Evaluation of malting quality of spring barley genetic resources from different regions of origin

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Abstract

A set of 92 genetic resources of spring barley split into groups according to the areas of origin was studied in terms of grain malting quality. The following malting parameters were monitored in this study: nitrogen content in barley grain, malt extract, relative extract at 45 °C, Kolbach index, diastatic power, apparent final attenuation, friability, β-glucans in wort, haze of wort measured at the angles of 15° and 90°. In the studied set, the largest variability was found in the haze of wort (90°), the smallest in the apparent final attenuation. The optimal values of the extract content in the malt dry matter according to the malting quality index were only detected in the genotypes originating from Europe. The group of the genetic resources from South America and Australia, together with the genotypes from the Middle East and Africa, differed statistically significantly in the values of the Kolbach index from other groups. The two-row genotypes differed statistically significantly in the values of the malt extract content, relative extract at 45 °C, Kolbach index, diastatic power, friability and β-glucan content in wort. Although the European and non-European groups differed in a number of traits, the non-European groups also included genetic resources that in their malting parameters approached or equaled the European malting varieties (such as Psaknon). In this study, several significant correlations were found; the strongest correlations were between friability and malt extract (r = 0.85), friability and Kolbach index (r = 0.84).

Key words: Hordeum vulgare L., genetic resources, malting quality

1 Introduction

Barley is one of the world´s most important crops. Breeding and growing of malting barley has a long tradition in the territory of the Czech Republic. According to the FAOSTAT (2017), the biggest barley producers in Europe are Spain, France, and Germany. For malting, varieties with a two-row ear type are prevailingly used in Europe; nevertheless, there are also six-row malting varieties. However, for malting, only the highest quality part of the production is used. The quality of malting barley is affected by a number of factors, the most important of which include a genotype and weather conditions during growing (Przulj et al., 2014). Farmers can therefore influence the quality of their production mainly by choosing a variety, to a lesser extent by agricultural engineering employed.

Malt contains various compounds that come directly from barley kernels or are formed during malting. The barley used in the malting process thus has a significant impact on the quality of the final product – beer. High malting quality of barley grain has not been unambiguously defined yet. Producers of malt and subsequently beer consider a quality raw material (barley grain, malt) the material that suits the technology of malt production or beer employed by them. The quality of malt can be characterized by dozens of different traits (Leistrumaitë and Paplauskienë, 2005).

Large grains with a uniform size above 2.5 mm are required to ensure uniform malting because large grains have a higher starch content and lower protein levels

than smaller grains (Fox et al., 2006). One of the most important traits is the nitrogen content of a barley grain. The content of nitrogenous substances in a barley grain is easily influenced by the growing conditions and the agricultural engineering used, including the application of nitrogenous fertilizers (Condón et al., 2009). Higher contents of nitrogenous substances in a grain were found in years with dry and warm weather at the time of the grain maturation (Cativelli et al., 2011; Morgan and Riggs, 1981; Savin and Nicolas, 1996; Savin and Nicolas, 1999). High protein contents are in a strong correlation with a low starch content and thus low extract content (Fox et al., 2003). A key indicator of the malting quality is a malt extract, which is affected by a number of independent components (Przulj et al., 2013).

So far, breeding programs have used mainly high productivity varieties that come from a narrow gene pool. Further improvements in malting quality must rely on new combinations of genes and germplasm (Matthies et al., 2014). Plant genetic resources are an indispensable source of genetic variability and their use in breeding programs increases the chances for success in designing new productive cultivars with good quality properties (Bockelman et al., 2010), or even varieties more resistant to biotic and abiotic stressors.

The genetic diversity of barley is preserved both in gene banks (*ex-situ*) and in nature (*in-situ*). In the Czech Republic, the genetic resources are preserved within the National Program on Conservation and Utilization of Plant Genetic Resources and Agro-biodiversity. At present, a total of 3046 items are kept in the Collection of Spring Barley Genetic Resources and every year the collection is enriched with other newly bred varieties and genotypes that might be of an interest for breeders and researchers.

The aim of this study was to evaluate the genetic resources selected from the collection of spring barley in terms of their malting characteristics and assess their potential for the use in breeding of malting varieties.

2 Material and Methods

The grain samples were obtained from the collection of the genetic resources of spring barley kept within the National Program on Conservation and Utilization of Plant Genetic Resources and Agro-biodiversity (MZe, 2017). An experimental set of 92 genetic resources of spring barley was grown on plots of 2.5 m^2 after a previous crop of winter rape on the lands of the Agricultural Research Institute Kroměříž, Ltd. (49°17'N, 17°22'E, 235 m a.s.l.), average annual temperature 8.7 °C, average annual rainfall 559 mm in 2010–2011. The course of the weather during the growing seasons (2010 and 2011) is shown in Figure 1. No fungicides or morphoregulators were applied during the growing season. The set included hulled genotypes, both with a two-row and six-row type of the ear.

The graded grain samples (2.5 mm) weighing 500 g from the 2010 and 2011 harvest years were used for malting. Malts were prepared in a laboratory malting device (KWM Uničov, the Czech Republic) according to the methodology of Mitteleuropäische Brautechnische Analysenkommission (MEBAK, 2011) in the following conditions: 72 h steeping at 14 °C with CO_2 exhaustion, steeping periods on 1st day 5 h, on 2nd day 4 h and on 3rd day 3 h. Germination time was 72 h at 14 °C. Pre-drying 12 h at 55 °C, kilning 4 h at 80 °C. In this study, the following parameters were monitored: starch content in barley grain (%), barley bulk density (g/dm³), malt extract (%), relative extract at 45 °C (%), Kolbach index (%), diastatic power (WK), apparent final attenuation (%), friability (%), β-glucans in wort (mg/dm³), wort haze measured at 12° and 90°. The studied malting parameters (Table 2) were determined according to the methodologies of the EBC Analysis Committee (2010) and MEBAK (2011).

To process the results, the evaluated genetic resources were divided according to the areas of their breeding into five groups (Figure 2): A – Western Europe (Great Britain, Germany, the Netherlands, Denmark, France, Portugal); B – Central and Eastern Europe (former Czechoslovakia, the

Figure 1 *Average temperatures and sum of precipitation during the growing seasons 2010 and 2011*
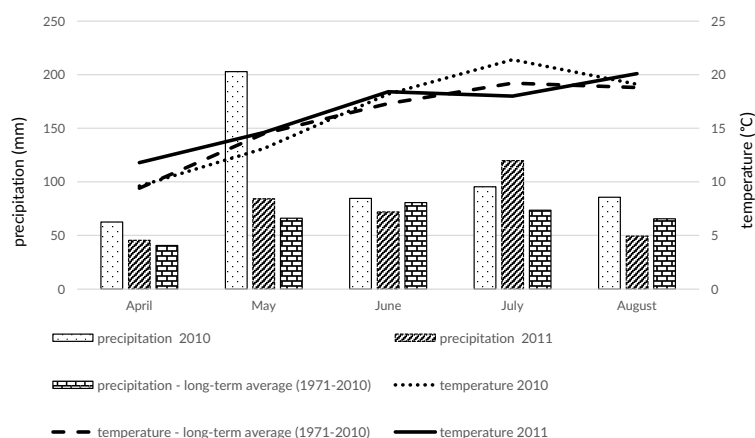
Czech Republic, Slovakia, Austria, Russia); C – North America (Canada, USA); D – South America and Australia (Bolivia, Argentina, Uruguay, Australia); E – Middle East and Africa (Israel, Egypt, Turkey). The studied genetic resources of individual groups are listed in Table 1, Table 2 and Table 3.

Statistica 12.0 was used for the statistical evaluation of the results.

