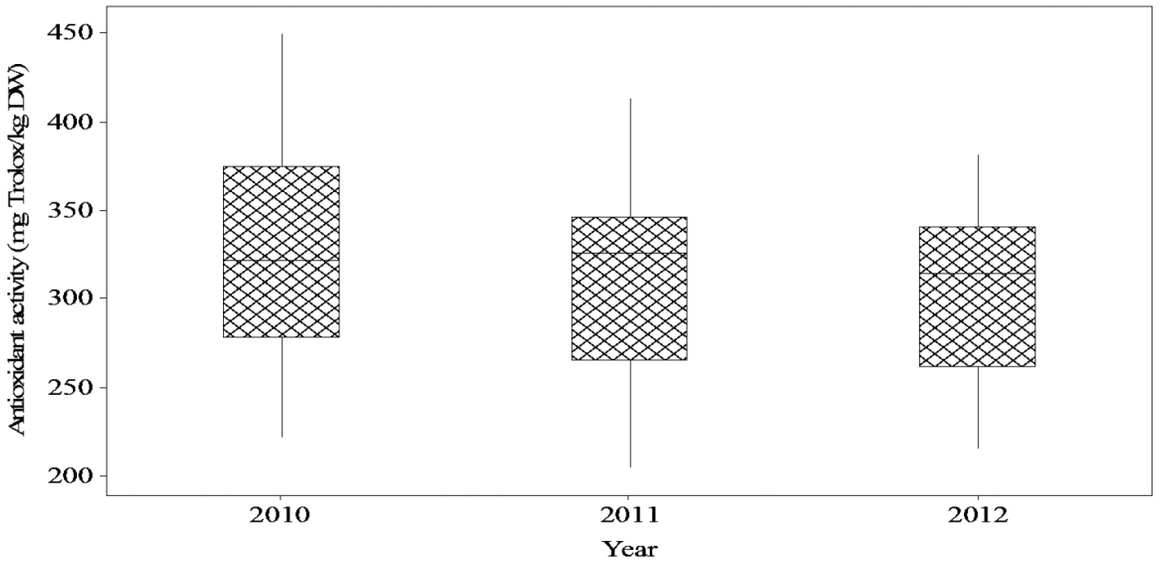


Figure 7. Antioxidant activity in 26 varieties harvested in 2010, 2011 and 2012.

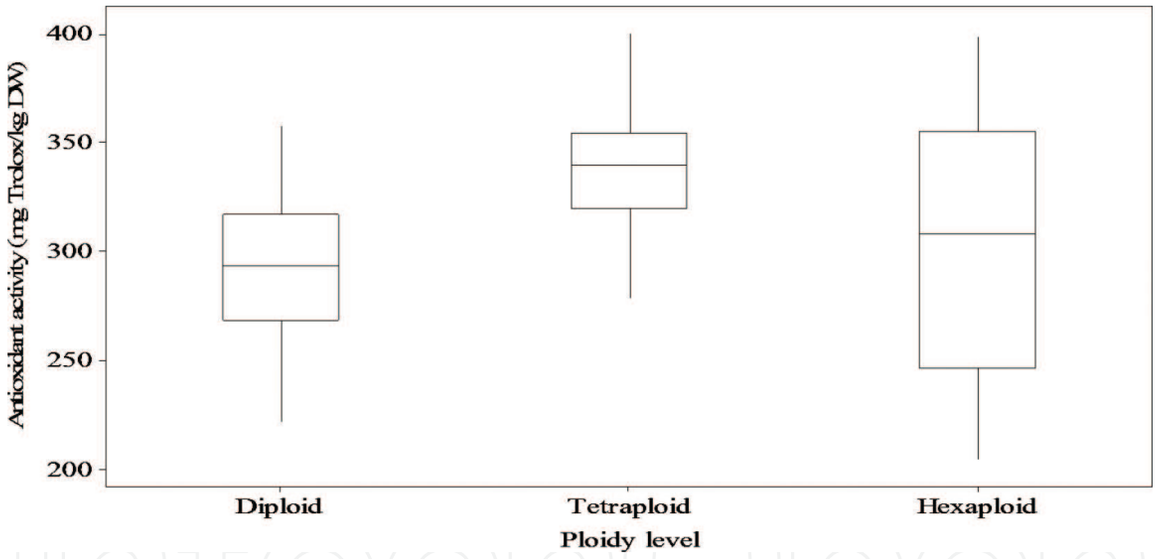


Figure 8. Content of antioxidants in wheat grains from the harvests 2010, 2011 and 2012.

Analysing ANOVA, Tukey's HSD revealed statistically significant differences between tetraploid and diploid as well as tetraploid and hexaploid. The mean antioxidant of tetraploid from 2010 to 2012 (340.49 ± 39.11 mg Trolox/kg DW) was higher than the value of diploid and hexaploid (293.64 ± 34.82 mg Trolox/kg DW) and (303.08 mg Trolox/kg DW), respectively. Our results are different from those of Lachman et al. [14]. While antioxidant values in our findings increase from diploid (einkorn) to tetraploid, the reverse is true for Lachman's results. This is because our experiment used 26 varieties in 3 years compared to seven varieties in 2 years.

