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Genetic resources of hulled wheat species in Czech organic farming

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Abstract

As organic farmers are searching for new market and sale opportunities, the organic farming system may grow and process a wider range of species than the conventional farming system. Concerning wheat especially the hulled wheat species einkorn, emmer wheat and spelt wheat are in recent years of growing interest for organic farmers. Field trials were carried out at three Czech locations from 2009 to 2010 to study the performance of 4 einkorn, 8 emmer wheat and 7 spelt wheat accessions. All trials were spring sown and bread wheat variety SW Kadrilj was used as check. The results show that some accessions of the hulled wheat species are inclined to lodging. On the other hand, they are resistant to foliar diseases, e.g. powdery mildew and leaf rust. Hulls serve as barriers against Fusarium head blight infection and therewith associated DON contamination of grains. Grain yield of hulled wheats is inferior compared to common wheat. Grains are characterised by high protein contents (up to 18.1%), however, protein quality is lower so that hulled wheats are not suitable to common baking procedures. Productivity of hulled wheat crops needs to be increased in order to extend their acreage in organic farming systems. The different technological and nutritional quality of hulled wheat species offers the possibility for new food products to be launched on the market and, hence, possibilities for regional marketing.

Keywords

Einkorn, emmer, genetic resources, spelt, *Triticum*, wheat

Introduction

Plant genetic resources are a unique non renewable resource of an improvement in the genetic base of field crops (ØSTERGÅRD et al. 2009). Genetic diversity has become more important during the last several years. Relevant resources of diversity and strategies for an implementation of genetic diversity in organic breeding programmes have to be identified (SERPOLAY et al. 2001).

Wheat is one of the most important crops for the organic farming system (WILLER and KILCHER 2009). It was initially grown and processed by people 10000 years ago as part of the Neolithic Revolution. Animal hunting and fruit gathering ceased to be primary means of living and a settled agriculture emerged and developed (SHEWRY 2009). Nowadays, common wheat (*Triticum aestivum* L.) is the dominant cereal species worldwide (WILLER and KILCHER 2009). Einkorn (*Triticum monococcum* L.), emmer wheat (*Triticum dicoccum* (Schrank) Schuebl.) and spelt wheat (*Triticum spelta* L.) used to belong to the oldest domesticated species and they were also widespread (SUCHOWILSKA et al. 2009). Einkorn is an obsolete diploid cereal species being evidenced by archeologists 10000 years ago (WIESER et al. 2009). It spread to our region in the neolithic period (STEHNO 2001). Nowadays, einkorn is grown on a limited surface in Western Turkey, on the Balkan peninsula, in Italy, Spain, Switzerland, Germany (WIESER et al. 2009) and Austria. Emmer wheat is a tetraploid hulled wheat species. It has been traditionally grown and used as a part of the human diet (MARCONI and CUBADDA 2005). It is still grown as a minor crop in Ethiopia, India, Italy (MARINO et al. 2009) or in Turkey (GIULIANI et al. 2009). The hexaploid spelt wheat is considered to be an obsolete cultural European wheat species. It used to grow widespread in Central Europe in the past as it was (is) resistant to cold and is able to provide acceptable grain yields even on low fertility soils (FELDMAN 2001). Spelt wheat is nowadays mainly grown in Central and Western Europe, i.e. Germany, Switzerland, Austria, Czech Republic and Hungary (TROCOLLI and CODIANNI 2005).

An abundance of information on positive as well as negative features of hulled wheat landraces is crucial determining their application in the breeding process and growing in sustainable farming systems (organic farming, low-input farming). Organic farmers seek varieties characterised by a higher genetic diversity and thereby ability to adapt to a farm's land and climatic conditions. A wider genetic diversity of varieties also enhances their ability to respond to unexpected environmental conditions (BECKER and LEON 1988, CECCARELLI et al. 2001, FINCKH 2008). Regarding the increasing requirements for diversity and quality of foodstuffs hulled wheat species have become more interesting and attractive (ZAHARIEVA et al. 2010). Therefore, organic farmers look for varieties characterised by a higher nutritional value and suitability for processing and production of a wide range of regional products, and, thereby, providing a competitive advantage for these organic farmers by offering unique products.

