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Ancient wheat species can extend biodiversity of cultivated crops

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Wheat genetic resources may be grown in organic farming systems or in less favourable areas for bread wheat species. Characteristics of hulled wheat species (23 varieties of einkorn, emmer wheat, spelt wheat) were studied and evaluated within a two-year trial period (which was executed on certified organic fields) and they were compared to characteristics of landraces and modern bread wheat varieties. The main aim of our study was to evaluate the potential uses of genetic resources of wheat in organic farming. The hulled wheat species were resistant to mildew and brown rust. Their grains were less contaminated with DON than the grains of the control varieties. The grain yield rate was reduced. Per hectare crude protein yield was higher in spelt and emmer wheat species than in the control varieties. High protein proportion in grain was an important advantage of the hulled wheat species. Spelt wheat is suitable for production of products similar to bread wheat (they have similar technological qualities). Einkorn and emmer wheat contain worse-quality gluten and therefore are suitable for the production of unyeasty products, that is pasta, mush, traditional unyeasty bread, etc.

Key words: Genetic resources, wheat, einkorn, emmer, spelt, organic farming, quality.

INTRODUCTION

Crops grown in the Czech farming system represent a negligible part of the existing diversity. Over 50% of the daily global requirements for proteins and calories are met by just three crops – maize, wheat and rice (FAO, 1996) – and only 150 crops are commercialised on a significant global scale. On the other hand, ethnobotanic surveys indicate that, worldwide, more than 7,000 plant species are cultivated or harvested from the wild (Wilson, 1992). The range of grown crops has been changing throughout the history of farming and new and more efficient crops have continuously been introduced. It has been dangerous for ancient landraces which have been an important source for further breeding (Collins and Hawtin, 1999). Farming and natural genetic diversity have been currently seriously endangered (Dotlačil et al.,

2002). Biodiversity is therefore considered as the essential natural resource like soil and water since 1992 when this value of biodiversity had been internationally recognized by the Convention on biodiversity (UNCED, Rio de Janeiro, 1992). As for the landraces, only little bred species and crops having some specific characteristics (for example good quality, adaptability to particular stress) may be used in practice (Dotlačil et al., 2002). They cannot usually compete with the modern bred and extended wheat species (Ehdaie et al., 1991) in the categories of efficiency and productivity. In spite of this fact, they have become more interesting for farmers as they have particular specific qualitative characteristics, for example high nutrition and dietetic values (Dotlačil et al., 2002). The genetic diversity of wild forms and species of cultural or related crops significantly contribute to the improvement of crop characteristics. This genofond may be used in the breeding process itself (Reynolds et al., 2007) in order to enhance the resistance to diseases or improve characteristics of varieties (Gollin and Smale,

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1999). The knowledge of suitability is especially important both for breeding of cereals and for sustainable farming (organic farming, low input farming).

Triticum monococcum L., *Triticum dicoccum* (Schrank) Schuebl. and *Triticum spelta* L. also known as einkorn, emmer and spelt, respectively were among the earliest *Triticeae* domesticated by man (Suchowilska et al., 2009). Today, einkorn is grown in marginal farmlands in Western Turkey, the Balkan countries, Italy, Spain, Switzerland and Germany (Wieser et al., 2009). Emmer remains an important crop in Ethiopia and a minor crop in India, Italy and Turkey (Marino et al., 2009). Spelt continues to be a major cereal in isolated regions throughout Middle Europe, primarily in Germany, the Czech Republic, Austria, Hungary and Switzerland (Troccoli and Codianni, 2005). Current trends towards low-impact and sustainable agriculture as well as an increase in the utilisation of organic and simultaneously functional products suggest that these ancient wheat species still play a certain role in human nutrition (Brandolini et al., 2008). For example, spelt and emmer are cultivated on many organic farms in Europe not only because they are supposed to have a higher nutritive value in comparison with common wheat but also due to their higher resistance to unfavourable environmental factors as well as lower fertilisation and soil demands (Suchowilska et al., 2009). The importance of genetic resources of the field crops is about to increase in the farming sector as they are able to adapt to changing environmental conditions provoked by the global climate changes (Kotschi, 2006). If we grow them in marginal regions, they provide a lower but more stable yield rate (Collins and Hawtin, 1999). Not only the growing of these crops, but also the further processing and marketing of its final products are crucial. They are usually considered regional specialties. Such a concept is supported in EU countries as an additional alternative to intensive farming. This focuses on traditional and regional species (Dotlačil et al., 2002).