Figure 2 *Scheme of division of genetic resources into individual groups according to their origin*


3   Results and Discussion

The malting quality of barley varieties is evaluated on the basis of the level of degradation of cell walls, nitrogenous substances and starch. Further, some of sensory wort characters are also assessed. The average values of the important malting parameters recorded in the evaluated set of the genetic resources are given in Table 4. The biggest variability was found in malt haze (90°), however, the six-row and two-row genotypes did not differ statistically significantly in this parameter (Table 5). The least variable parameter according to the coefficient of variation (CV) was apparent final attenuation (CV = 2.70%).

Level of cytolytic modification
Cytolytic modification of malt is the result of the action of a whole complex of enzymes which break down hemicellulose inside the endosperm to simple sugars. The content of β-glucans in wort affects lautering and filtration time. In brewing, these β-glucans affect the amount of the obtained extract, and thus the brewing yield as well.

Malt friability is an important indicator of malt quality; it indirectly informs about the level of the cell wall degradation during malting. The values in the studied set ranged from 32.0% to 99.0%, with an average value of 74.15%. Prokeš et al. (2007) found a larger range of values in the set of 113 Czech and foreign genetic sources (15.4%–90.8%), but the varieties with the lowest average value of friability were mainly the materials from Japan with a six-row ear and hulless caryopsis. In the studied set, the lowest value of malt friability (35.5%) was found in Cebada Capa from Argentina (Table 3). In all groups with non-European genetic resources, the level of friability was lower than 75% (Table 7). But even within these groups, genetic resources can be found close to the European varieties in this trait. For example, in the group of varieties from North America (C), malt friability of the varieties Conrad (80.5%) and Long Glumes (78.0%)
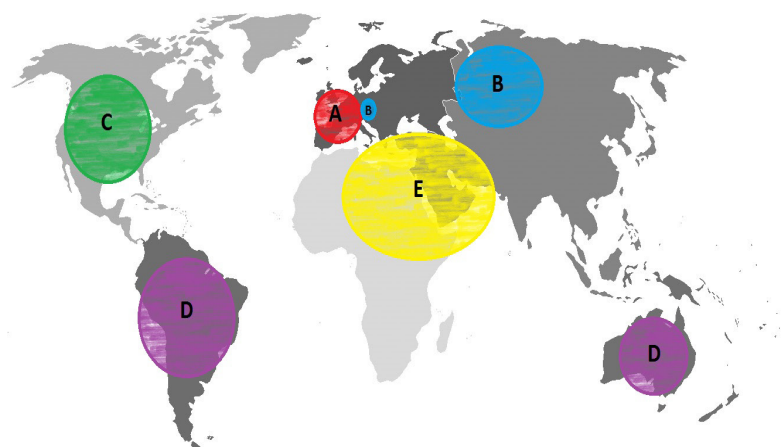
approached the average values of the A and B groups of European varieties (78.7% and 76.8%). In the group of varieties from South America and Australia (D), Psaknon reached the average value of 76.0%. The highest value of malt friability (94.5%) was found in the German variety Germina (Table 1). In the studied set, both the individual years (Table 6) and the average values of two-row and six-row genotypes differed statistically significantly (Table 5). Strong positive correlations were found between friability and the Kolbach index (r = 0.84). An equally important correlation between friability and the malt extract (r = 0.81) was also found in a study of historical data of barley collections of an European origin performed by Matthies et al. (2014). Further, a strong negative correlation was recorded between friability and the content of β-glucans in wort (r = -0.77). Šimić et al. (2015) found in their study of winter and spring barley an even higher statistically significant negative correlation between the content of β-glucans in wort and friability (r = -0.93). The individual areas were divided into three statistically significant groups based on their friability values (Table 7). The lowest average values were found in groups D and E (49.8% and 50.3%), middle in group C (62.5%), the highest then in groups A and B (78.69% and 76.82%).

The β-glucan content in wort is another very important parameter monitored within the malt evaluation as β-glucans increase the viscosity of sweet wort and inhibit filtration. The content of β-glucans in wort in the evaluated set of genotypes was highly variable (CV = 60.59%). As reported by Zheng et al. (2011), levels of β-glucans are influenced by both genetic and environmental factors; the genetic factors appear to be of greater importance (Zheng et al., 2011). Psota (2008) found only half the maximum content (60.0–628.0 mg/dm³) in his study compared to our data. Statistically significant differences were detected in this parameter both between the growing years

Table 1 Average values of the studied traits in the individual genetic resources of spring barley from Western Europe (Group A)

