Grain quality of emmer germplasm (*Triticum dicoccon*) from the National Collection of Bulgaria*

Gergana N. Desheva, Bozhidar N. Kyosev, Siyka D. Stoyanova & Maria D. Sabeva

Institute of Plant Genetic Resources "K. Malkov", 2 Druzhba str. 4122 Sadovo, Plovdiv Distr., Bulgaria; e-mail: gergana_desheva@abv.bg (corresponding author)

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Abstract. The present work was carried out to study grain quality of 39 accessions of emmer wheat from the collection of the National Gene Bank of Bulgaria. Two accessions (BGR32746 and BGR19034) possessed the highest wet and dry gluten content and sedimentation value and medium gluten quality. A statistically significant positive correlation was obtained between crude protein content and lysine content, crude ash, wet gluten content and dry gluten content. Hierarchical cluster analysis grouped the accessions into four clusters. The information presented in this study is intended both for breeders who could involve emmer landraces in the breeding programs and for direct practical use by farmers and small bakeries.

Key words: bread-making quality, cluster analysis, emmer, physical characteristics, statistical correlations

Introduction

Cultivated emmer wheat *Triticum dicoccon* Schrank is a tetraploid species belonging to the genus *Triticum* with hulled grain. It is one of the earliest domesticated wheats derived from wild emmer (*Triticum dicoccoides* Schweinf.) (Troccoli & Codianni 2005; Zaharieva & al. 2010). Emmer is an ancient wheat crop which 20 years ago was considered an underutilized or neglected crop and which it seemed was probably going to be completely abandoned because of its low productivity and threshing and other agrotechnical problems (Perrino 2003; de Vita & al. 2006). In the last years, economic, political and social changes, including those concerning major needs for the conservation of biodiversity and especially of agrobiodiversity, have called the attention of scientists, researchers, politicians, international and national organizations, regional public and private enterprises to the potential of underutilized crops. At the same time there has been an increase of interest in human health as influenced by nutrition, and in environment protection. All these factors suggested investigating the properties of ancient wheat and especially of *Triticum dicoccon* Schrank from the agricultural and nutritional points of view (Perrino 2003). Emmer is currently mainly used as human food and part of the human diet, although it is also used for animal feed (Marconi & Cubadda 2005). Emmer is cultivated on many organic farms in Europe not only because it is supposed to have a higher nutritive value in comparison with common wheat, but also due to its higher resistance to unfavorable environmental factors, as well as lower fertilization and soil demands (Suchowilska & al. 2009).

Information about emmer grain composition and nutritional value is scarce and sometimes controversial (Zaharieva & al. 2010). Emmer wheat is characterized by high protein and mineral concentrations. The grain protein concentration can reach 16–23 %

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(Blanco & al. 1990; Damania & al. 1992; Perrino & al. 1993; Cubadda & Marconi 1994; Piergiovanni & al. 1996; de Vita & al. 2006; Stehno 2007; Moudrý & al. 2011; Konvalina & Moudrý 2007; Konvalina & al. 2012a, b, 2013; Stolikova & al. 2014). Higher lysine content (up to 3.65%) was reported by Galterio & al. (1994) and Stehno (2007). Fat content in emmer ranges from 1.02 to 3.80% (Hanchinal & al. 2005). Crude fibre content is higher in emmer than in durum wheat (Annapurna 2000). Mineral content was found by Hanchinal & al. (2005) to range from 1.14% to 2.46% and to be lower than in durum wheat, although Cubadda & Marconi (1996) reported higher ash content in an emmer landrace and Piergiovanni & al. (2009) reported higher mineral content in the emmer cultivar. Higher dry gluten content was found in emmer than in durum and bread wheat (Piergiovanni & al. 2009). A high variation was reported for gluten strength (Blanco & al. 1990; Perrino & al. 1993). Information on the rheological properties and baking and pasta-making is scarce (Zaharieva & al. 2010).

According to Konvalina & Moudrý (2007); Konvalina & al. (2012, 2013), emmer wheat is a crop with potential for sustainable development of agriculture in the future. It has interesting features for wheat breeding (e.g. resistance to wheat diseases and drought, root system efficiency). The emmer grain has large potential for development of new products because of its high protein content and beneficial nutritional value. Along with this, it is a crop especially for small-scale farming that relates to local food processing.

The aim of this study was to evaluate the grain quality of 38 accessions of *T. dicoccon* Schrank from the collection maintained at the National Genebank of Bulgaria at the Institute of Plant Genetic Resources (IPGR).