Our research and our study was aimed at the evaluation of yield formation and technological quality of the hulled wheat species, yet we also wanted to know if these wheat species were suitable for sustainable farming systems and if they could be grown in marginal regions. The analysis of their characteristics and the evaluation of their advantages and disadvantages was another important objective of our research.

MATERIALS AND METHODS

Varieties involved in the research

The evaluated varieties (Table 1) came from the gene bank of the Research Institute of Crop Production in Prague-Ruzyně (VURV). Genetic resources of einkorn (*T. monococcum* L.), emmer wheat [*T. dicoccum* (Schrank) Schuebl], spelt (*T. spelta* L.) and landraces of bread wheat – intermediate form (alternative) (*Triticum aestivum* L.) were chosen. Two bread wheat varieties (*T. aestivum* L.), Jara and

SW Kadrilj. were chosen as control.

Establishment and management of the trials

Varieties were sown in a randomized complete block design on the organic certified trial parcels in Prague (Czech University of Agriculture - CZU, VURV) and Ceske Budejovice (CB) during 2009 and 2010. The seeding rate was adjusted for a density of 350 germinable grains per m^2. Rows were 125 mm wide. The crop stands were treated in compliance with the European legislation [the European Council Regulation (EC) No. 834/2007, the European Commission Regulation (EC) No. 889/2008] and the IFOAM recommendations (the International Federation of Organic Agriculture Movements).

Characteristics of the trial stations

The University of South Bohemia in Ceske Budejovice (CB): mild warm climate, soil type – pseudogley cambisols, kind of soil – loamy sand soil, altitude of 388 m. The University of Life Sciences – Research station Prague – Uhřívněves (Czech University of Agriculture): warm and mid-dry climate, soil type – brown soil, kind of soil – loamy clay soil, altitude of 295 m. The Research Institute of Crop Production in Prague – Ruzyne (VURV): warm mid-dry climate, soil type – degraded chernozem, kind of soil – clay and loamy soil, altitude of 340 m. Detailed characteristics are in the Tables 2 and 3.

Features measured and analysed in the growing period

The following traits were studied during the growing period (Zadoks et al., 1974): length of plant (at the end of the flowering stadium – DC 69); index of lodging (combination of intensity and degree of lodging of the crop stand on each parcel, mean of two measurements after the heading – DC 59, before the harvest – DC 87); the degree of mildew infestation (DC 37; 51 – 61; 77) and brown rust infestation (DC 77) were expressed by a score in accordance with symptoms of a disease on plants (9 = no infestation). After the harvest we measured yield and calculated crude protein content.

Laboratory analyses

Deoxynivalenol (DON)

At first, the toxin was extracted from a sample (deionizied water was used as a solvent). 100 µl of the extract was diluted in 1 ml of DONQ dilution buffer. 300 µl of the diluted extract was applied onto the strip (ROSA®-DON quantitative test). Incubation of the strip - 10 min at a temperature of 45°C (ROSA®-M incubator). The assessment of the test – by ROSA®-M Reader (results in ppb).

Baking quality

The following parameters were tested after the harvest 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) and gluten index (ICC 155).

Statistical data processing

The Statistica 9.0 (StatSoft. Inc., USA) was used for statistical data

Table 1. List of used varieties.