Variety	ECN [1]	Type of ear [2]	Nitrogenous substances in barley grain (%)	Extract of malt (%)	Relative extract at 45 °C (%)	Kolbach index (%)	Diastatic power (WK)	Apparent final attenuation (%)	Friability (%)	β-glucans in sweet wort (mg/dm³)	Haze of wort 90°	Haze of wort 12°
Antigone	03C0602733	2	12.4 ± 0.65 [3]	83.2 ± 0.05	50.5 ± 1.05	48.1 ± 0.65	454.0 ± 2.00	82.3 ± 0.95	82.5 ± 6.50	225.0 ± 86.00	1.03 ± 0.105	1.71 ± 0.595
Aphrodite	03C0602139	2	12.4 ± 1.00	82.5 ± 0.50	42.7 ± 1.20	45.7 ± 0.40	282.5 ± 21.50	79.7 ± 0.00	71.0 ± 0.00	519.5 ± 106.50	11.32 ± 3.750	9.42 ± 2.225
Baronesse	03C0602278	2	11.3 ± 0.15	81.2 ± 0.25	40.1 ± 1.55	42.1 ± 0.35	320.5 ± 13.50	78.6 ± 0.10	74.5 ± 4.50	359.5 ± 125.50	7.05 ± 1.440	7.83 ± 1.190
Biatlon	03C0602694	2	11.4 ± 0.35	85.0 ± 0.40	51.3 ± 1.55	57.4 ± 0.25	296.5 ± 9.50	79.9 ± 1.05	92.5 ± 0.50	157.5 ± 46.50	1.71 ± 0.185	1.74 ± 0.315
Bigo	03C0601024	6	11.7 ± 0.95	79.7 ± 0.20	38.4 ± 2.20	43.7 ± 0.15	431.0 ± 74.00	80.8 ± 1.60	68.5 ± 8.50	681.5 ± 322.50	1.59 ± 0.360	2.10 ± 0.805
Bingo Carslberg	03C0602012	2	13.0 ± 0.05	79.6 ± 0.30	37.5 ± 0.65	36.2 ± 0.05	319.5 ± 25.50	78.5 ± 0.25	52.5 ± 2.50	896.5 ± 0.50	3.73 ± 1.795	3.25 ± 1.275
Bolina	03C0602738	2	12.3 ± 1.60	82.7 ± 0.55	50.4 ± 2.40	50.8 ± 2.95	304.0 ± 54.00	81.6 ± 1.75	86.0 ± 3.00	218.0 ± 33.00	1.99 ± 0.405	2.49 ± 0.640
Brenda	03C0602434	2	12.3 ± 0.75	84.5 ± 0.35	42.2 ± 1.15	46.7 ± 1.90	422.5 ± 27.50	84.2 ± 1.40	84.5 ± 2.50	317.0 ± 118.00	5.21 ± 3.360	4.56 ± 2.565
Calgary	03C0602693	2	11.4 ± 0.65	82.7 ± 0.45	44.0 ± 1.85	47.8 ± 0.60	320.0 ± 25.00	83.6 ± 1.75	75.5 ± 4.50	318.0 ± 84.00	1.66 ± 0.000	1.76 ± 0.225
Cambrinus	03C0602642	2	12.6 ± 0.55	79.8 ± 0.05	39.4 ± 1.00	44.0 ± 0.05	363.5 ± 33.50	80.5 ± 0.95	68.5 ± 3.50	627.0 ± 39.00	10.32 ± 0.685	10.02 ± 0.080
Carvilla	03C0602731	2	12.1 ± 0.10	83.3 ± 0.25	47.3 ± 1.60	45.2 ± 0.80	359.5 ± 8.50	82.5 ± 0.05	89.0 ± 0.00	196.0 ± 17.00	1.10 ± 0.005	1.12 ± 0.100
Casino	03C0600958	2	12.3 ± 0.95	79.5 ± 0.45	36.7 ± 0.75	41.1 ± 0.05	199.5 ± 16.50	79.0 ± 0.85	70.5 ± 2.50	529.5 ± 73.50	1.44 ± 0.080	1.75 ± 0.240
Cask	03C0602298	2	11.1 ± 0.50	80.2 ± 0.30	41.1 ± 1.60	41.6 ± 0.30	270.0 ± 13.00	79.9 ± 0.65	70.0 ± 1.00	746.5 ± 142.50	4.83 ± 2.850	4.43 ± 1.760
Class	03C0602721	2	11.9 ± 0.45	83.5 ± 0.30	50.3 ± 1.50	46.2 ± 1.00	426.5 ± 26.50	83.4 ± 0.50	85.5 ± 0.50	232.0 ± 28.00	0.89 ± 0.095	1.16 ± 0.140
Cocktail	03C0602724	2	11.2 ± 0.10	83.2 ± 0.55	50.3 ± 4.80	49.9 ± 1.60	310.5 ± 6.50	79.8 ± 0.30	86.5 ± 0.50	219.5 ± 0.50	1.34 ± 0.315	1.74 ± 0.500
Diplom	03C0602661	2	11.0 ± 0.70	84.4 ± 0.25	44.9 ± 2.80	52.5 ± 0.80	271.5 ± 45.50	82.5 ± 0.35	87.0 ± 0.00	262.5 ± 6.50	0.91 ± 0.275	0.84 ± 0.230
Felicitas	03C0602706	2	11.6 ± 1.40	82.1 ± 0.80	41.4 ± 3.10	45.2 ± 5.50	360.5 ± 20.50	82.9 ± 0.25	81.0 ± 9.00	286.5 ± 91.50	0.97 ± 0.370	0.78 ± 0.255
Germina	03C0602707	2	11.3 ± 1.35	84.0 ± 0.15	49.3 ± 2.45	52.2 ± 1.25	401.0 ± 63.00	82.6 ± 0.35	94.5 ± 3.50	95.5 ± 2.50	1.2 ± 0.015	1.44 ± 0.085
Grosso	03C0602133	2	12.2 ± 0.10	82.4 ± 0.30	39.5 ± 0.85	40.2 ± 0.60	291.5 ± 2.50	78.1 ± 0.40	64.0 ± 2.00	613.0 ± 121.00	6.55 ± 0.110	5.69 ± 0.130
Isotta	03C0602730	2	12.2 ± 0.95	83.1 ± 0.40	48.7 ± 0.30	47.4 ± 0.25	408.0 ± 58.00	80.8 ± 0.35	82.5 ± 5.50	182.5 ± 33.50	9.74 ± 6.530	8.86 ± 5.275
Katharina	03C0602441	2	11.6 ± 0.50	82.6 ± 0.25	41.2 ± 1.95	44.6 ± 2.40	315.0 ± 3.00	80.3 ± 0.45	79.0 ± 6.00	371.5 ± 26.50	1.58 ± 0.505	1.55 ± 0.515
Magnum	03C0601654	2	12.3 ± 1.10	79.1 ± 0.05	35.8 ± 0.65	34.5 ± 2.40	176.5 ± 1.50	77.6 ± 0.15	61.5 ± 11.50	741.5 ± 122.50	6.14 ± 2.990	5.98 ± 2.795
Maris Mink	03C0601412	2	11.8 ± 1.25	81.1 ± 1.15	40.9 ± 1.95	39.9 ± 1.40	325.5 ± 18.50	81.2 ± 1.60	65.0 ± 11.00	444.0 ± 41.00	2.12 ± 0.230	2.34 ± 0.405
Mauritia	03C0602708	2	11.1 ± 1.60	84.6 ± 0.55	54.2 ± 4.25	56.4 ± 6.55	338.0 ± 15.00	83.3 ± 1.30	92.5 ± 6.50	136.0 ± 74.00	1.38 ± 0.065	1.72 ± 0.360
Nadja	03C0601216	2	12.1 ± 1.50	81.9 ± 1.10	43.1 ± 2.20	45.5 ± 6.15	245.0 ± 29.00	80.9 ± 0.15	77.5 ± 10.50	264.0 ± 62.00	1.11 ± 0.160	1.16 ± 0.245
NFC Tipple	03C0602727	2	10.9 ± 1.90	82.9 ± 2.10	55.6 ± 1.85	53.0 ± 2.20	381.0 ± 62.00	83.3 ± 2.35	83.0 ± 15.00	131.0 ± 74.00	1.19 ± 0.375	1.72 ± 1.105
Orthega	03C0602509	2	10.7 ± 0.75	81.0 ± 0.70	35.8 ± 0.40	36.8 ± 2.20	226.0 ± 23.00	76.8 ± 0.75	67.5 ± 10.50	831.5 ± 11.50	1.74 ± 0.785	1.79 ± 0.745
Sabarlis	03C0601477	2	11.8 ± 1.60	80.1 ± 0.95	40.3 ± 3.95	43.1 ± 1.30	256.5 ± 69.50	76.8 ± 1.15	77.0 ± 10.00	348.0 ± 3.00	3.42 ± 2.260	3.30 ± 1.485
Salome	03C0601217	2	12.2 ± 1.40	81.7 ± 0.85	44.3 ± 0.45	47.9 ± 3.85	302.0 ± 62.00	80.8 ± 0.60	76.5 ± 8.50	340.5 ± 42.50	1.10 ± 0.090	1.44 ± 0.180
Saxo	03C0602354	2	12.2 ± 1.75	82.9 ± 1.55	45.9 ± 2.35	49.0 ± 1.60	286.0 ± 30.00	76.8 ± 1.25	76.5 ± 7.50	345.5 ± 25.50	7.47 ± 4.705	7.85 ± 2.985
Sebastian	03C0602773	2	11.2 ± 2.00	84.7 ± 0.50	49.4 ± 0.15	51.2 ± 2.00	359.5 ± 77.50	82.1 ± 0.90	86.0 ± 12.00	214.5 ± 118.50	1.25 ± 0.075	1.31 ± 0.200
Sigrid	03C0602519	2	11.6 ± 1.20	80.8 ± 0.80	42.1 ± 2.55	42.9 ± 1.00	294.0 ± 54.00	78.6 ± 0.55	82.0 ± 10.00	278.0 ± 80.00	1.16 ± 0.045	1.38 ± 0.270
Sudan	03C0601046	6	12.1 ± 0.65	80.0 ± 0.10	43.7 ± 0.75	48.2 ± 5.50	373.0 ± 5.00	80.6 ± 1.45	74.0 ± 10.00	348.5 ± 170.50	1.00 ± 0.030	0.85 ± 0.015
Tocada	03C0602709	2	10.8 ± 0.65	84.1 ± 0.10	43.7 ± 3.30	49.9 ± 6.05	287.5 ± 22.50	81.2 ± 0.20	91.0 ± 4.00	213.0 ± 62.00	1.22 ± 0.220	0.99 ± 0.335
Vintage	03C0602301	2	11.0 ± 1.45	82.3 ± 0.65	39.3 ± 1.15	42.8 ± 1.70	307.0 ± 46.00	81.7 ± 0.10	84.0 ± 11.00	411.0 ± 181.00	3.68 ± 2.980	3.34 ± 2.755
Waggon	03C0602725	2	11.3 ± 1.90	82.6 ± 1.10	48.8 ± 4.15	50.2 ± 5.50	282.5 ± 51.50	80.3 ± 0.50	87.5 ± 11.50	334.0 ± 157.00	1.25 ± 0.290	1.57 ± 0.390
Westminster	03C0602734	2	11.5 ± 1.70	86.2 ± 0.15	54.4 ± 1.35	56.0 ± 4.05	317.5 ± 24.50	80.4 ± 0.40	84.5 ± 12.50	261.5 ± 153.50	1.01 ± 0.110	1.04 ± 0.005

