The Utilization of Wheat Genetic Resources in Breeding for Bread-making Quality

V. DVOŘÁČEK, L. DOTLAČIL, J. HERMUTH, A. PROHASKOVÁ, Z. STEHNO and L. SVOBODOVÁ

Crop Research Institute, 161 06 Prague-Ruzyně, Czech Republic; e-mail: dvoracek@vurv.cz

Abstract: This paper describes the structure and content of the Czech wheat germplasm collection. The collection, at present, includes 10 800 wheat accessions. Evaluation data, of variable content are available on 73% of the accessions, pedigree data on 80% of released cultivars. The annual distribution of seed samples to users amounts to about 1200 accessions. Attention is paid to increasing the value of the collection for users by way of deeper evaluation and choice of donors for important characters. With this intention, 8 modern cultivars (most of them with high bread-making quality) and 20 genetic lines derived from European landraces and obsolete cultivars were tested in field trials carried out over two years in Prague-Ruzyně. As expected, modern cultivars were superior in almost all of the agronomic characters evaluated. However, older lines showed significantly higher protein contents, and some of them also had a higher wet gluten content, gluten index and Zeleny sedimentation volume. However, low variability was found for starch content. Some lines with high protein content had an acceptable productivity, and could also meet acceptable levels for other quality characters. Satisfactory performance was found in lines such as Viglašská červenoklasá 12/B, Szekacz 19 37/B, Mindeszentpusztai 44/B, Szekacz 1242 47/E, Ukrajinka 52/A and Eszterhazi Mindenes 117/C. Among the new, more productive cultivars, Bohemia, RU 440-6 and Akteur combine high quality of gluten with relatively higher protein content. Selected genotypes will be further tested in a broader range of environments.

Keywords: agronomic characters; grain quality; landraces and obsolete cultivars; wheat

The wheat collection at the Crop Research Institute (CRI) Prague-Ruzyně consists of 10 800 accessions, including little used wheat species, and over 1000 wild relatives. It is the largest Czech crop collection and its size and intensive evaluation relates to the importance of wheat in Czech agriculture. The collection includes wheat landraces and obsolete cultivars released since the beginning of the last century, as well as obsolete and modern cultivars and precise genetic stocks. The accessions represent 31 wheat species, the majority being *T. aestivum* L. at 9300 accessions. Cultivars from breeding programmes comprise the largest part of the entire collection (65%) followed by genetic stocks (27%) and landraces (7%); landraces are considered as a valuable part of the collection.

Landraces arose through a combination of natural selection and selection performed by farmers (Belay *et al.* 1995). Old wheat cultivars were often bred by being selected from populations of landraces – or landraces were used as parents in crosses (Bareš & Dotlačil 1990). Landraces, and obsolete cultivars derived from them, are usually well-adapted to the climate and soil conditions of regions where they were bred, and often they are tolerant to local biotic and abiotic stresses (Tahir *et al.* 1988; Li *et al.* 1997). There is, of course, a difference in the yield potential between old and modern cultivars, which represents the progress gained by breeding. As MacKey (1993) noted, the genetic gain expressed as a percentage of the increase in grain yield since 1898 was 49% for winter wheat, the highest gain among crops analyzed. However, some landraces and obsolete cultivars can provide relatively good yields under specific conditions. Shroyer and Cox (1990) found old wheat cultivars that proved relatively good yields, close to modern cultivars, especially under low-input conditions. The possible utilization of landraces and obsolete cultivars in low-input systems and organic farming systems has also been discussed by Brush and Meng (1998). "On farm" conservation of landraces in conditions similar to those under which they were developed can allow their further dynamic evolution (Brush 1995).

It is known that wheat landraces often have a higher protein content than modern cultivars (Bordes *et al.* 2008). The good baking quality of modern cultivars is, in contrast to older cultivars, commonly based on a better gluten quality. However, lower protein (especially gluten) content can be regarded as one of reasons for a lower stability of baking quality in recent wheat cultivars. This research was aimed at testing the hypothesis that landraces and obsolete cultivars, which demonstrate high protein content, as well as a good gluten quality and acceptable productivity, would make good donors of quality traits to modern breeding programmes. Such donors could be utilized in wheat breeding aimed at a better quality and high stability. In addition, such materials could also contribute to the enhancement of the genetic base of new cultivars (Bedő *et al.* 1998). Some older or newly bred cultivars (e.g. developed through participatory breeding) might also be useful in organic agriculture.