Name of variety	Identifier[1]	Origin[2]	Botanical variety
Einkorn - *T. monococcum* L.			
T. monococum 38	01C0204038	GEO	*hohensteinii* Flaksb.
T. monococum 44	01C0204044	ALB	*vulgare* Koern.
No. 8910	01C0204542	DNK	*macedonicum* Papag.
Schwedisches Einkorn	01C0204053	SWE	*vulgare* Koern.
Emmer - *T. diccocum* (Schrank) Schuebl			
Rudico	01C0200948	CZE	*rufum* Schuebl.
Weisser Sommer	01C0203993	DEU	*dicoccum*
May-Emmer	01C0203990	CHE	*dicoccum*
T. dicoccon (Brno)	01C0204022	CZE	*rufum* Schuebl.
T. dicoccon (Dagestan)	01C0204016	RUS	*serbicum* A. Schulz
T.dicoccon (Palestine)	01C0201261	ISR	*serbicum* A. Schulz
T. dicoccon (Tapioszele)	01C0201280	-	*semicanum* Koern.
T. dicoccum (Tabor)	01C0204318	-	*rufum* Schuebl.
Spelt - *T. spelta* L.			
T. spelta (Ruzyne)	01C0201257	CZE	*arduini* (Mazz.) Koern.
T. spelta (Tabor 22)	01C0204322	-	*duhamelianum* Koern.
T. spelta (Tabor 23)	01C0204323	-	*duhamelianum* Koern.
Spalda bila jarni	01C0200982	CZE	*album* (Alef.) Koern.
VIR St. Petersburg	01C0204865	CZE	*album* (Alef.) Koern.
T. spelta (Kew)	01C0200984	-	*caeruleum* (Alef.) Koern.
T. spelta No. 8930	01C0204506	-	*album* (Alef.) Koern.
Bread wheat - *T. aestivum* L. – intermediate landraces			
Postoloprtska presivka 6	01C0200043	CZE	*lutescens* (Alef.) Mansf.
Rosamova ceska cervena	01C0200051	CZE	*milturum* (Alef.) Mansf.
Cervena perla	01C0100124	CZE	*milturum* (Alef.) Mansf.
Kasticka presivka	01C0200031	CZE	*milturum* (Alef.) Mansf.
Bread wheat - *T. aestivum* L. - control			
Jara	01C0200100	CZE	*lutescens* (Alef.) Mansf.
SW Kadrilj	01C0104877	SWE	*lutescens* (Alef.) Mansf.

[1]EVIGEZ (http://genbank.vurv.cz/genetic/resources/asp2/default_c.h); [2]Abbreviations of countries comply with ISO 3166-1 alpha-3.

Table 2. Agrochemical soil analysis.

Locality	Year	pH $CaCl_2$)	N-NH_4	N-NO_3	P	K	Ca	Mg
					(mg.kg^{-1})			
CB	2009	5.91	15.5	8.1	120	65	114	1452
	2010	6.67	2.42	7.3	111	86	1808	129
CZU	2009	6.13	11.41	10.0	109	130	155	3134
	2010	6.67	3.84	15.8	68	145	2837	143
VURV	2009	7.20	19.9	9.0	130	298	202	5163
	2010	7.43	4.64	12.2	109	380	5277	183

Table 3. Climatic characteristics of localities.

Locality	Year	Growing period (month)						Year mean
		4	5	6	7	8	Mean	
Temperatures (°C)								
CB	1961-1990	8.1	12.0	16.2	17.1	17.1	14.2	8.2
	2009	12.7	14.3	15.8	19.2	20.4	16.8	9.5
	2010	9.1	13.0	17.6	20.9	18.1	15.7	8.4
CZU	1961-1990	8.2	13.4	16.3	18.2	17.5	14.7	8.3
	2009	13.6	14.7	16.1	19.5	20.0	16.8	9.2
	2010	10.0	12.6	17.9	21.6	18.4	16.1	7.8
VURV	1961-1990	7.7	12.7	15.9	17.5	17.0	14.2	7.9
	2009	13.0	14.2	15.1	18.6	19.6	16.1	9.2
	2010	9.0	11.8	17.2	20.9	17.7	15.3	7.8
Precipitation (mm)								
CB	1961-1990	46.5	70.1	93.0	77.8	78.8	323.9	529.9
	2009	24.3	111.0	197.8	128.2	93.2	554.5	837.5
	2010	61.1	117.9	103.8	111.0	110.9	504.7	727.8
CZU	1961-1990	46.0	64.0	74.1	74.3	72.1	330.5	575.1
	2009	15.6	95.3	72.2	121.9	31.8	336.8	478.9
	2010	32.0	93.1	62.2	118.0	139.6	444.9	651.5
VURV	1961-1990	38.2	77.2	72.7	66.2	69.6	323.9	525.9
	2009	83.5	89.9	64.5	22.6	15.6	276.1	478.9
	2010	37.0	78.3	57.6	128.0	123.5	424.4	651.5

processing. Regression and correlation analyses provided the evaluation of interdependence. The comparison of mean values were provided by the Tukey HSD test.