1) National accession number; 2) two-row ear type, six-row ear type; 3) mean and standard error of the mean

Table 2 *Average values of the studied traits in the individual genetic resources of spring barley from Central and Eastern Europe (Group B)*

Variety	ECN [1]	Type of ear [2]	Nitrogenous substances in barley grain (%)	Extract of malt (%)	Relative extract at 45 °C (%)	Kolbach index (%)	Diastatic power (WK)	Apparent final attenuation (%)	Friability (%)	β-glucans in sweet wort (mg/dm³)	Haze of wort 90°	Haze of wort 12°
Akcent	03C0602182	2	13.1 ± 0.20[3]	81.2 ± 0.25	46.0 ± 0.85	47.0 ± 0.10	379.0 ± 16.00	80.5 ± 0.35	66.0 ± 3.00	376.0 ± 58.00	1.18 ± 0.285	1.43 ± 0.325
Amalia	03C0602202	2	13.0 ± 0.35	80.8 ± 0.30	37.7 ± 0.80	37.3 ± 1.45	347.5 ± 5.50	80.5 ± 0.45	66.5 ± 0.50	488.0 ± 84.00	4.53 ± 1.135	4.28 ± 1.405
Amos	03C0602458	2	12.8 ± 0.90	82.0 ± 0.95	44.1 ± 1.90	47.1 ± 2.35	265.5 ± 24.50	76.5 ± 0.20	65.0 ± 5.00	628.0 ± 6.00	1.84 ± 0.275	2.41 ± 0.450
Amulet	03C0602342	2	13.7 ± 0.75	81.9 ± 0.05	40.3 ± 1.10	44.4 ± 4.20	445.0 ± 9.00	79.9 ± 0.10	69.0 ± 7.00	344.0 ± 180.00	1.01 ± 0.110	3.76 ± 2.240
Argument	03C0602841	2	12.1 ± 1.05	83.0 ± 0.00	43.6 ± 0.65	46.9 ± 0.80	360.0 ± 3.00	80.8 ± 0.65	81.5 ± 5.50	193.5 ± 65.50	7.76 ± 2.510	6.52 ± 2.950
Atribut	03C0602343	2	12.8 ± 0.20	83.7 ± 0.70	49.6 ± 2.00	52.8 ± 0.10	372.5 ± 3.50	79.5 ± 0.65	81.0 ± 1.00	437.5 ± 107.50	1.29 ± 0.140	1.39 ± 0.450
Bojos	03C0602742	2	12.2 ± 1.30	85.1 ± 0.40	44.7 ± 0.05	46.9 ± 3.30	400.0 ± 52.00	81.9 ± 0.15	90.0 ± 3.00	179.0 ± 54.00	0.75 ± 0.160	0.68 ± 0.090
Boratinskij	03C0601443	2	13.0 ± 0.60	80.8 ± 0.40	39.1 ± 1.30	42.2 ± 1.70	272.5 ± 10.50	80.2 ± 1.95	65.0 ± 3.00	432.0 ± 13.00	8.60 ± 3.900	6.96 ± 2.945
Donum	03C0602368	2	11.1 ± 1.05	84.0 ± 0.80	40.2 ± 0.60	46.8 ± 2.90	241.5 ± 17.50	82.2 ± 0.85	81.0 ± 10.00	362.5 ± 136.50	8.12 ± 5.255	6.71 ± 4.335
Druzba	03C0600123	2	11.7 ± 0.60	83.4 ± 0.25	43.1 ± 0.40	46.5 ± 1.55	261.0 ± 5.00	80.3 ± 1.20	74.0 ± 1.00	381.5 ± 39.50	1.44 ± 0.540	1.58 ± 0.640
Galan	03C0602267	2	12.5 ± 1.20	81.1 ± 0.10	47.3 ± 4.45	47.4 ± 0.50	293.5 ± 41.50	76.8 ± 0.40	71.0 ± 3.00	307.5 ± 75.50	7.73 ± 5.745	7.13 ± 4.515
Granat	03C0602485	2	12.0 ± 0.70	82.4 ± 0.40	38.4 ± 2.55	38.7 ± 3.85	282.5 ± 45.50	75.9 ± 1.20	70.5 ± 6.50	523.5 ± 32.50	3.21 ± 0.155	3.13 ± 0.675
Heris	03C0602572	2	11.6 ± 0.75	82.7 ± 0.55	39.5 ± 5.00	40.6 ± 4.25	263.0 ± 18.00	77.8 ± 0.60	75.5 ± 6.50	318.5 ± 25.50	10.79 ± 5.575	10.26 ± 5.375
Jarek	03C0600068	2	12.1 ± 1.35	81.8 ± 0.40	47.4 ± 1.65	46.7 ± 2.10	258.0 ± 30.00	77.0 ± 1.25	70.5 ± 6.50	329.0 ± 66.00	9.67 ± 7.300	9.20 ± 5.835
Jaspis	03C0600066	2	11.2 ± 0.90	82.9 ± 0.25	46.6 ± 0.35	48.0 ± 0.20	220.0 ± 6.00	78.0 ± 0.35	81.0 ± 8.00	218.5 ± 20.50	8.77 ± 6.205	8.38 ± 5.050
KM 1192	03C0600085	2	13.0 ± 0.45	78.2 ± 0.50	40.7 ± 2.25	37.6 ± 1.15	233.5 ± 18.50	77.5 ± 0.35	57.0 ± 0.00	1187.5 ± 287.50	2.86 ± 1.755	2.70 ± 1.450
Kompakt	03C0602423	2	12.2 ± 1.35	84.2 ± 0.05	47.2 ± 0.50	50.2 ± 3.35	362.5 ± 27.50	79.9 ± 0.85	85.5 ± 5.50	219.5 ± 16.50	3.73 ± 2.545	3.66 ± 2.390
Krasnodarskij 35	03C0600328	2	11.4 ± 1.40	81.2 ± 1.40	39.6 ± 1.45	39.6 ± 1.85	275.5 ± 0.50	80.2 ± 1.25	62.0 ± 8.00	771.5 ± 125.50	3.58 ± 2.070	3.45 ± 1.555