MATERIAL AND METHODS

A set of 8 winter wheat cultivars and 20 lines with various HMW-GS (high molecular weight glutenin subunits) derived from European wheat landraces and obsolete cultivars were evaluated over two years of field trials (2009–2010) carried out at Prague-Ruzyně. These materials were selected on the basis of previous results (including data on the genetic diversity among cultivars, based on SSR and protein markers) from the Czech wheat genetic resource collection as potential donors of economically important characters, especially grain quality. The experimental design consisted of three randomized blocks with single plots of 4.5 m^2. Standard growing practices were applied but without growth regulators, and only 40 N/kg was applied in early spring. Earliness and plant height were recorded. At plant maturity, 30 spikes from each plot were randomly sampled and replicated for subsequent analyses of spike productivity parameters: grain number per spike and spikelet, thousand grain weight (TGW) and grain weight per spike. After harvest, grain yield per plot was estimated, and grain samples taken for analyses of quality characters. The quality analyses included assessments of crude protein content (CP) by the Kjeldahl method (ČSN EN ISO 20483), wet gluten content (WG) and gluten index (GI) according to Curic *et al.* (2001), and sedimentation index using the Zeleny test, ČSN ISO 5529. The software Statistica 9.0CZ was used for ANOVA and basic statistical analyses.

RESULTS AND DISCUSSION

This study follows up on the earlier evaluation of Czech wheat genetic resources maintained at the CRI Prague-Ruzyně, where we identified old cultivars and landraces with valuable characters for present-day breeding. Lines derived from European winter wheat landraces and obsolete cultivars represent a specific and valuable part of the experimental materials in the wheat collection. Most of the landraces are mixed populations, or at least consist of several different lines. Therefore, we selected plants from populations on the basis of field observations, and through isolation of lines with specific HMW-GS by means of single-seed PAGE. The lines were further grown as single-seed progenies and the most promising for specific quality characteristics were chosen to this experiment.

The genotypes evaluated showed significant genetic variability in earliness (Table 1). Flowering varied from 152 (days from sowing) (Bílá od Dukovan, line 5/B) to 160 days (Acteur). We found similar variability in maturity; the earliest line Hatvani 5612 48/A reached maturity after 200.5 days, with the line Altsteirer linie 64/C showing the longest vegetative phase. Earlier flowering seemed to be more frequent in lines obtained from landraces. Huge variability was observed in

Table 1. Agronomic characters evaluated in the 21 winter wheat lines derived from landraces and obsolete cultivars grown in the first half of the 20th century, and in 7 modern wheat cultivars (in bold letters) – mean values of two year experiments (2009–2010)

Cultivar/character	Origin	Flowering (days)[1]	Maturity (days)[1]	Plant height (cm)	Grains per spikelet	Grain weight per spike (g)	TGW (g)	Yield (t/ha)
Bílá od Dukovan 5/B	CSK	151.7	202.5	137.5	2.3	2.0	50.0	5.8
Viglašská červenoklasá 12/B	CSK	151.8	203.5	140.0	2.3	1.9	48.8	5.7
Vouska z Třemošnice 13/B	CSK	152.3	201.5	135.0	2.0	1.4	44.0	5.4
Bergland 18/B	AUT	153.0	201.0	135.8	2.3	2.1	49.5	5.5
Tschermaks weisser Marchfelder 20/B	AUT	155.2	201.5	138.3	1.8	1.5	44.4	5.9
Szekacz 19 37/B	HUN	152.0	201.0	142.5	2.2	1.8	48.4	5.4
Mindeszentpusztai 44/B	HUN	152.0	201.5	135.8	2.2	1.6	43.8	5.0
Szekacz 1242 47/B	HUN	154.2	201.5	138.3	2.2	2.0	48.4	5.7
Szekacz 1242 47/E	HUN	154.2	202.5	139.2	2.0	1.9	50.4	5.3
Hatvani 5612 48/A	HUN	153.2	200.5	128.3	1.7	1.2	39.7	5.5
Ukrajinka 52/A	SUN	153.0	205.0	135.0	2.1	1.8	47.4	6.0
Stepowa 53/D	POL	153.2	201.0	134.2	1.9	1.3	40.5	5.6
Slovenská 2 63/A	CSK	154.0	202.0	138.3	2.0	1.5	42.6	5.7
Altsteirer linie 64/C	AUT	156.7	209.0	131.7	2.2	1.9	46.8	5.0
Verrosaz 1229 BA 74/C	CHE	155.3	205.0	139.2	2.0	1.5	40.3	5.3
Ostka Czerwona Lopusta 111/B	POL	155.0	204.5	140.0	1.9	1.8	49.0	6.4
Ostka Czerwona Lopusta 111/C	POL	154.8	205.5	141.7	2.1	1.8	47.8	6.1
Szekacz 116/A	HUN	153.7	203.0	135.0	2.3	1.6	40.1	5.8
Eszterhazi Mindenes 117/C	HUN	151.7	202.5	131.7	1.8	1.4	40.2	4.9
Fleischman 481 119/A	HUN	152.7	201.5	130.8	1.7	1.2	41.5	5.5
Hassan-Orif	UZB	151.3	202.0	102.5	2.3	2.1	51.0	7.1
Bohemia	CZE	152.7	203.0	105.0	2.6	2.2	47.0	8.5
Akteur	DEU	160.0	207.5	98.3	2.4	2.2	43.9	7.9
Biscay	DEU	156.0	204.0	84.2	2.6	2.0	41.7	8.1
Florett	FRA	154.7	205.0	86.7	2.2	1.6	38.6	8.4
RU 440-6	CZE	156.2	204.5	103.3	2.2	2.3	52.5	6.7
Šárka	CZE	153.2	204.5	97.5	2.6	2.2	44.5	7.2
Rheia	CZE	152.2	203.5	95.8	2.4	2.2	49.3	7.6
% contribution to the total variation and significance of certain effects from ANOVAs	G	5.6**	73.5**	89.3**	41.3**	62.1**	76.0**	64.68**
	E	90.6**	4.5**	4.0**	N.s.	N.s.	N.s.	13.49**
	G × E	3.2**	22.0**	3.7**	20.7**	N.s.	9.7**	12.98**