This work provides information on characteristics of hulled wheat genetic resources which can be valuable and important for sustainable farming systems. Objectives are: (a) an identification of weak points of hulled wheat landraces for organic farming; (b) an analysis of protein formation in

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Table 1: **List of used genetic resources**

Accession name	Accession Id.[1]	Origin[2]	Botanical variety[3]
Triticum monococcum L.			
Triticum monococum 38	01C0204038	GEO	*hohensteinii* Flaksb.
Triticum monococum 44	01C0204044	ALB	*vulgare* Koern.
No. 8910	01C0204542	DNK	*macedonicum* Papag.
Schwedisches Einkorn	01C0204053	SWE	*vulgare* Koern.
Triticum diccocum (Schrank) Schuebl.			
Rudico	01C0200948	CZE	*rufum* Schuebl.
Weisser Sommer	01C0203993	DEU	*dicoccum*
May-Emmer	01C0203990	CHE	*dicoccum*
Triticum dicoccon (Brno)	01C0204022	CZE	*rufum* Schuebl.
Triticum dicoccon (Dagestan)	01C0204016	RUS	*serbicum* A. Schulz
Triticum dicoccon (Palestine)	01C0201261	ISR	*serbicum* A. Schulz
Triticum dicoccon (Tapioszele)	01C0201280	-	*semicanum* Koern.
Triticum dicoccum (Tabor)	01C0204318	-	*rufum* Schuebl.
Triticum spelta L.			
Triticum spelta (Ruzyne)	01C0201257	CZE	*arduini* (Mazz.) Koern.
Triticum spelta (Tabor 22)	01C0204322	-	*duhamelianum* Koern.
Triticum spelta (Tabor 23)	01C0204323	-	*duhamelianum* Koern.
Spalda bila jarni	01C0200982	CZE	*album* (Alef.) Koern.
VIR St. Petersburg	01C0204865	CZE	*album* (Alef.) Koern.
Triticum spelta (Kew)	01C0200984	-	*caeruleum* (Alef.) Koern.
Triticum spelta No. 8930	01C0204506	-	*album* (Alef.) Koern.
Triticum aestivum L.			
SW Kadrilj	01C0104877	SWE	*lutescens* (Alef.) Mansf.

[1] EVIGEZ (http://genbank.vurv.cz/genetic/resources/asp2/default_c.h)
[2] ISO 3166-1 A3 country codes (ftp://ftp.fu-berlin.de/doc/iso/iso3166-countrycodes.txt)
[3] Classification according to DOROFEEV et al. (1979)

relation to grain yield; (c) an evaluation of basic parametres of technological (baking) quality.

Material and methods

Genetic resources of einkorn, emmer wheat, spelt wheat and common wheat (*Table 1*) were provided by the genebank of the Crop Research Institute, Prague-Ruzyně. The varieties were sown in a randomized, complete block design on organic fields in Prague (two sites) and České Budějovice (one site) in 2009 and 2010. Seeding rate was adjusted for a density of 350 germinable grains per m². Crop stands were treated in compliance with European legislation (European Council Regulation (EC) 834/2007, European Commission Regulation (EC) 889/2008). The experimental site of the University of South Bohemia, České Budějovice (USB), at 388 m a.s.l. is characterised by a mild warm climate, the soil is classified as pseudogley cambisol and the surface texture is sandy loam. The site of the Czech University of Life Sciences, Prague (CULS) at an altitude of 295 m a.s.l. is characterised by a warm and mid-dry climate, brown soil with a clay loam surface texture. The experimental site of the Crop Research Institute, Prague-Ruzyně (CRI), at 340 m a.s.l. is characterised by a warm, mid-dry climate, the soil is classified as degraded chernozem and the surface texture is clay and loam. Results of soil analysis are presented in *Table 2*. Climatic conditions of the experimental sites are demonstrated in *Figure 1*.

The following evaluations were carried out during the vegetation period: plant height (at the end of the flowering, DC69), lodging index (combination of intensity and degree of lodging; mean of two measurements: after heading, DC 59, and before harvest, DC 87), powdery mildew (DC37, 51-61, 77) and leaf rust infestation (DC 77) expressed on a 0 to 9 scoring scheme (0=totally infected; 9=no symptoms). After harvest grain yield and protein content were measured and protein yield was calculated.