Material and methods

The study was conducted at the Konstantin Malkov IPGR – Sadovo in 2014. Thirty-eight accessions (*T. dicoccon* Schrank) from the collection of the National Genebank were studied (Table 1). The grain physical characteristics such as thousand kernel weight and general vitreousness were determined according to the methods described in BDS ISO 520 (2003) and BDS 13378 (1976). The following chemical characteristics of grain were studied: crude protein content (%) by Kejeldahl's method, and grain lysine (%) by the method of Ermakov & al. (1972) and lysine content (% of protein). Crude fibre, crude ash and moisture content were determined according to standard methods (Osborne & Voogt 1978).

Wet and dry gluten content was estimated after grinding the grain into flour and hand washing according to BDS 13375 (1988). The sedimentation value of the whole wheat flour was determined using the method of Pumpyanskiy (1971). Bread-making strength index and gluten weakness were detected according to BDS 13375 (1988). The whole emmer

Table 1. List with accessions included in the study.

No.	BGR	Genus	Species	Subtaxa
1	10995	*Triticum*	*dicoccon*	ssp.
2	10998	*Triticum*	*dicoccon*	ssp.
3	17305	*Triticum*	*dicoccon*	var. *farrum*
4	17306	*Triticum*	*dicoccon*	var. *pycnurum*
5	17308	*Triticum*	*dicoccon*	var. *pycnurum*
6	17309	*Triticum*	*dicoccon*	var. *rufum*
7	17310	*Triticum*	*dicoccon*	var. *subfarrum*
8	17311	*Triticum*	*dicoccon*	var. *tricoccum*
9	19034	*Triticum*	*dicoccon*	var. *alboliguliforme*
10	19035	*Triticum*	*dicoccon*	var. *compactomiegei*
11	19036	*Triticum*	*dicoccon*	var. *farrum*
12	19037	*Triticum*	*dicoccon*	var. *farrum*
13	19038	*Triticum*	*dicoccon*	var. *farrum*
14	19039	*Triticum*	*dicoccon*	var. *farrum*
15	19040	*Triticum*	*dicoccon*	var. *ficte-semicanum*
16	19041	*Triticum*	*dicoccon*	var. *immaturum*
17	19042	*Triticum*	*dicoccon*	var. *nigrocyar*
18	19043	*Triticum*	*dicoccon*	var. *novicium*
19	19044	*Triticum*	*dicoccon*	var. *pseudomacrather*
20	19045	*Triticum*	*dicoccon*	var. *pseudopraecox*
21	19046	*Triticum*	*dicoccon*	var. *pycnurum*
22	19047	*Triticum*	*dicoccon*	var. *pycnurum*
23	19048	*Triticum*	*dicoccon*	var. *tricoccum*
24	22611	*Triticum*	*dicoccon*	var. *compactomiegei*
25	26764	*Triticum*	*dicoccon*	ssp.
26	26765	*Triticum*	*dicoccon*	ssp.
27	26766	*Triticum*	*dicoccon*	ssp.
28	26767	*Triticum*	*dicoccon*	ssp.
29	30015	*Triticum*	*dicoccon*	ssp.
30	30016	*Triticum*	*dicoccon*	var. *rufum*
31	30017	*Triticum*	*dicoccon*	ssp.
32	30018	*Triticum*	*dicoccon*	ssp.
33	30019	*Triticum*	*dicoccon*	var. *atratum*
34	30039	*Triticum*	*dicoccon*	
35	31904	*Triticum*	*dicoccon*	var. *muticum*
36	32746	*Triticum*	*dicoccon*	var. *vitic.*
37	32747	*Triticum*	*dicoccon*	var. *farrum*
38	32748	*Triticum*	*dicoccon*	var. *haussknechtianum*

wheat meal flour of each accession was also tested for fermentation value (Pelchenke & al. 1953).

The experimental data of evaluated properties were analyzed using the SPSS 13.0 statistics. The analysis of variance was applied to determine the descriptive characteristics: mean value, standard error of means, standard deviation, and coefficient of variation. LSD test was carried out to explore the significance of differences between the mean standard and the respective accession in the data set. Cluster analysis based on Ward's method and squared Euclidian distance was performed (Ward 1963). Pearson's correlation coefficients were determined according to Lidansky (1988).