**$P \leq 0.01$; N.s. = non significant; [1]days from the 1st January; G – genotype; E – year plant height, ranging from the 84.2 cm (Biscay) to 105 cm (Bohemia). All lines developed from landraces were much taller (128–143 cm), which is one of characters restricting the use of wheat landraces in modern breeding, as well as their lower productivity. Even when yield estimates in our experiments are calculated only on the base of micro plots and based only on two years of results, the yield difference between materials derived from landraces (estimated mean yield 5.7 t/ha) and cultivars (mean yield 7.7 t/ha) is obvious. The old materials had a mean yield by 26% lower than specifically bred cultivars. MacKey (1993) noted that the yield gap between landraces and cultivars grown in the early 90th was almost 50%. The low productivity of landraces is usually caused by a lower spike productivity, mainly due to a lower number of grains per spikelet and per spike. The two best yielding lines were selected from Ostka Czerwona Lopusta – 111/B, 111/C (6.4 and 6.1 t/ha, respectively), both can be characterized by a high TGW.

The data on five quality characters are summarized in Table 2. We found significant differences among cultivars in all characters; as well as significant G × E interactions. Crude protein content is, beside gluten quality, one of the most important characters for good baking quality in wheat. As the results of our experiments indicate, most of the modern cultivars with good baking quality show lower crude protein content in comparison to landraces and obsolete cultivars, whereas gluten quality is relatively higher. However, we also found materials with an acceptable gluten index and Zeleny sedimentation value among lines derived from landraces and obsolete cultivars.

Crude protein content varied from 15.1% to 16.8% in lines selected from landraces, with a mean value of 15.9%, 2.3% higher than the mean value of more recent cultivars (13.6%). Gluten protein is the main factor determining wheat quality for specific end-use (Ortiz *et al.* 2008). Therefore, high protein and gluten content in landraces and obsolete cultivars can be used to promote breeding for end-use quality. We found in our earlier study (Dotlačil *et al.* 2010) that there were a few landraces with a protein content close to 18% (e.g. cvs. Bergland, Ukrajinka, Sippbachzeller, Innichen Nr. 25001, Barbu du Finistre). Unfortunately these lines usually showed poor productivity, and only a mean or even lower gluten quality. Therefore, we preferred to select lines with a higher crude protein content, but also with acceptable spike productivity and gluten quality. As for crude protein, the wet gluten value in the lines derived from landraces was also noticeably higher (27.9–41.8%) than that in the modern cultivars (22.3–34.1%). Genetic variability for wet gluten was higher in both groups of genotypes when compared to crude protein variability. Two other characteristics investigated, gluten index and Zeleny sedimentation value, showed slightly lower values in the lines derived from landraces than in new cultivars. Four cultivars with high bread making quality (Hassan – Orif, Bohemia, Akteur and Florett) showed a gluten index higher than 90%. However, comparable values were found in the lines Fleischman 481 119/A (97.6%) and Stepowa 53/D (91.9%), and acceptable values in Hatvani 5612 48/A (86.3%) and Szekacz 116/A (84.5%). Old Hungarian cultivars have good characteristics for gluten – Bedő *et al.* (1998). High Zeleny sedimentation volumes were found in new cultivars with good technological quality – RU 440-6 (64.3 ml), Bohemia (60.7 ml) and Akteur (54.5 ml). Additionally, in lines derived from landraces, it was easy to find materials with quite comparable values (e.g. Zeleny sedimentation volumes ranging between 51.2 ml and 59.5 ml were recorded in 10 lines, the best being Stepowa 53/D).