RESULTS

The main aim of the work was to evaluate the basic differences in agronomically important traits and quality parameters of genetic resources of wheat. Additionally, we evaluated its potential for low input and organic growing. The first evaluated parameter was length of the plant because of its relationship to weed competiveness of plants (Tables 4 and 5). As for the studied and evaluated wheat species, emmer and spelt wheat plants were longest (127 cm). There were little differences between the varieties, for example *T. spelta* (Kew) (137.5 cm), *T. spelta* (Tabor 22) (119.9 cm). Short straw were einkorn varieties (mean value = 114.1 cm). Nevertheless the einkorn varieties were less resistant to lodging (index of lodging = 5.6). High variability, represented by a range of minimum and maximum values (Table 5) was among the einkorn varieties. Concerning einkorn varieties, No. 8910 and Schwedisches einkorn were most resistant to

lodging. As for emmer wheat varieties, Rudico (7.0) was the most resistant variety and *Triticum dicoccon* (Dagestan) (4.7) was the least resistant. The selection of resistant spelt wheat varieties will be difficult as all spelt wheat varieties are inclined to lodging (Table 5). Low resistance to lodging was in the case of the hulled wheat species and landraces of intermediate forms of bread wheat, the main reason for a decrease in grain yield (negative correlation values in Table 6). All einkorn varieties were resistant to brown rust and mildew (Table 5). Most emmer wheat varieties were also resistant. *T. dicoccon* (Palestine) was slightly infested (mildew = 8.6; brown rust = 8.3). Some varieties of spring spelt were less resistant to mildew (Ruzyne and Kew). All the spelt varieties were nevertheless less resistant to brown rust. Landraces of intermediate forms of bread wheat were less resistant to mildew (strong negative corelation to the yield) (Table 6). Lower resistance was also in the case of both varieties of control varieties. From the point of viewing food safety (evaluated as DON contamination in grain), we found either no or strong contamination in cases of individual varieties from all groups of varieties. There was especially an individual response of the varieties to *Fusarium* spp. infection pressure. Mean grain

Table 4. Summary of bread wheat varieties results.

Parameter	Bread wheat					
	Intermediate landraces			Control		
	Mean and SD	Min.	Max.	Mean and SD	Min.	Max.
Plant length (cm)	120.4±9.7[ab]	84	132	103.4±22.0[d]	62	142
Lodging (0-9)	5.9±2.8[ab]	1	9	7.6±2.0[b]	2.7	9
Mildew (0-9)	7.4±1.3[c]	5.2	9	8.4±0.6[a]	7.2	9
Rust (0-9)	6.0±0.8[a]	4.3	7	6.2±1.9[a]	3.0	9
DON (ppb)	192.1±295.4[a]	0	1100	234.2±314.1[a]	0	980
Yield (t.ha^{-1})	1.7±0.9[a]	0.4	3.8	3.0±1.7[c]	0.4	6.9
Protein yield (kg.ha^{-1})	236.0±148.2[b]	56	563	389.3±228.9[a]	60	884
Protein content (%)	13.7±2.6[b]	8.8	18.5	13.2±2.2[b]	10.1	16.9
Wet gluten (%)	34.7±9.4[ab]	18.4	50.7	31.6±8.6[a]	20.0	46.1
Gluten index	43.6±11.1[c]	19	66	66.0±15.5[d]	41	92
SDS (ml)	57.6±15.4[b]	29	86	66.9±15.6[d]	33	87

Within column values followed by the same letter are not significantly different at P < 0.05 (Tukey HSD test); the letters are given in alphabetical order with increasing level of a parameter (comparisson of all groups of varieties).

contamination rates of DON did not exceed the permitted limit norms (1.25 mg/kg = limit for contamination according to EC Regulation No. 1126/2007). Spelt wheat grains contained a low proportion of DON (0.11 mg/kg) and there were minimum differences between spelt wheat varieties (Table 5).