Krasnodarskij 95	03C0601541	2	12.6 ± 2.15	80.0 ± 1.50	42.8 ± 1.20	39.5 ± 3.40	287.0 ± 20.00	79.2 ± 1.60	59.0 ± 12.00	678.0 ± 124.00	2.36 ± 0.240	2.91 ± 0.260
Ladik	03C0602487	2	11.9 ± 1.80	82.4 ± 0.50	38.0 ± 3.30	38.9 ± 6.45	264.5 ± 25.50	80.9 ± 0.20	79.0 ± 11.00	314.0 ± 96.00	1.28 ± 0.400	1.37 ± 0.460
Malz	03C0602668	2	10.8 ± 1.35	84.8 ± 0.20	47.5 ± 3.25	50.3 ± 5.55	286.5 ± 14.50	82.3 ± 0.75	91.0 ± 7.00	271.5 ± 120.50	1.01 ± 0.030	1.03 ± 0.105
Nitran	03C0602712	2	11.8 ± 2.00	83.9 ± 0.85	47.5 ± 0.50	50.5 ± 4.25	484.5 ± 112.50	82.6 ± 0.40	91.0 ± 6.00	171.5 ± 54.50	1.36 ± 0.155	1.92 ± 0.060
Olbram	03C0602420	2	12.0 ± 1.15	84.2 ± 0.90	47.7 ± 1.95	51.1 ± 5.20	286.0 ± 27.00	80.4 ± 0.05	88.0 ± 1.00	207.5 ± 17.50	2.41 ± 1.375	3.62 ± 2.225
Olympijec	03C0600121	2	12.2 ± 0.80	81.3 ± 0.30	39.2 ± 1.55	40.8 ± 4.80	377.0 ± 48.00	80.6 ± 0.40	71.0 ± 7.00	460.0 ± 112.00	1.38 ± 0.385	1.45 ± 0.480
Omskij 13709	03C0602112	2	11.7 ± 1.20	84.4 ± 0.40	47.5 ± 1.55	50.7 ± 6.70	278.0 ± 21.00	79.9 ± 0.60	90.5 ± 4.50	200.0 ± 48.00	1.48 ± 0.555	1.87 ± 0.585
Orbit	03C0600067	2	10.7 ± 0.80	82.3 ± 0.30	42.2 ± 0.95	47.0 ± 3.35	262.0 ± 44.00	80.9 ± 0.30	77.5 ± 9.50	561.0 ± 186.00	1.39 ± 0.085	1.68 ± 0.120
Pejas	03C0602459	2	11.1 ± 1.35	82.7 ± 0.60	42.5 ± 0.10	49.2 ± 4.95	244.5 ± 43.50	78.5 ± 1.05	82.0 ± 8.00	290.0 ± 79.00	1.10 ± 0.190	1.24 ± 0.045
Pribina	03C0602722	2	12.5 ± 0.40	83.2 ± 0.05	43.4 ± 1.50	46.8 ± 4.10	247.0 ± 6.00	80.1 ± 0.15	80.5 ± 5.50	299.0 ± 101.00	1.68 ± 0.460	2.00 ± 0.490
Prikumskij 22	03C0601208	2	13.5 ± 1.30	81.0 ± 1.20	40.9 ± 2.80	39.2 ± 5.80	308.0 ± 30.00	78.9 ± 0.00	63.5 ± 10.50	670.5 ± 9.50	1.90 ± 0.750	2.26 ± 0.855
Profit	03C0600073	2	12.5 ± 1.30	81.7 ± 0.45	44.0 ± 2.30	45.0 ± 1.40	351.5 ± 9.50	77.5 ± 0.70	76.0 ± 9.00	308.5 ± 78.50	5.66 ± 2.995	6.47 ± 2.130
Prosa	03C0602524	2	11.7 ± 0.65	83.0 ± 0.25	39.5 ± 3.10	46.9 ± 4.60	352.5 ± 59.50	81.7 ± 0.35	84.5 ± 5.50	249.5 ± 56.50	10.66 ± 3.310	8.15 ± 2.170
Pumper 6 ZLG	03C0600617	6	12.8 ± 1.70	76.9 ± 1.40	45.3 ± 2.10	42.6 ± 1.00	439.5 ± 61.50	79.6 ± 0.60	62.0 ± 5.00	481.0 ± 183.00	1.66 ± 0.135	2.14 ± 0.560
Radegast	03C0602744	2	11.9 ± 0.80	84.2 ± 0.40	43.6 ± 2.25	48.1 ± 5.20	370.0 ± 16.00	78.8 ± 1.95	83.5 ± 6.50	158.0 ± 36.00	1.15 ± 0.465	1.17 ± 0.160
Respekt	03C0602695	2	11.3 ± 1.20	84.7 ± 0.35	49.0 ± 1.00	51.4 ± 4.50	342.0 ± 60.00	81.3 ± 0.80	86.5 ± 6.50	293.5 ± 79.50	1.17 ± 0.390	1.48 ± 0.365
Rubin	03C0600059	2	11.1 ± 1.25	83.6 ± 0.55	45.7 ± 1.70	50.7 ± 2.90	270.5 ± 50.50	81.8 ± 0.30	85.5 ± 8.50	269.5 ± 83.50	3.43 ± 2.120	4.54 ± 2.835
Serva	03C0601407	2	11.5 ± 1.65	81.0 ± 0.55	35.2 ± 0.45	36.2 ± 3.65	283.5 ± 44.50	79.9 ± 0.20	69.0 ± 9.00	722.0 ± 20.00	7.63 ± 2.235	7.65 ± 3.185
Stabil	03C0602370	2	10.9 ± 1.20	82.5 ± 0.15	43.9 ± 1.50	49.9 ± 2.55	284.0 ± 36.00	82.3 ± 0.15	87.5 ± 5.50	333.0 ± 11.00	1.11 ± 0.185	1.21 ± 0.085
Svit	03C0602186	2	11.1 ± 1.35	82.8 ± 0.85	48.6 ± 0.20	50.2 ± 4.20	243.5 ± 32.50	77.9 ± 0.05	82.0 ± 10.00	414.0 ± 153.00	2.23 ± 0.605	3.13 ± 1.215
Tolar	03C0602486	2	11.4 ± 0.85	83.2 ± 0.15	41.3 ± 2.15	48.1 ± 3.75	465.0 ± 28.00	81.1 ± 0.70	87.0 ± 4.00	304.0 ± 7.00	1.47 ± 0.460	1.65 ± 0.765
Vladan	03C0602457	2	11.4 ± 1.00	83.8 ± 0.20	46.6 ± 1.90	52.3 ± 3.90	302.0 ± 30.00	79.8 ± 0.40	84.5 ± 9.50	349.0 ± 173.00	4.05 ± 0.095	4.63 ± 1.005