Deoxynivalenol (DON) content was determined by the ROSA®-DON Quantitative test. The toxin was extracted from the grain sample (deionizied water was used as a solvent), 100 µl of the extract was diluted in 1 ml of buffer. 300 µl of the diluted extract was applied on the test strip which was subsequently incubated for 10 min at 45°C (ROSA®-M Incubator). Results (in ppb) were assessed using the ROSA®-M Reader (Charm Sciences, Inc., Lawrence, MA).

After dehulling of grains the following quality traits were determined following standard methods of the International Association for Cereal Science and Technology (ICC): crude protein content (ICC 105/2), SDS sedimentation test

Table 2: **Soil analysis of experimental sites**

	pH	$N\text{-}NH_4$	$N\text{-}NO_3$	P	K	Ca	Mg
Site/year	($CaCl_2$)			(mg·kg⁻¹)			
USB (České Budějovice)							
2009	5.91	15.5	8.1	120	65	114	1452
2010	6.67	2.42	7.3	111	86	1808	129
CULS (Prague-Uhřívněves)							
2009	6.13	11.41	10.0	109	130	155	3134
2010	6.67	3.84	15.8	68	145	2837	143
CRI (Prague-Ruzyně)							
2009	7.20	19.9	9.0	130	298	202	5163
2010	7.43	4.64	12.2	109	380	5277	183