Results and discussions

Physical characteristics of grain

The physical characteristics of emmer kernels, which relate to milling performance and overall assessment of emmer wheat quality, are presented in Table 2 and Table 3. Significant variation in the degree of vitreousness and thousand kernel weight were observed among the genotypes. Vitreousness ranged from 66 % for BGR17305 to 99 % for BGR26765. Thirteen accessions have shown vitreousness above 90 %. Thousand kernel weight as a function of kernel size, shape, dryness, purity and density could be also an index of potential milling yield (Matsuo & Dexter 1980). In our investigation, it varied between 21.80 g and 49.95 g. The highest thousand kernel weight was confirmed statistically for three accessions: BGR19043 (49.95 g), BGR19034 (48.20 g) and BGR17311 (46.60 g).

Chemical characteristics of grain

The results from chemical analysis are presented in Table 2 and Table 3. The grain protein content is a crucial criterion for assessing wheat quality. According to Petrova (2007), quantity of protein depends on genotype, environment and the growing conditions. Emmer wheat is characterized by high protein, as compared to modern durum and/or bread wheat (Zaharieva & al. 2010). Many authors reported high variation in protein content of emmer genotypes (Galterio & al. 2001; Grausgruber 2004; Marconi & Cubadda 2005; de Vita & al. 2006; Konvalina & al. 2013; Giacintucci & al. 2014). In our study, crude protein ranged from 14.14 % to 20.71 % (Table 3). The lowest protein content about 14.4–14.71 % was observed in four landraces (BGR 19043, BGR 17311, BGR 30019 and BGR 30018). The highest protein content confirmed statistically was observed in BGR17310 (20.71 %), next followed by BGR 30016 (20.38 %) and BGR 17309 (20.24 %). Eighteen accessions had crude protein content between 18–20 % (Table 2). As suggested by Stolickova & Konvalina (2014) and Mondini & al. (2014), the content of proteins in emmer may rise up to 20 %, but usually it gets to 18 %. The mean protein content in our accessions was detected at 17.93 %.

However, the crude protein content is not the crucial factor of grain quality. It is also important for describing the structure of protein fractions, baking quality and the composition of amino acids. According to Konvalina & al. (2008), lysine is the limiting amino acid, both for emmer wheat and for bread wheat. Lysine in the studied accessions varied from 0.30 % to 0.58 %. The highest lysine content was observed in BGR10998 (0.58 %) and BGR26764 (0.54 %). These accessions are characterized also with high lysine content towards protein content in kernel (respectively 3.17 % and 3.09 %, Table 2).

The ash content is also one of the best indicators of flour yield; hence, the wheat with lower content of ash may have more endosperm and ultimately yield good flour extraction (William & al. 1986; Khan & al. 2009). Konvalina & al. (1996) reported the almost equal contents of ash and of fat in whole meal of spelta and emmer: about 2 % of each characteristic. In our study, there were no significant differences in crude ash content within the tested accession (CV = 7.37 %) (Table 3). However, crude ash in the grain of emmer varied between 1.66 % and 2.77 %. Twenty genotypes had values near the mean value (mean standard) – 1.99 %. The highest crude ash content was found in BGR30039 (2.27 %), followed by BGR19038 (2.24 %), BGR19042 (2.22 %) and BGR17310 (2.21 %). BGR32748 and BGR19039 showed the lowest ash content (1.66 % and 1.68 %) (Table 2).

Crude fiber content varied from 1.23 % to 2.17 %. BGR19042, BGR26764, BGR26766, and BGR32747 showed the highest content, while BGR19043, BGR30039 and BGR19036 the lowest. These accessions had significant differences at the 0.05 level, as compared with the mean standard value (1.64 %) (Table 2).

Table 2. Physical characteristics of grain and chemical characteristics of whole emmer flour of different emmer landraces.