[1] National accession number; [2] two-row ear type, six-row ear type; [3] mean and standard error of the mean

Table 3 *Average values of the studied traits in the individual genetic sources of spring barley of non-European origin (Groups C, D and E)*

Variety	ECN [1]	Type of ear [2]	Group [3]	Nitrogenous substances in barley grain (%)	Extract of malt (%)	Relative extract at 45 °C (%)	Kolbach index (%)	Diastatic power (WK)	Apparent final attenuation (%)	Friability (%)	β-glucans in sweet wort (mg/dm³)	Haze of wort 90°	Haze of wort 12°
AC Klinck	03C0602748	6	C	12.0 ± 0.30 [4]	81.1 ± 0.75	40.9 ± 0.00	44.8 ± 1.75	338.0 ± 1.00	81.2 ± 0.05	63.5 ± 1.50	759.0 ± 7.00	2.29 ± 0.105	2.78 ± 0.020
Bolron	03C0600990	6	C	14.2 ± 0.85	76.5 ± 0.30	45.0 ± 2.00	40.3 ± 0.50	465.5 ± 38.50	81.1 ± 0.85	60.5 ± 3.50	310.5 ± 34.50	0.93 ± 0.005	1.15 ± 0.205
Brock	03C0601167	6	C	13.0 ± 0.35	80.0 ± 0.50	43.5 ± 1.80	40.6 ± 3.20	305.0 ± 9.00	78.6 ± 1.25	56.5 ± 4.50	776.0 ± 63.00	3.12 ± 0.375	3.64 ± 0.735
CI 7584	03C0600282	6	C	14.3 ± 0.50	77.0 ± 1.20	37.6 ± 0.10	31.7 ± 1.40	374.5 ± 11.50	78.8 ± 0.95	36.5 ± 1.50	921.5 ± 12.50	1.22 ± 0.190	1.36 ± 0.295
Conrad	03C0602729	2	C	12.2 ± 0.60	82.9 ± 0.15	56.6 ± 4.80	55.9 ± 4.30	416.5 ± 11.50	77.2 ± 2.85	80.5 ± 3.50	203.0 ± 105.00	2.11 ± 0.070	2.34 ± 0.375
Long Glumes	03C0601379	2	C	12.0 ± 1.30	80.5 ± 0.25	45.5 ± 4.30	48.0 ± 8.05	301.5 ± 13.50	81.5 ± 0.00	78.0 ± 10.00	239.0 ± 80.00	1.21 ± 0.085	1.87 ± 0.595
Prillar	03C0601629	2	C	12.7 ± 1.90	79.2 ± 1.90	41.7 ± 4.50	39.4 ± 1.05	322.0 ± 41.00	76.6 ± 0.10	62.0 ± 6.00	535.0 ± 152.00	1.63 ± 0.095	2.03 ± 0.365
Bolivia	03C0601014	2	D	14.3 ± 1.05	76.2 ± 0.75	38.5 ± 0.70	36.7 ± 0.95	302.0 ± 45.00	79.8 ± 1.30	43.0 ± 3.00	535.5 ± 99.50	1.44 ± 0.175	1.51 ± 0.135
Cebada Capa	03C0600996	6	D	13.4 ± 0.35	74.1 ± 1.10	33.3 ± 1.15	29.4 ± 2.10	254.0 ± 7.00	76.1 ± 0.30	35.5 ± 2.50	1104.4 ± 274.50	8.00 ± 1.065	8.72 ± 0.410
Psaknon	03C0601160	2	D	11.8 ± 0.55	82.9 ± 0.05	41.3 ± 1.00	45.5 ± 3.50	335.0 ± 15.00	78.0 ± 1.45	76.0 ± 5.00	353.0 ± 9.00	2.07 ± 0.910	2.29 ± 0.925
Ricardo	03C0601011	6	D	13.3 ± 1.35	75.4 ± 0.60	32.1 ± 0.45	32.2 ± 4.00	233.5 ± 18.50	78.1 ± 0.15	44.5 ± 9.50	516.5 ± 159.50	9.88 ± 2.790	8.97 ± 2.860
Israeli 46	03C0600997	2	E	13.3 ± 1.50	79.9 ± 0.10	39.6 ± 1.00	38.6 ± 1.85	288.0 ± 24.00	78.8 ± 0.55	57.0 ± 6.00	666.5 ± 91.50	3.15 ± 1.330	3.28 ± 1.225
Jerusalem II	03C0601524	2	E	14.6 ± 0.50	75.4 ± 1.10	45.0 ± 1.25	34.9 ± 1.55	208.0 ± 0.00	77.0 ± 1.30	39.5 ± 7.50	999.5 ± 18.50	1.47 ± 0.140	1.58 ± 0.465
Palestine 10	03C0601027	2	E	13.4 ± 1.15	78.9 ± 1.25	41.2 ± 1.80	40.3 ± 4.60	237.5 ± 26.50	77.1 ± 0.00	56.0 ± 2.00	563.0 ± 135.00	1.84 ± 0.240	2.57 ± 0.680
Turk	03C0601969	2	E	13.1 ± 1.10	76.0 ± 0.70	34.4 ± 1.50	32.9 ± 0.35	293.0 ± 15.00	78.7 ± 0.60	48.5 ± 0.50	751.5 ± 214.50	2.76 ± 1.790	2.65 ± 1.490

[1] National accession number; [2] 2-row, 6-row; [3] Group: C – North America, D – South America and Australia, E – Near East aned Africa; [4] mean and standard error of the mean

Table 4 *Average values and variabilities of the studied traits (N = 184)*

Parameter	Unit	Mean	Min.	Max.	Standard deviation	Coefficient of variation	Standard error of the mean
Content of nitrogenous substances in barley grain	%	12.06	9.00	15.30	1.42	11.79	0.11
Extract of malt	%	81.17	73.00	86.30	2.52	3.09	0.19
Relative extract at 45 °C	%	43.43	31.60	61.40	5.36	12.34	0.40
Kolbach index	%	44.97	27.30	62.90	5.36	12.34	0.50
Diastatic power	jWk	316.53	175.00	597.00	74.47	23.53	5.49
Apparent final attenuation	%	79.91	74.30	85.60	2.15	2.70	0.16
Friability	%	74.15	32.00	99.00	15.02	20.25	1.11
β-glucans in sweet wort	mg/dm³	419.93	57.00	1475.00	254.45	60.59	18.76
Haze of wort 90°	j. EBC	3.26	0.59	16.97	3.60	110.55	0.27
Haze of wort 12°	j. EBC	3.32	0.52	15.63	3.15	94.87	0.23

Table 5 Average values of the studied traits and their variability in the individual ear types

Type of ear	N	Nitrogenous substances in barley grain (%) Mean ± SEM[1]	CV[2], %	Extract of malt (%) Mean ± SEM[1]	CV[2], %	Relative extract at 45 °C (%) Mean ± SEM[1]	CV[2], %	Kolbach index (%) Mean ± SEM[1]	CV[2], %	Diastatic power (WK) Mean ± SEM[1]	CV[2], %
6-row	18	12.94 ± 0.305 b[3]	10.010	77.85 ± 0.585 a	3.188	39.96 ± 1.186 a	12.589	39.27 ± 1.646 a	17.790	357.11 ± 20.598 b	24.471
2-row	166	11.96 ± 0.109 a	11.744	82.12 ± 0.167 b	2.617	43.81 ± 0.409 b	12.037	45.59 ± 0.502 b	14.186	312.13 ± 5.577 a	23.023

Type of ear	N	Apparent final attenuation (%) Mean ± SEM[1]	CV[2], %	Friability (%) Mean ± SEM[1]	CV[2], %	β-glucans in sweet wort (mg/dm3) Mean ± SEM[1]	CV[2], %	Haze of wort 90° Mean ± SEM[1]	CV[2], %	Haze of wort 12° Mean ± SEM[1]	CV[2], %
6-row	18	79.40 ± 0.452 a	2.416	55.72 ± 3.483 a	26.517	655.44 ± 73.832 b	47.791	3.30 ± 0.794 a	102.248	3.52 ± 0.761 a	91.758
2-row	166	79.96 ± 0.169 a	2.722	76.15 ± 1.060 b	17.937	394.39 ± 18.201 a	59.460	3.25 ± 0.282 a	111.727	3.30 ± 0.245 a	95.512

1) SEM – standard error of the mean, 2) CV – coefficient of variation, 3) Homogenous Groups P ≤ 0.05

Table 6 Average values of the studied traits and their variability in the individual years

Harvest	Nitrogenous substances in barley grain (%) Mean ± SEM[1]	CV[2], %	Extract of malt (%) Mean ± SEM[1]	CV[2], %	Relative extract at 45 °C (%) Mean ± SEM[1]	CV[2], %	Kolbach index (%) Mean ± SEM[1]	CV[2], %	Diastatic power (WK) Mean ± SEM[1]	CV[2], %
2010	11.06 ± 0.114 a[3]	9.888	81.98 ± 0.262 a	3.064	43.41 ± 0.536 a	11.854	47.33 ± 0.686 b	13.902	291.13 ± 6.650 a	21.909
2011	13.05 ± 0.097 b	7.118	81.44 ± 0.262 a	3.090	43.45 ± 0.583 a	12.876	42.61 ± 0.638 a	14.372	341.93 ± 7.925 b	22.230

Harvest	Apparent final attenuation (%) Mean ± SEM[1]	CV[2], %	Friability (%) Mean ± SEM[1]	CV[2], %	β-glucans in sweet wort (mg/dm³) Mean ± SEM[1]	CV[2], %	Haze of wort 90° Mean ± SEM[1]	CV[2], %	Haze of wort 12° Mean ± SEM[1]	CV[2], %
2010	80.03 ± 0.250 a	2.998	79.79 ± 1.502 b	18.062	379.90 ± 28.351 a	71.581	4.23 ± 0.455 b	103.055	4.09 ± 0.401 b	94.068
2011	79.78 ± 0.196 a	2.361	68.51 ± 1.404 a	19.663	459.96 ± 24.005 b	50.059	2.28 ± 0.236 a	99.165	2.56 ± 0.209 a	78.351

1) SEM – standard error of the mean, 2) CV – coefficient of variation, 3) Homogenous Groups P ≤ 0.05

Table 7 Average values of the studied traits and their variability in the individual groups of origin