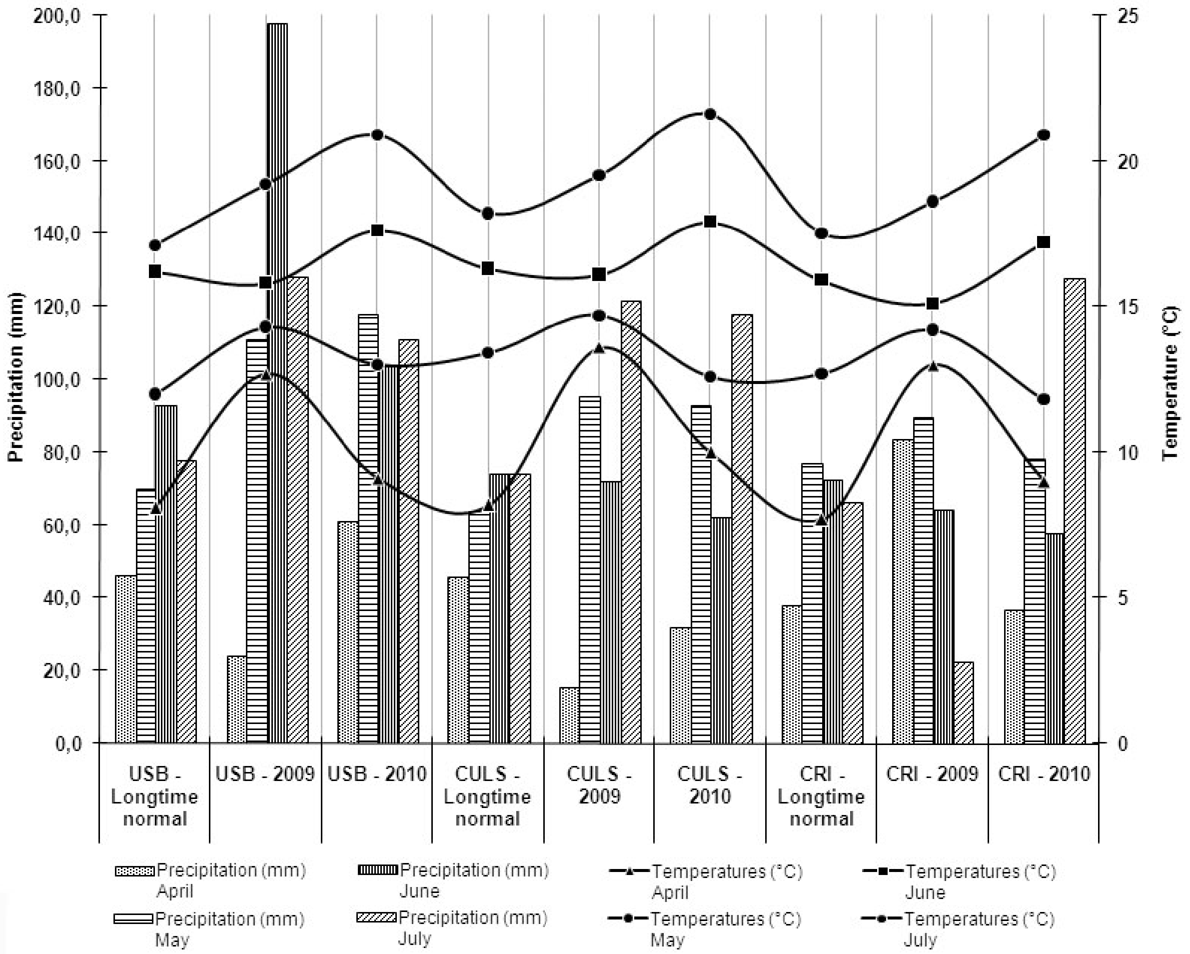

Figure 1: **Climate conditions of the experimental sites**

(ICC 151), wet gluten content (ICC 106/2) and gluten index (ICC 155).

Data were statistically processed by Statistica 9.0 software (StatSoft, Inc., Tulsa, OK) program. Regression and correlation analyses were used for the evaluation of interdependence. Comparison of variety means were carried out by the Tukey HSD test.

Results and Discussion

A large amount of data were produced within the framework of our ongoing research. In the following only selected results will be presented revealing both advantages and disadvantages of hulled wheat genetic resources.

Plant height and resistance to lodging are two crucial factors in regard to weed competitiveness (CUDNEY et al. 1991, KONVALINA et al. 2010). Among the studied plant material variability of plant height was low (*Table 3*). The only exception was Schwedisches Einkorn with a mean of 100.4 cm. It was one of the most resistant accession against lodging. Increased plant height, however, does not automatically result in reduced resistance to lodging (PAGNOTTA et al. 2005) which was also observed in the present plant material for e.g. *T. dicoccon* (Dagestan) (plant height: 115.8 cm; lodging score: 4.7) and *T. dicoccon* (Tapioszele) (134.1 cm; 6.8). Resistance to lodging is more often determined by the width and firmness than the length of the culm (KONVALINA et al. 2010). The results show that the choice of resistant cultivars or the improvement of lodging resistance should be the essential selection criteria.

A high resistance to pests and diseases is essential in natural-friendly farming systems since these systems are based on limited or no chemical protection (WOLFE et al. 2008). The majority of the tested hulled wheat accessions were resistant to powdery mildew (*Blumeria graminis*) and leaf rust (*Puccinia recondita*). *T. dicoccon* (Dagestan), *T. spelta* (Ruzyně) and *T. spelta* (Kew) were the only accessions with a slightly higher susceptibility to powdery mildew. In regard to leaf rust the einkorn and emmer accessions were highly resistant after natural infection, whereas the majority of spelt wheat accessions showed similar susceptibility than SW Kadrilj (*Table 3*). Our study showed that highly resistant genotypes to both foliar diseases are present in genetic resources stored in genebanks and that this material represents a valuable resource for wheat breeding (HEISEY et al. 1997, WOLFE et al. 2008).

Food safety is essential for sustainable farming systems especially in case of direct processing of products at farms. Infections with *Fusarium* spp. can result not only in yield losses, but also in a contamination of the grain by mycotoxins, e.g. deoxynivalenol (DON) (KÖHL et al. 2007,

Table 3: **Agronomic traits of hulled wheat genetic resources** (Means over three sites and two years; means followed by the same letter are not significantly different at *P*<0.05)