BGR	Crude protein, %	Lysine, %	Lysine in protein, %	Crude fibre, %	Crude ash, %	Thousand Kernel weight, g	Vitreousness, %	Sedimentation value, cm3	Pelshenki test, min	Wet gluten content, %	Gluten weakness, mm	Bread-making strength index	Dry gluten content, %
St	**17.93**	**0.38**	**2.05**	**1.64**	**1.99**	**36.03**	**85.78**	**23.78**	**35.50**	**35.80**	**9.02**	**63.38**	**12.57**
BGR19034	19.85+	0.42+	2.09	1.71	2.13+	48.2+	85.0	26.5+	31.0-	44.6+	6.25-	79.0+	15.83+
BGR19035	18.11+	0.34-	1.85-	1.43	1.91-	42.4+	85.0	24.00	34.0-	36.41	10.0+	58.0-	13.14+
BGR22611	19.63+	0.44+	2.22	1.65	2.04	43.4+	80.0-	23.50	34.0-	37.52	8.5-	65.0+	13.22+
BGR19036	18.76+	0.34-	1.81-	1.39-	2.19+	32.0-	85.0	20.0-	41.0+	43.08+	5.25-	88.5+	15.08+
BGR19037	17.50-	0.36-	2.03	1.81	2.03	29.4-	75.0-	20.0-	30.0-	27.56-	5.5-	74.0+	9.50-
BGR19039	16.64-	0.37	2.20	1.65	1.68-	43.8+	74.0-	25.5+	23.0-	28.96-	12.75+	48.5-	10.17-
BGR19040	17.11-	0.34-	1.96	1.49	1.88-	36.00	90.0+	24.5+	34.0-	32.60	8.0-	65.0+	11.82-
BGR19041	17.94	0.33-	1.81-	1.77	2.05	31.8-	91.0+	22.5-	52.0+	36.90	5.75-	83.5+	12.77+
BGR19042	19.10+	0.34-	1.78-	2.15+	2.22+	34.0-	95.0+	25.5+	28.0-	34.32	11.0+	55.0-	12.10-
BGR19043	14.14-	0.30-	2.09	1.23-	1.75-	49.95+	84.50	24.00	30.0-	24.9-	7.0-	58.0-	8.10-
BGR19044	16.46-	0.37	0.25-	1.86	1.85-	36.20	82.0-	25.0+	29.0-	28.52-	13.0+	48.0-	9.87-
BGR19045	18.39+	0.33-	1.10-	1.51	2.00	32.2-	98.0+	26.5+	31.0-	37.36	7.25-	71.5+	12.93+
BGR19046	17.35-	0.31-	1.79-	1.69	2.05	39.4+	95.0+	26.0+	34.5-	39.10	7.0-	73.0+	14.27+
BGR17306	18.57+	0.31-	1.65-	1.62	2.00	40.8+	88.0+	23.0-	26.0-	38.36	10.25+	57.5-	13.47+
BGR17308	18.39+	0.34-	1.85-	1.58	2.03	40.8+	86.50	24.00	29.0-	39.22	11.0+	55.0-	13.87+
BGR19048	15.99-	0.37	2.28+	1.64	1.94	42.4+	82.0-	26.0+	28.0-	23.28-	8.75-	47.5-	7.95-
BGR17311	14.44-	0.31-	2.12	1.45	1.95	46.6+	93.0+	26.0+	27.0-	32.20	6.0-	78.0+	11.59-
BGR30015	15.64-	0.31-	1.98	1.57	1.99	38.6+	91.0+	26.0+	37.0+	33.80	7.0-	72.0+	11.88-
BGR30019	14.71-	0.30-	2.08	1.49	2.02	44.8+	73.0-	25.0+	37.0+	31.1-	8.5-	62.00	10.89-
BGR19038	19.35+	0.45+	2.3+	1.79	2.24+	28.8-	80.0-	20.0-	51.0+	26.8-	6.75-	75.0+	14.37+
BGR17305	17.80	0.44+	2.44+	1.47	1.90-	32.2-	66.0-	23.0-	32.0-	35.04	7.0-	73.0+	12.18-
BGR32747	18.23+	0.40+	2.19	1.90+	2.12+	31.0-	75.0-	22.0-	36.5+	36.84	5.0-	91.0+	13.30+
BGR17309	20.24+	0.44+	2.15	1.64	2.03	30.2-	79.5-	23.0-	29.0-	33.84	13.0+	50.0+	11.25-
BGR30016	20.38+	0.43+	2.11	1.77	2.05	31.2-	77.0-	26.5+	32.0-	38.90	12.25+	52.0+	12.01-
BGR17310	20.71+	0.38	1.82-	1.59	2.21	39.4+	82.0-	25.5+	34.0-	43.96+	9.25	61.0+	15.44+
BGR32746	19.73+	0.38	1.90	1.52	1.74-	30.2-	96.5+	27.0+	40.0+	45.8+	7.75-	68.5+	14.50+
BGR31904	17.50-	0.35-	1.99	1.42	2.07	44.6+	82.0-	23.50	33.0-	34.72	15.75+	46.0-	12.02-
BGR32748	16.7-	0.45+	2.69+	1.45	1.66-	34.6-	90.0+	20.5-	31.0-	22.6-	10.0+	43.5-	8.25-
BGR10995	19.90+	0.41+	2.04	1.64	2.02	34.0-	74.0-	24.5+	55.0+	41.8+	7.0-	73.0+	14.94+
BGR10998	18.15+	0.58+	3.17+	1.86	1.82-	23.0-	93.0+	21.0-	26.0-	38.00	12.0+	53.0-	12.49
BGR26764	17.49-	0.54+	3.09+	2.03+	2.03	21.8-	79.0-	21.5-	30.0-	41.2+	10.0+	58.0-	13.18+
BGR26767	18.01	0.39	2.14	1.76	2.14+	34.2-	91.5+	24.00	28.0-	25.5-	12.75+	45.5-	8.76-
BGR26765	18.49+	0.37	2.00	1.68	1.88-	35.60	99.0+	23.50	29.0-	38.28	12.0+	53.0-	13.30+
BGR26766	19.17+	0.35-	1.83-	1.94+	2.04	29.2-	96.5+	21.0-	100.0+	41+	7.25-	71.5+	14.86+
BGR30017	17.76+	0.47+	2.62+	1.66	1.98	22.8-	82.0-	22.0-	24.0-	43.04+	8.0-	67.0+	14.04+
BGR30018	14.75-	0.33-	2.24+	1.76	1.87-	42.6+	98.5+	23.0-	55.0-	36.60	11.75+	53.5-	12.86+
BGR30039	19.90+	0.45+	2.24+	1.2-	2.27+	29.4-	87.00	24.5+	34.0-	43.72+	10.0+	58.0-	15.47+
BGR19047	18.27+	0.37	2.02	1.52	2.00	41.6+	98.0+	24.00	34.0-	42.88+	6.5-	77.0+	15.42+
LSD 0.05	**0.162**	**0.021**	**0.173**	**0.221**	**0.078**	**0.433**	**1.790**	**0.567**	**0.843**	**3.882**	**0.252**	**1.512**	**0.202**