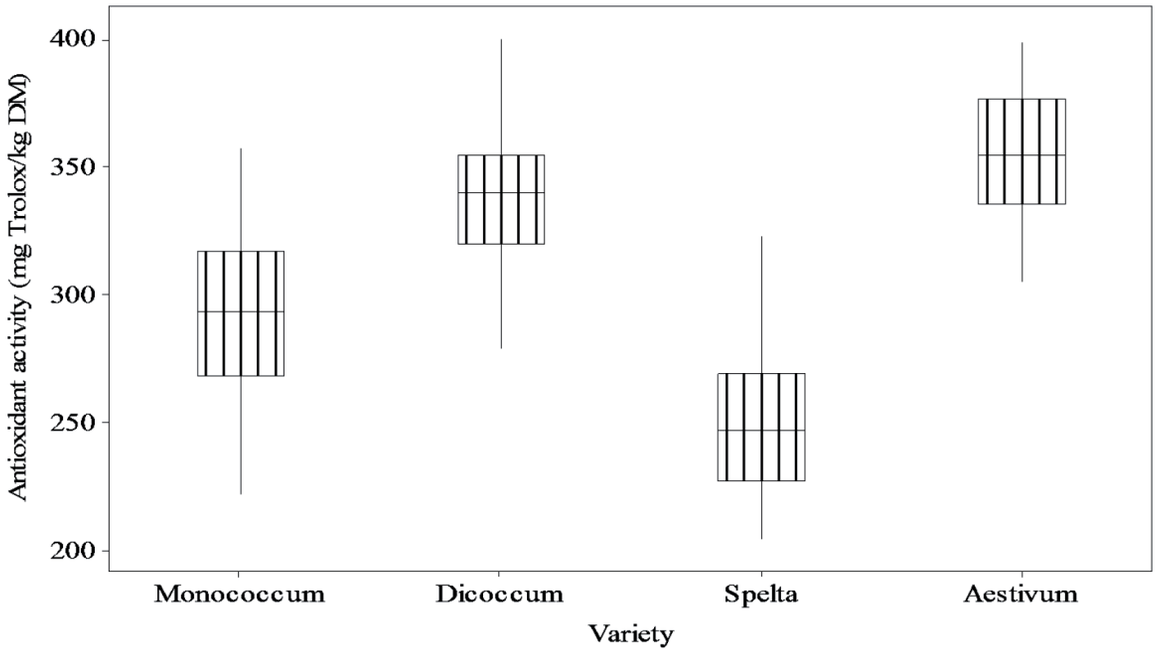


Figure 9. Antioxidant activity values of four species.

Figure 9 illustrates the differences of four varieties. *T. aestivum* and emmer wheat shared the highest value with 354.44 ± 24.97 mg Trolox/kg DW) and 340.49 ± 39.11 mg Trolox/kg DW, respectively, followed by *T. monococcum* (293.64 ± 34.82 mg Trolox/kg DW). Having 251.54 ± 29.60 mg Trolox/kg DW, *T. spelta* had the lowest value in total of four species ($P < 0.05$).

2.3. Conclusions

Compared to samples originating from Ceske Budejovice, samples originating from Vienna attained higher and more balanced values in all the stages of Mixolab II. testing. SW Kadrilj was the only common wheat variety that attained a similar protein weakening speed when heated and worked mechanically (C2). There were enormous differences between *Triticum macha* Dekapr. and Menabde and *Triticum spelta* L. Baking technology must be adapted to the requirements of these two wheat species; dough must be worked more sensitively. In spite of this fact, these species can be used for baking purposes.

The working hypothesis, i.e. the use of spelt, einkorn and emmer wheat is technically feasible within the pasta production, was confirmed based on the testing. All wheat varieties are high in protein. Boiling time is not significantly different and pasta swells to the extent close to the pasta commonly available on the market. The taste of evaluated pasta was not assessed negatively, and the consumers, who are used to consuming more whole grain products, could feel the distinctive flavour of products made of einkorn and emmer wheat and spelt, which generally fades fast during milling from pasta made of white durum wheat or bread wheat flour.

Wheat contains huge essential antioxidants such as dietary fibre, tocopherols, tocotrienols, etc. The consumption of wheat is associated with reducing risk of chronic diseases including

type 2 diabetes, obesity and cardiovascular disease. In this study, the content antioxidant activity of 26 varieties of whole wheat is reported. Antioxidant activity was ranged from 225.45 mg Trolox/kg DW to 400.83 mg Trolox/kg DW. The antioxidant activity values were significantly different among varieties, ploidy level and wheat accessions.

The general conclusion is that hulled wheat species had a high protein content and wet gluten content. Einkorn and emmer were not suitable for 'classical' baking processing. But there is potential for other products such as wheat rice (einkorn) or pasta (emmer). Spelt will be possible to be used in 'classical' baking industry. The best solution will be the use of spelt wheat grain mixed with bread wheat grain. Also, this study showed a genotypical variation in the antioxidant activity of einkorn, emmer, spelta and *T. aestivum*.

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