Species/Accession	Plant height (cm)	Lodging (0-9)	Powdery mildew (0-9)	Leaf rust (0-9)	DON (ppb)
Triticum monococcum					
38	123.6[b-g]	4.8[a]	9.0[e]	8.8[f]	116.7[a]
44	114.4[bc]	4.7[a]	9.0[e]	8.8[f]	350.0[ab]
No. 8910	117.9[b-e]	6.2[ab]	8.9[de]	8.8[f]	80.0[a]
Schwedisches Einkorn	100.4[a]	6.7[ab]	8.9[de]	8.9[f]	128.3[a]
Mean + Std. dev.	114.1±9.9	5.6±1.0	9.0±0.1	8.8±0.0	168.8±122.3
Triticum diccocum					
Rudico	128.1[d-h]	7.0[ab]	9.0[e]	8.6[ef]	23.3[a]
Weisser Sommer	132.3[f-h]	6.5[ab]	9.0[e]	8.7[f]	21.7[a]
May-Emmer	132.9[f-h]	6.3[ab]	9.0[e]	8.7[f]	33.3[a]
Brno	113.9[b]	4.8[a]	8.9[de]	8.6[f]	158.3[a]
Dagestan	115.8[b-d]	4.7[a]	8.5[c-e]	8.4[ef]	350.0[ab]
Palestine	126.0[b-h]	5.6[ab]	8.6[c-e]	8.3[ef]	100.0[a]
Tapioszele	134.1[gh]	6.8[ab]	8.9[de]	8.6[ef]	791.7[b]
Tabor	133.1[f-h]	6.2[ab]	9.0[e]	8.4[ef]	63.2[a]
Mean + Std. dev.	127.0±8.0	6.0±0.9	8.9±0.2	8.5±0.2	192.7±265.5
Triticum spelta					
Ruzyne	129.8[e-h]	5.4[ab]	8.2[b-d]	6.7[b-d]	41.7[a]
Tabor 22	119.9[b-f]	6.0[ab]	8.8[c-e]	7.3[cd]	83.3[a]
Tabor 23	128.1[d-h]	6.4[ab]	8.8[c-e]	6.8[b-d]	133.3[a]
Spalda bila jarni	127.3[c-h]	6.5[ab]	8.6[c-e]	6.2[ab]	120.8[a]
VIR St. Petersburg	122.6[b-g]	6.0[ab]	8.6[c-e]	6.6[b-d]	70.0[a]
Kew	137.5[h]	5.0[a]	8.2[b-d]	7.6[de]	83.3[a]
No. 8930	122.5[b-g]	5.8[ab]	8.6[c-e]	6.4[a-c]	241.7[a]
Mean + Std. dev.	126.8±5.9	5.9±0.5	8.5±0.3	6.8±0.5	110.6±65.4
Triticum aestivum					
SW Kadrilj	88.7[a]	8.25[b]	8.7[c-e]	6.2[ab]	246.7[a]

NEDĚLNÍK et al. 2007). In the present study DON contamination has not exceeded the EU regulated limit of 1250 ppb (EC regulation 1126/2007). Spelt wheat (110.6 ppb) and einkorn (168.9 ppb) were characterised by very low DON contamination. Generally, differences between accessions were negligible (*Table 3*). DON contamination was also low for emmer wheat with the exception of *T. dicoccon* (Tapioszele) (791 ppb). Hulls play a role as resistance factor against *Fusarium* infection reducing mycotoxin contamination of the grain: they protect the grains and are removed before final processing of the grains (BUERSTMAYR et al. 2003).

Yield stability is a priority in organic farming (WOLFE et al. 2008). However, farmers also need varieties with an economically profitable yield potential and a high end use quality. Due to the negative correlation between the grain yield and protein content protein yield per ha was used as indicator of interesting outliers. SW Kadrilj exhibited a mean grain yield of 3.7 $t \cdot ha^{-1}$. Mean grain yield of organically grown wheat in the Czech Republic was 3.14 $t \cdot ha^{-1}$, while 5.29 $t \cdot ha^{-1}$ was realised for conventional grown wheat (MZE 2009, 2010). The difference between organic and conventional yield is similar to data presented by other authors, i.e. 20 to 30% reduction (MÄDER et al. 2002, LAMMERTS VAN BUEREN et al. 2002). Einkorn and emmer wheat reached 57% and spelt wheat reached 70% of the yield of SW Kadrilj. Einkorn accession No. 8910 (2.3 $t \cdot ha^{-1}$), emmer wheat Rudico (2.9 $t \cdot ha^{-1}$) and spelt wheat accessions Tabor 22, Tabor 23 and No. 8930 (2.3 $t \cdot ha^{-1}$) were the highest yielding varieties of hulled wheat (*Table 4*). *T. spelta* No. 8930 reached a higher protein yield (475 $kg \cdot ha^{-1}$) than SW Kadrilj (450 $kg \cdot ha^{-1}$) (*Figure 2*). Compared to SW Kadrilj the group of einkorn wheats reached a relative protein yield of 72%, the emmer wheats of 77%, and the spelt wheats of 94%. Within the species the accessions were significantly variable. This variability can be used for the selection of genotypes with acceptable protein yield and good end use quality.