Most emmer wheat varieties were not contaminated with DON (Rudico, Weiser sommer, May emmer). *T. dicoccon* (Tapioszele) was, on the other hand, a problematic variety (0.79 mg/kg). Hulled wheat species attained lower yield rates (Table 5) than the control varieties SW Kadrilj and Jara (Table 4). Einkorn varieties attained the lowest yield rates (mean 2.1 t/ha). As for emmer wheat varieties, Rudico attained the highest yield rate (2.8 t/ha) and *T. dicoccon* (Tapioszele) attained the lowest yield rate (1.5 t/ha). Concerning spring spelt wheat varieties, the mean yield rates was 2.6 t/ha. The yield rate was calculated after dehullling, hulls were approximately 25% of the yield. A comparison of the per hectare crude protein yield showed an interesting fact. It attained a mean value of 389.3 kg/ha in the control varieties (SW kadrilj – 450.1 kg/ha), whereas it was lower in einkorn varieties where it varied from 301.4 to 346.8 kg/ha. Emmer wheat varieties attained similar values too, except for Rudico (432.3 kg/ha). Two spelt wheat varieties attained higher values of the per hectare crude protein yield than the control ones (*T. spelta* Tabor 22 – 453.2 kg/ha; *T. spelta* No. 8930 – 475.0 kg/ha). High protein yield was influenced by high grain yield and protein content as the shown results of correlation analysis (Table 6).

From the point of view of quality we evaluated crude protein content first. The control varieties attained the lowest values of protein content in our research (SW Kadrilj – 12.3%). Emmer wheat varieties attained the

highest proportion of proteins in grain – a mean value of 16.8% (*T. dicoccon* Tapioszele – 17.4%), whereas spelt wheat varieties attained a mean value of 16.5% (*T. spelta* No. 8930 – 17.5%) and einkorn varieties attained a mean value of 15.8% (*T. monococum* 44 – 16.9%). The maximum values were more interesting because in hulled wheat species it was possible to find varieties with very high protein content (einkorn 19.9%; emmer 22.6%; spelt 20.1%) (Table 5). The high protein content in hulled wheat species also influenced higher wet gluten more than the control wheat varieties. The technological quality of the hulled wheat species was very different from the modern control variety SW Kadrilj. Generally, the varieties suitable for baking should attain high gluten index values (70) and high sedimentation values (50 ml). Einkorn and emmer wheat varieties attained very low gluten index values (12.7 to 20.7 ml). Such gluten was weak and not good for the production of yeasty goods. Einkorn and emmer wheat varieties also attained low values of the SDS test (einkorn – a mean value of 29.9 ml; emmer wheat – mean value of 31.8 ml).

The sedimentation test values are reflected in a volume of bakery products which means that einkorn or emmer wheat bakery products are not too yeasty and they are flat. Spelt wheat attained higher gluten index values (28.2 to 44.5) and higher sedimentation values (46.2 to 70.2 ml) which were close to the values attained by the control wheat varieties like SW Kadrilj (gluten index = 75.0; SDS test = 74.7 ml).

DISCUSSION

Most of the evaluated varieties of hulled wheat had long stalks which is according to Cudney et al. (1991) important

Table 5. Summary of hulled wheat species results.

Parameter	Einkorn			Emmer			Spelt		
	Mean and SD	Min.	Max.	Mean and SD	Min.	Max.	Mean and SD	Min.	Max.
Plant length (cm)	114.1 ± 10.6^a	98	132	127.0 ± 15.6^c	83	148	126.8 ± 10.4^{bc}	93	145
Lodging (0-9)	5.6 ± 2.9^a	1	9	6.0 ± 2.1^{ab}	2	9	5.9 ± 2.6^a	2	9
Mildew (0-9)	8.9 ± 0.1^b	8.5	9	8.8 ± 0.3^b	7.7	9	8.5 ± 0.6^a	6	9
Rust (0-9)	8.8 ± 0.2^b	8.3	9	8.5 ± 0.6^b	7.0	9	6.8 ± 1.0^c	4.5	8
DON (ppb)	168.8 ± 321.1^a	0.0	1500	192.7 ± 696.3^a	0	4600	110.6 ± 253.1^a	0	1300
Yield (t.ha^{-1})	2.1 ± 1.3^{ab}	0.6	3.8	2.1 ± 1.2^{ab}	0.4	4.9	2.6 ± 1.4^{bc}	0.2	4.6
Protein yield (kg.ha^{-1})	324.1 ± 210.8^{ab}	89	642	348.0 ± 195.3^a	65	682	422.6 ± 238.6^a	36	873
Protein content (%)	15.8 ± 2.4^a	11.4	19.9	16.8 ± 2.4^a	11.8	22.6	16.5 ± 2.0^a	11.3	20.1
Wet gluten (%)	38.5 ± 9.8^{bc}	23.5	58.7	41.4 ± 8.3^{cd}	24.2	59.0	44.4 ± 7.7^d	24.8	59.9
Gluten index	15.0 ± 4.9^a	5	29	15.2 ± 9.9^a	4	39	36.4 ± 14.7^b	12	63
SDS (ml)	29.9 ± 9.6^a	14	44	31.8 ± 12.8^a	11	58	59.6 ± 13.5^{bc}	34	78