Group*	N	Nitrogenous substances in barley grain (%) Mean ± SEM[1]	CV[2], %	Extract of malt (%) Mean ± SEM[1]	CV[2], %	Relative extract at 45 °C (%) Mean ± SEM[1]	CV[2], %	Kolbach index (%) Mean ± SEM[1]	CV[2], %	Diastatic power (WK) Mean ± SEM[1]	CV[2], %
A	74	11.70 ± 0.148 a[4]	10.870	82.28 ± 0.221 c	2.312	44.41 ± 0.678 c	13.134	46.35 ± 0.711 b	13.190	321.22 ± 8.602 bc	23.037
B	80	11.98 ± 0.155 a	11.606	82.43 ± 0.203 c	2.203	43.40 ± 0.464 bc	9.573	45.78 ± 0.666 b	13.018	314.05 ± 8.559 b	24.375
C	14	12.90 ± 0.371 b	10.759	79.58 ± 0.630 b	2.962	44.40 ± 1.773 bc	14.941	42.94 ± 2.219 b	19.334	360.43 ± 17.097 c	17.748
D	8	13.15 ± 0.484 b	10.419	77.12 ± 1.309 a	4.801	36.28 ± 1.466 a	11.435	35.94 ± 2.551 a	20.078	281.12 ± 17.912 ab	18.021
E	8	13.59 ± 0.479 b	9.979	77.54 ± 0.790 a	2.885	40.04 ± 1.530 ab	10.806	36.64 ± 1.485 a	11.462	256.62 ± 15.284 a	16.846

Group	N	Apparent final attenuation (%) Mean ± SEM[1]	CV[2], %	Friability (%) Mean ± SEM[1]	CV[2], %	β-glucans in sweet wort (mg/dm³) Mean ± SEM[1]	CV[2], %	Haze of wort 90° Mean ± SEM[1]	CV[2], %	Haze of wort 12° Mean ± SEM[1]	CV[2], %
A	74	80.62 ± 0.257 c	2.748	78.69 ± 1.426 c	15.588	370.19 ± 26.684 a	62.007	3.03 ± 0.403 ab	114.229	3.02 ± 0.350 a	99.483
B	80	79.76 ± 0.211 b	2.366	76.82 ± 1.334 c	15.530	392.56 ± 25.338 a	57.731	3.61 ± 0.447 ab	110.769	3.68 ± 0.387 ab	94.038
C	14	79.25 ± 0.624 ab	2.945	62.50 ± 4.015 b	24.035	534.86 ± 77.868 b	54.474	1.78 ± 0.203 a	42.610	2.16 ± 0.250 a	43.189
D	8	77.98 ± 0.620 a	2.248	49.75 ± 6.256 a	35.565	627.38 ± 124.561 bc	56.157	5.34 ± 1.504 b	79.615	5.37 ± 1.437 b	75.714
E	8	77.89 ± 0.429 a	1.560	50.25 ± 3.239 a	18.231	745.12 ± 79.518 c	30.184	2.30 ± 0.496 ab	60.847	2.52 ± 0.458 ab	51.493

*Group: A – Western Europe, B – Central and Eastern Europe, C – North America, D – South America and Australia, E – Near East aned Africa; 1) mean and standard error of the mean 2) SEM – standard error of the mean 2) CV – coefficient of variation, 3) CV – coeffcient of variation, 4) Homogenous Groups P ≤ 0.05

(379.90 mg/dm³ and 459.96 mg/dm³ in 2010 and 2011, resp.) and genetic resources with the two-row and six-row type of the ear (394.39 mg/dm³ and 655.44 mg/dm³, resp.). The average value of the set (419.93 mg/dm³) was increased mainly by the genotypes of the non-European origin groups (C, D, E); this was caused by a higher representation of the six-row varieties in these groups. But even within these groups, genetic resources with low levels of β-glucans in sweet wort could be found: for example, Conrad (203.0 mg/dm³), Long Glumes (239.0 mg/dm³) and Bolron (310.5 mg/dm³) in the group of varieties from North America (C), Psaknon (353.0 mg/dm³) in the group of varieties from South America and Australia (D) – Table 3. The highest average value (745.12 mg/dm³) was found in group E (Middle East and Africa). However, the variety with the highest β-glucan content belonged to the group of varieties from Central and Eastern Europe: the Czech breeding line KM 1192 (1187.5 mg/dm³). The lowest average value of β-glucan content in sweet wort was measured in the German variety Germina (95.5 mg/dm³). A high content of β-glucans in wort had a statistically significant negative effect on the malt extract, the relative extract at 45 °C, the Kolbach index, the apparent final attenuation and friability (Table 8). For this reason, breeders try to breed varieties with the lowest possible β-glucan content in the grain.

Level of proteolytic modification
Proteolytic modification of malt is a process of degradation of proteins by hydrolytic enzymes. The content of nitrogenous substances in barley caryopses and the degree of their modification during malting affect the beer foam capacity, wholesomeness of beer, occurrence of chill haze, filterability and colour of wort.

The content of nitrogenous substances in barley grain is one of the most important characteristics. In the studied set of genotypes, the values ranged from 9.0% to 15.3%, with the average of 12.1% (Table 4). Statistically significant differences between the two-row and six-row varieties (Table 5) and the growing years (Table 6) were recorded. All other groups (C, D and E) differed statistically significantly from the European varieties (groups A and B) in this parameter, but they did not differ from each other (Table 7). In the group of varieties from South America and Australia (D), Psaknon (11.8%) differed from the group with its average of nitrogen content in barley grain (13.2%); in this parameter it was comparable with the European varieties (groups A and B – the average values of 11.7% and 12.0%, resp.). Within the studied set, statistically significant positive correlations were found between the content of nitrogenous substances in the grain and diastatic power (r = 0.36) and β-glucan content in wort (r = 0.37). Further, negative correlations were found in connection with the malt extract (r = -0.53), Kolbach index (r = -0.60), apparent final attenuation (r = -0.27), friability (r = -0.73) (Table 8).

The Kolbach index represents the degree of protein modification. Statistically significant differences were found both between the two-row and six-row genotypes and between the studied years (Table 5, Table 6). The values ranged from 27.3 to 62.9%. Amabile et al. (2014) reported the range of values of the Kolbach index in a set of 30 malting two-row and six-row barley mainly from the area of South America in the range of 38.7–64.8%. In the observed set, the group from South America and Australia (35.9%) together with the group from the Middle East and Africa (36.6%) differed statistically significantly in this parameter from the other groups (Table 7).

Table 8 *Matrix of correlation between the studied traits in the set of spring barley genetic resources*

Parameter	NS	E	RE45	KI	DP	AFA	F	BG	H90	H12
NS	–									
E	0.53***2)	–								
RE45	-0.16	0.52***2)	–							
KI	-0.60***	0.74***	0.77***	–						
DP	0.36***	0.09	0.29***	0.08	-					
AFA	-0.27***	0.44***	0.24	0.36***	0.33***	–				
F	-0.73***	0.85***	0.54***	0.84***	0.03	0.46***	–			
BG	0.37***	-0.63***	-0.58***	-0.72***	-0.22	-0.43***	-0.77***	–		
H90	-0.18	-0.08	-0.24***	-0.09	-0.25***	-0.26***	-0.02	0.09	–	
H12	-0.15	-0.11	-0.22	-0.1	-0.23	-0.32***	-0.05	0.1	0.97***	–

1) NS – Nitrogenous substances in barley grain, E – Extract of malt, RE45 – Relative extract at 45°C, KI – Kolbach index, DP – Diastatic power, AFA – Apparent final attenuation, F – friability, BG – β-glucans in sweet wort, H90 – Haze of wort 90°, H12 – Haze of wort 12°; 2) *** – p ≤ 0.001.