Protein yield increased in relation to grain yield whereas protein content decreased with increasing grain yield (*Figure 2*). Emmer wheat varieties contained the highest concentration of protein (mean: 16.8%). *T. dicoccon* (Palestine) showed a mean protein content of 18.1% which is +5.8% compared to SW Kadrilj. Mean contents for spelt wheat and einkorn were 16.5% and 15.8%, respectively. The high protein content of old landraces was also reported by several other authors (e.g. DOTLAČIL et al. 2002, 2010). Wet gluten content was high in all hulled wheat species (37.7-48.8%) whereas it reached only 27.3% in SW Kadrilj. Contrary, einkorn and emmer wheat varieties showed low values of gluten index (12.7-20.7) and SDS sedimentation volume (18-45.7 ml). Their dough is usually sticky, is hard to work and baked products have an inferior baking volume (D´EGIDIO et al. 1993, ABDEL-AAL et al. 1997, CORBELLINI et al. 1999). Spelt wheat varieties reached higher gluten indices (37.6-48.8) and sedimentation volumes (46.2-70.2 ml). Therefore, spelt wheat varieties which are suitable for common baking procedures are available in the present genepool. Due to their inferior gluten quality einkorn and emmer wheat are not suitable for common baking procedures but they have to be used in a different way. Production of flour mixtures is one possibility. Moreover, there are a lot of products made from hulled wheat species, e.g. pasta, non yeast bread, biscuits, etc. (ABDEL-AAL and HUCL 2005, FRÉGEAU-REID and ABDEL-AAL 2005, MARCONI and CUBADDA 2005).

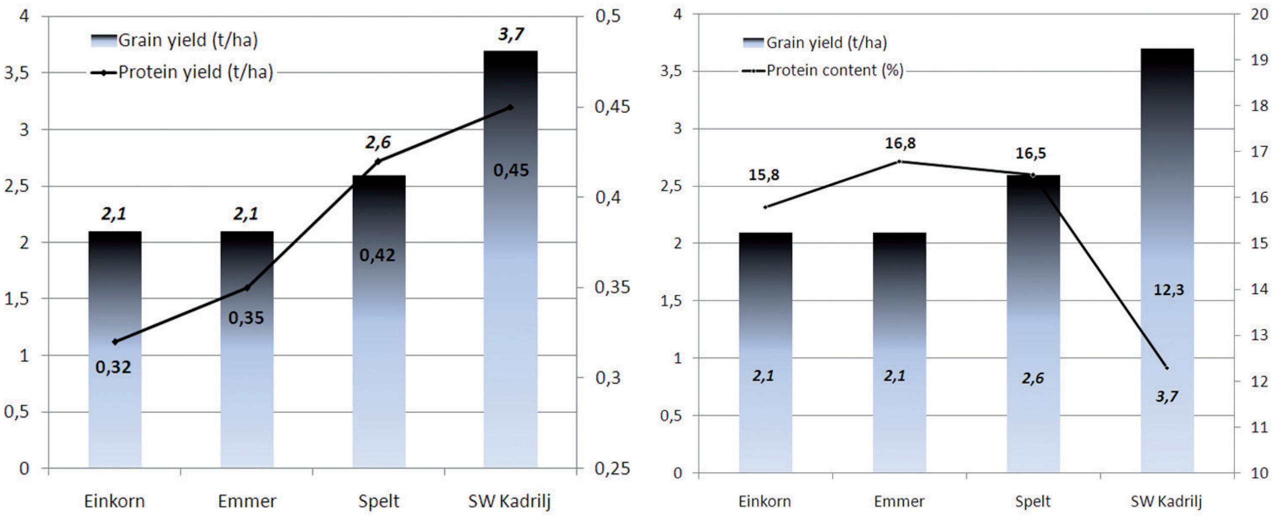

Figure 2: **Grain yield, protein yield and protein content of hulled wheat species compared to common wheat variety SW Kadrilj**

Table 4: **Grain yield and quality traits of hulled wheat genetic resources** (Means over three sites and two years; means followed by the same letter are not significantly different at P<0.05)