Within column values followed by the same letter are not significantly different at $P < 0.05$ (Tukey HSD test); the letters are given in alphabetical order with increasing level of a parameter (comparisson of all groups of varieties).

Table 6. Correlation between selected agronomically important traits.

Parameter	Hulled wheat						Bread wheat			
	Einkorn		Emmer		Spelt		Intermediate		Control	
	GY	PC	GY	PC	GY	PC	GY	PC	GY	PC
Plant length	-0.11^{ns}	0.14^{ns}	0.35^*	0.13^{ns}	-0.04^{ns}	0.09^{ns}	0.28^{ns}	0.09^{ns}	0.13^{ns}	0.07^{ns}
Lodging	-0.29^{ns}	-0.76^{**}	-0.37^{**}	-0.47^{**}	-0.45^{**}	-0.62^{**}	-0.53^{**}	-0.73^{**}	-0.41^{ns}	-0.48^{ns}
Mildew	0.20^{ns}	0.21^{ns}	-0.20^{ns}	0.09^{ns}	0.13^{ns}	-0.12^{ns}	-0.71^{**}	-0.41^*	-0.25^{ns}	-0.24^{ns}
Rust	-0.82^{**}	0.19^{ns}	-0.57^{**}	0.20^{ns}	0.10^{ns}	0.45^{**}	-0.17^{ns}	-0.13^{ns}	0.15^{ns}	0.56^{ns}
DON	-0.31^{ns}	0.41^*	-0.21^{ns}	0.29^*	-0.28^{ns}	0.29^{ns}	-0.15^{ns}	0.52^{**}	0.14^{ns}	0.31^{ns}
Protein yield	0.95^{**}	0.11^{ns}	0.94^{**}	0.08^{ns}	0.96^{**}	0.26^{ns}	0.94^{**}	0.52^{**}	0.96^{**}	0.01^{ns}
Wet gluten	-0.05^{ns}	0.64^{**}	-0.22^{ns}	0.65^{**}	0.03^{ns}	0.94^{**}	0.29^{ns}	0.96^{**}	-0.19^{ns}	0.97^{**}
Gluten index	-0.48^*	-0.17^{ns}	-0.01^{ns}	0.12^{ns}	-0.25^{ns}	-0.15^{ns}	0.07^{ns}	-0.33^{ns}	0.51^{ns}	0.11^{ns}
SDS	0.17^{ns}	0.46^*	0.26^{ns}	0.25^{ns}	-0.15^{ns}	0.38^*	0.19^{ns}	0.80^{**}	0.30^{ns}	0.46^{ns}

GY = grain yield; PC = protein content; *statistically significant $P < 0.05$; ** highly statistically significant $P < 0.01$; ^{ns}not significant.

for high weed competiveness. On the other hand, plants must have firm stalks, nevertheless (Stehno et al., 2010) and must be resistant to lodging. Among the evaluated varieties, there were accessions resistant to lodging (regardless of the length of the stalk). The earlier published fact