We also analyzed starch content in the grain to get supplementary information on this major component of grain quality and its relationship to protein content. In contrast to protein variability, starch content showed rather low genetic variation (61.2–63.7% in the lines and 63.5–65.7% in modern cultivars). The highest starch content was in the French line Florett. The data indicate an increasing starch content with decreasing protein content ($R = -0.88$; $P \leq 0.01$).

A high protein content in landraces is obviously one of the important characters for wheat breeders. However, relationships between protein content and spike productivity, and between protein content and plant height (in our experiments $R = -0.68$; $P \leq 0.01$ and +0.68; $P \leq 0.01$, respectively) have to be taken into consideration. As concerns gluten quality, only gluten index was negatively correlated with protein content ($R = -0.56$; $P \leq 0.01$), whereas no relationships was found to Zeleny sedimentation volume. Thus, it appears that it is possible to choose genotypes which combine higher protein content with an acceptable level of productivity and desirable gluten quality as donors. Most of the lines selected in our experiments could meet such demands; e.g. Viglašská červenoklasá 12/B,

Table 2. Grain quality characters in 21 winter wheat lines derived from landraces and obsolete cultivars grown in the first half of the 20th century, and in 7 modern wheat cultivars (in bold letters) – mean values of two year experiments (2009–2010)

Cultivar/character	Origin	Crude protein content (%)	Wet gluten content (%)	Gluten index (%)	Zeleny sed. volume (ml)	Starch content (%)
Bílá od Dukovan 5/B	CSK	15.8	38.4	46.0	52.0	62.2
Viglašská červenoklasá 12/B	CSK	16.1	40.5	44.3	55.8	62.2
Vouska z Třemošnice 13/B	CSK	16.2	38.3	23.9	33.7	62.0
Bergland 18/B	AUT	16.2	40.8	31.4	31.0	62.4
Tschermaks weisser Marchfelder 20/B	AUT	15.8	35.2	44.4	41.7	62.6
Szekacz 19 37/B	HUN	16.2	40.3	37.8	52.0	62.5
Mindeszentpusztai 44/B	HUN	16.3	41.8	43.9	45.7	61.6
Szekacz 1242 47/B	HUN	15.5	34.0	74.1	54.7	62.7
Szekacz 1242 47/E	HUN	16.2	36.9	58.4	55.8	62.2
Hatvani 5612 48/A	HUN	15.2	32.0	86.3	53.0	62.9
Ukrajinka 52/A	SUN	15.9	35.9	56.3	52.7	62.3
Stepowa 53/D	POL	15.4	31.7	91.9	59.5	62.9
Slovenská 2 63/A	CSK	16.6	37.2	19.3	29.7	62.2
Altsteirer linie 64/C	AUT	15.6	33.2	71.2	51.2	62.7
Verrosaz 1229 BA 74/C	CHE	15.6	37.5	55.3	40.8	62.4
Ostka Czerwona Lopusta 111/B	POL	16.3	39.3	25.3	34.3	61.3
Ostka Czerwona Lopusta 111/C	POL	16.6	41.2	28.8	34.8	61.2
Szekacz 116/A	HUN	15.2	31.1	84.5	56.8	63.2
Eszterhazi Mindenes 117/C	HUN	16.8	36.9	43.6	44.2	61.3
Fleischman 481 119/A	HUN	15.1	27.9	97.6	55.3	63.7
Hassan-Orif	UZB	14.0	29.2	92.3	47.2	64.4
Bohemia	CZE	14.0	28.3	90.1	60.7	63.6
Akteur	DEU	14.1	29.3	97.1	54.5	64.5
Biscay	DEU	12.8	26.8	35.6	26.2	65.2
Florett	FRA	12.3	22.3	96.4	37.3	65.7
RU 440-6	CZE	14.6	34.1	70.7	64.3	63.5
Šárka	CZE	13.2	25.3	83.3	30.8	65.1
Rheia	CZE	13.7	27.8	71.8	29.8	64.3
% contribution to the total variation and significance of certain effects from ANOVAs	G	79.0**	83.3**	72.0**	79.4**	35.2**
	E	10.6**	N.s.	0.7*	1.4**	56.0**
	G × E	4.4**	7.5**	12.3**	14.3**	4.2**

*$P \leq 0.05$; **$P \leq 0.01$; N.s. = non significant; G – genotype; E – year

Szekacz 19 37/B, Mindeszentpusztai 44/B, Szekacz 1242 47/E, Ukrajinka 52/A and Eszterhazi Mindenes 117/C. All that showed a high protein content and good gluten quality. It is advantageous that some modern highly productive cultivars (Bohemia, RU 440-6 and Akteur) were found to combine high quality of gluten and a higher protein content. Also genotypes with high protein content accompanied by low gluten characters (as e.g. 16.6% in Slovenská 2 63/A) could be of breeders' interest.

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