Species/Accession	Grain yield ($t \cdot ha^{-1}$)	Protein yield ($kg \cdot ha^{-1}$)	Protein content (%)	Wet gluten (%)	Gluten index	SDS sedimentation (ml)
Triticum monococcum						
38	2.1^{a}	338.8^{ab}	16.5^{c-h}	37.7^{b-f}	17.2^{ab}	36.7^{c-f}
44	1.9^{a}	301.4^{ab}	16.9^{f-h}	38.3^{b-f}	12.8^{a}	36.3^{c-f}
No. 8910	2.3^{ab}	346.8^{ab}	15.3^{b-g}	39.2^{b-g}	14.8^{a}	19.2^{ab}
Schwedisches Einkorn	2.1^{a}	312.1^{ab}	14.6^{a-f}	38.9^{b-f}	15.2^{ab}	27.33^{a-c}
Mean + Std. dev.	2.1±0.2	324.8±21.5	15.8±1.1	38.5±0.7	15.0±1.8	29.9±8.3
Triticum diccocum						
Rudico	2.8^{ab}	432.3^{ab}	16.0^{c-h}	39.8^{b-g}	17.8^{ab}	41.0^{d-f}
Weisser Sommer	2.4^{ab}	398.5^{ab}	17.0^{f-h}	43.0^{c-g}	20.7^{a-c}	45.7^{f-h}
May-Emmer	2.4^{ab}	390.2^{ab}	16.7^{f-h}	40.9^{b-g}	16.8^{ab}	44.5^{e-g}
Brno	2.1^{a}	325.5^{ab}	15.8^{b-h}	38.3^{b-f}	12.3^{a}	22.7^{ab}
Dagestan	2.3^{ab}	345.3^{ab}	15.9^{b-h}	41.4^{b-g}	15.2^{ab}	18.0^{a}
Palestine	1.6^{a}	286.1^{ab}	18.1^{h}	42.3^{c-g}	13.1^{a}	28.7^{a-d}
Tapioszele	1.5^{a}	267.9^{ab}	17.4^{gh}	41.7^{b-g}	13.1^{a}	22.2^{ab}
Tabor	1.9^{a}	338.0^{ab}	17.2^{f-h}	43.5^{c-g}	12.7^{a}	31.8^{b-e}
Mean + Std. dev.	2.1±0.4	348.0±56.4	16.8±0.8	41.4±1.7	15.2±3.0	31.8±10.8
Triticum spelta						
Ruzyne	2.5^{ab}	404.9^{ab}	16.2^{c-h}	43.3^{c-g}	39.3^{d-f}	46.2^{f-i}
Tabor 22	2.7^{ab}	453.2^{b}	16.3^{c-h}	43.9^{c-fg}	38.8^{d-f}	59.7^{jk}
Tabor 23	2.7^{ab}	443.9^{ab}	16.7^{e-h}	44.3^{d-g}	34.7^{de}	61.3^{jk}
Spalda bila jarni	2.6^{ab}	443.8^{ab}	17.0^{f-h}	47.1^{fg}	32.7^{c-e}	61.5^{jk}
VIR St. Petersburg	2.6^{ab}	372.9^{ab}	15.1^{b-g}	37.6^{b-ef}	36.8^{de}	57.7^{h-k}
Kew	2.2^{ab}	364.1^{ab}	16.5^{d-h}	46.1^{e-g}	44.5^{e-g}	70.2^{kl}
No. 8930	2.7^{a}	475.0^{b}	17.5^{gh}	48.8^{g}	28.2^{b-d}	60.3^{jk}
Mean + Std. dev.	2.6±0.2	422.5±42.4	16.5±0.7	44.4±3.6	36.4±5.2	59.6±7.1
Triticum aestivum						
SW Kadrilj	3.7^{b}	450.1^{b}	12.3^{a}	27.3^{a}	75.0^{h}	74.7^{l}

Conclusions

Hulled wheat landraces have a lot of favourable characteristics making the landraces very attractive, e.g. high protein content. Resistances to wheat diseases or the competitiveness to weeds are other positive aspects. In our study the following accessions were the most promising ones: einkorn No. 8910, emmer wheat varieties Rudico and Weisser Sommer, and spelt wheat No. 8930. Reduced resistance to lodging is a main weakness of old landraces. Spelt wheat varieties were less resistant to leaf rust and they reached lower crop stand productivity values which may lead to reduced grain yield. End use quality traits are significant inferior compared to common wheat. Therefore, hulled wheat species provide an opportunity for the production of various food products which are very different from the conventional common wheat products.

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