According to Hartman et al. (2017), the optimal values range from 42 to 48%. This range was also met by the average values found in the varieties belonging to groups A (46.4%), B (45.8%) and C (42.9%) – Table 7. The variety Psaknon from South America and Australia (group D) approached with its average values (45.5%) the averages of groups A and B. The lowest average values were measured for the Argentine variety Cebada Capa (29.4%), the American breeding line CI 7584 (31.7%) and Uruguayan Ricardo (32.2%). The highest values were found in the West European varieties Biathlon (57.4%), Mauritia (56.4%), and Westminster (56.0%) – Table 1. In the evaluated set of genotypes, a strong negative correlation was detected between the Kolbach index and the content of β-glucans in wort ($r = -0.72$). A similar correlation was also found by Jin et al. (2011) and Amabile et al. (2014).

Relative extract at 45 °C gives the activity of proteolytic enzymes and β-amylase. In the monitored group, the value of the relative extract ranged from 31.6% to 61.4%. The lowest average values of this parameter were found in the South American varieties Ricardo and Cebada Capa (32.1% and 33.3%) and the Turkish variety Turk (34.4%). The highest average values were reached by the Canadian variety Conrad (56.6% – Table 3) and the malting varieties from Great Britain – Westminster and NFC Tipple (54.4% and 55.6%) – Table 1.

The values of the relative extract at 45 °C differed statistically significantly in the two-row and six-row varieties. Only the group of varieties from South America and Australia (36.3%) differed statistically significantly from the genotypes from Western Europe (44.4%) in this trait (Table 7). A strong positive correlation was found between the relative extract at 45 °C and the Kolbach index ($r = 0.77$). Other significant positive correlations of the relative extract at 45 °C with other characteristics were found to be mild, with the values ranging from 0.24 to 0.53 (Table 8). Slight significant negative correlations were found between this parameter and the content of β-glucans in wort ($r = -0.58$) and wort haze at 90 °.

Level of amylolytic modification
Amylolytic modification informs about the activity of amylolytic enzymes that cleave starch. The intensity of amylolytic enzymes is reflected in the most important malt trait, the extractivity of malt. It is the percentage of malt that passes into solution under the conditions of mashing. The amount of fermentable sugars is essential for fermentation, for this reason, amylolytic modification can be characterized by the apparent final attenuation.

The value of **diastatic power** in the studied genetic resources ranged from 175.0 WK to 597.0 WK. Psota (2008) and Jin et al. (2011) reported smaller ranges of values for

this parameter (226–442 WK and 254–516 WK, resp.). The probable reason is that, in this study, a more variable set of materials was studied. A statistically significant difference between the individual years was proven. In 2010, genetic resources with a two-row type of the ear had a statistically significantly lower level of diastatic power compared to the six-row genotypes (Table 5). The group of genotypes "B" originating from Central Europe differed statistically significantly in this trait from those from North America (group C) and the Middle East and Africa (group E) – Table 7. Furthermore, in the values of diastatic power, the two-row genotypes differed statistically significantly from the six-row genotypes. Hartman et al. (2017) reported the optimal value of this parameter of 220–300 WK. Many European varieties did not meet this range, such as Antigone (454 WK), Brenda (423 WK), Class (427 WK), Germina (401 WK), Amulet (445 WK), Nitran (485 WK), and others (Tables 1 and 2). On the contrary, this range was met by a number of genetic resources from the groups of the non-European varieties - Cebada Capa (254 WK, group D), Ricardo (234 WK, group D), Israel 46 (288 WK, group E), Palestine 10 (238 WK, group E), Turk (293 WK, group E). The lowest average value of diastatic power was found in the British variety Magnum (177 WK); the highest in the already mentioned Slovak malting variety Nitran (485 WK) – Table 2.

The values of **the extract content in the malt dry matter** in the studied set ranged from 73.0 to 86.3% (Table 4). The boundary average values of this parameter for the individual varieties were 74.1% (the lowest), again for the Argentine variety Cebada Capa (Table 3), and 86.2% (the highest) for the British variety Westminster (Table 1). The individual monitored years did not differ in the content of malt extract (Table 6). The two-row genotypes had statistically significantly higher contents of malt extract (82.1%) compared to the six-row ones (77.9%). In terms of groups by origin, the genotypes were divided into three groups according to the content of malt extract, which differed statistically significantly (Table 7). The genotypes from groups D and E had the lowest (77.1% and 77.5%), genetic resources from group C medium (79.6%) and materials from groups A and B statistically significantly the highest (82.4% and 82.3%) average values of the malt extract content. The acceptable range of malt extract values of 81.5⬚83.0%, as reported by Hartman et al. (2017), was found only in the genotypes originating from Europe (groups A and B), where breeding for malting quality has been conducted since the 19th century and quality sources have been available. However, in group D, the highest average content of extract in the malt dry matter was found in Psaknon (82.9%), which by this value exceeded the average

values of the groups of the European varieties – A and B (82.3% and 82.4%). In the studied set, a positive highly significant correlation between the malt extract content and friability was found (r = 0.85). However, Mathies et al. (2014), who studied a group of 174 European spring and winter barley over 25 years, did not find such a correlation in their study.

Apparent final attenuation was the least variable parameter (Table 4). Its values ranged from 74.3% to 85.6%. A similar range of values was also reported by Psota et al. (2017) for a set of 35 old and modern varieties of a Slovak origin (73.5–82.5%). A larger range of values of this trait was found by Prokeš et al. (2007) in a set of 113 Czech and foreign varieties: from 58.6% to 84.1%. However, these sets included both hulled and hulless genetic resources. Neither the individual years nor the two-row and six-row genotypes differed in this trait. A lower average value of this parameter than in Cebada Capa (76.1%) was found only in Czech Granát (75.9%). The highest average value was detected in the group of varieties from Western Europe – group A (80.6%), which corresponds to the highest average values of this trait found within the individual varieties – Brenda (84.2%, Germany), Calgary (83.6%, France) and Class (83.4%, Great Britain) – Table 1. This group (A) differed statistically significantly from all other groups of the varieties, even from those of the origin from Central and Eastern Europe (group B). Hartman et al. (2017) reported the optimal range of this trait from 79.0–82.0%. The average values of groups D and E were below the level of this minimum limit value. However, a variety that complied with this range was also detected in group D; it was the variety Bolivia (79.8%). In this study, a positive correlation was found between the achievable degree of the apparent final attenuation and friability (r = 0.46), similarly as found by Matthies et al. (2014), r = 0.40.

Sweet wort sensory characters

Of the sweet wort sensory characters, only the haze of sweet wort was assessed. Wort clarity is considered a sign of well modified barley. According to Prokeš et al. (2007) the haze of clear wort should reach the values up to 2.5 EBC. In the studied groups, the haze of sweet wort was measured at angles of 12° and 90°. Both these traits showed the highest variability of all the studied parameters (Table 4). The genetic resources with the two-row and six-row ear type did not differ in their average values of haze (at 12° and 90°), but statistically significant differences were found in the individual years (Table 6). Similar differences in both traits were found between the individual groups, where only groups C and D, i.e. genetic resources originating from North America, differed from

genetic resources from South America and Australia. The lowest values of wort haze at 12° and 90° were reached by the Czech variety Bojos (0.68 and 0.75), which was registered already in 2005 and is still greatly demanded (Psota et al. 2020). The highest value of wort haze at 12° was found in the Czech variety Heris (10.3) and at 90° in the German variety Aphrodite (11.3).

4 Conclusion

The breeding programs of malting varieties in Western and Central Europe reflect the requirements of the local beer producers. As genetically related varieties are frequently used, suitable genotypes coming from the world's collections of genetic resources might bring new genetic diversity to European breeding. The obtained results show that even the non-European groups of varieties can offer promising genetic resources that could enhance the genetic variability in breeding of European malting varieties; such as the Australian two-row variety Psaknon that resembled the European malting varieties in a number of traits.

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6 References

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