by Pagnotta et al. (2005) was confirmed that short plants are not automatically more resistant to lodging. Brown rust is considered as one of the most serious wheat diseases in developing countries (Heisey et al., 1997). Einkorn and emmer wheat varieties were resistant to rust and also to mildew which is confirmed by Heisey et al. (1997). In the case of less resistant varieties of spring spelt it will be important to select more resistant accessions. The good resistance of plants is extremely important in nature-friendly farming systems because they perform under limited chemical treatment and protection of plants (Wolfe et al., 2008). Health and wholesomeness of farm products have to be guaranteed in the sustainable farming system. The crop stands may be attacked by *Fusarium*. Such infections can result in yield losses, but more importantly, in contamination of the grain with mycotoxins produced by the pathogens (Köhl et al., 2007). Harvested products are contaminated due to the accumulation of toxins such as deoxynivalenol (DON) produced by *Fusarium* spp. (Nedělník et al., 2007). In the case of all groups of varieties (einkorn, emmer, spelt, bread wheat), there was a higher contamination of grain by DON. Some varieties surpassed the level of the official norm of contamination (1.25 mg/kg = limit for contamination according to EC Regulation No. 1126/2007). There could be a possible selection of resistant varieties as the main preventive measure (Ittu et al., 2010), because in all groups of varieties, it is possible to find resistant accessions. There is also the positive role of the protective function of hulls. Because they protect grains and they are peeled away from them just before the final processing of grains (Buerstmayr et al., 2003). The yield level of hulled wheat varieties was lower than control varieties. However, many authors described the fact that in the case of wheat growing in less favoured conditions (hilly area, drought, etc.), there are smaller differences or the same yield (Marconi and Cubadda, 2005).

The yield level of hulled wheat varieties was lower than the published mean world wheat yield rates (3 t/ha) (Mitchell and Mielke, 2004). Generally, the yield rate is lower in organic farming systems as supporting instruments are limited in such farming systems (mineral fertilizers, pesticides) (Neacşu et al., 2010). The advantage of landraces of hulled wheat species is their good nutrient uptake ability (Trčková et al., 2005). It was the main reason of higher protein yield per hectar in the case of spring spelt in comparison to control varieties. Muurinen et al. (2006) explain it in such a way that the modern breeding process should provoke an increase in the yield rate by "grain dilution." The main advantage of hulled wheat varieties was very high protein content in grain (in the case of some varieties it was double the protein content of control varieties). The proportion of proteins in grain is the crucial wheat quality indicator (Shewry, 2009). Many literary sources present specific parametres of the production as a frequent reason for the

growing of the hulled wheat species (Suchowilska et al., 2009). There was different quality and suitability of grain for modern baking technology. The hulled wheat varieties contained more wet gluten than the control wheat varieties. The technological quality of the wheat species was very different. Einkorn and emmer wheat varieties attained very low gluten index values (12.7 to 20.7 ml) which was caused by an absence of the D genome (Marconi and Cubadda, 2005). Gluten was weak and is not good for the production of yeasty goods. In the case of spring spelt, the quality was very similar to the control variety. Generally said, the wheat species may be divided into two different groups: the first one involves the varieties suitable for baking (production of yeasty goods) and the second category involves the varieties suitable for other sorts of production (Shewry, 2009).

Conclusions

Resistance to diseases (mildew and brown rust) is the crucial advantage of einkorn and emmer wheat varieties (it has been confirmed by our research and trials). They have been also characterised by a lower DON grain contamination rate than bread wheat varieties. Some of the spelt wheat varieties have been infested and damaged by brown rust, but the DON grain contamination rates have been lowest there. Particular varieties have been less resistant to lodging. The selection of suitable and resistant varieties should be, therefore, done very carefully. Concerning the total yield rate, the studied hulled wheat varieties have attained lower yield rate values. Higher per hectare crude protein yield has been an important advantage of particular varieties (spelt wheat, emmer wheat) (being compared to SW Kadrilj, a control bread wheat variety). As for the yield formation, the hulled wheat varieties are suitable for growing in less favourable conditions (montane areas, dry regions) or in low-input and organic farming systems. Concerning the quality, the hulled wheat varieties have contained a higher proportion of proteins in grain. Spelt wheat is suitable for direct baking (the selection of varieties has to be done, however, very carefully). On the other hand, einkorn and emmer wheat varieties are suitable for the production of unyeasty goods (for example pasta, biscuits, etc.) as they have attained low sedimentation and gluten index values. All the hulled wheat species are good for the production of traditional food goods or they may be processed in so called craft bakery machines. Growing and processing of the hulled wheat species as organic products would bring higher added value to farmers.

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