Table 3. Summary statistics of the investigated quality characters.

	Minimum	Maximum	Mean	Std. error	Std. deviation	Variance	CV, %
Crude protein, %	14.14	20.71	17.93	0.28	1.70	2.88	9.47
Lysine, %	0.30	0.58	0.38	0.01	0.06	0.00	16.96
Lysine % in protein	0.25	3.17	2.04	0.08	0.49	0.24	24.18
Crude fibre, %	1.23	2.17	1.64	0.03	0.20	0.04	12.15
Crude ash, %	1.66	2.27	1.99	0.02	0.15	0.02	7.37
Thousand kernel weight, g	21.80	49.95	36.03	1.16	7.12	50.73	19.77
Vitreousness, %	66.00	99.00	85.78	1.37	8.44	71.29	9.84
Sedimentation value, cm^3	20.00	27.00	23.78	0.33	2.02	4.08	8.49
Pelshenki test, min	23.00	100.00	35.50	2.16	13.32	177.43	37.52
Wet gluten content, %	22.60	45.80	35.80	1.02	6.31	39.85	17.64
Gluten weakness, mm	5.00	15.75	9.02	0.44	2.68	7.20	29.75
Bread-making strength index	43.50	91.00	63.38	2.04	12.59	158.52	19.86
Dry gluten content, %	7.95	15.83	12.57	0.35	2.18	4.76	17.37

Food processing properties of emmer flour

The wet gluten ranged significantly from 22.60 % to 45.80 % in different emmer samples (Table 3). Significant positive differences, as compared with the mean standard value (35.80 %) at the 0.05 level, were shown by ten of evaluated accessions. Low wet gluten content was determined for BGR32748 and BGR19048, resp. 22.60 % and 23.28 %. Three accessions (BGR32746, BGR19034 and BGR19036) possessed high wet gluten content within the range 43.08–45.80 % and were described with medium gluten quality indicated by gluten weakness (7.75, 6.25 and 5.25 mm). Some other landraces (BGR17309, BGR30016, BGR30039, BGR26764 and BGR17310) showed high values of gluten weakness relating to low gluten quality**.** Our findings confirm the earlier reported results of other authors (Grausgruber & al. 2004), namely – emmer varieties possess high protein and wet gluten contents, but low gluten quality. It is known that dry gluten content correlates positively with the wet gluten content (Desheva & al. 2014). In the present study, it varied from 8.25 % (BGR32748) to15 % (BGR32746).

Sedimentation value determines the viscosoelastic character of gluten albumins and their quality, which ensure the fermentative processes in dough (Konvalina 2008). According to Petrova (2007), sedimentation volumes of 25 cm^3 to 35 cm^3 indicate moderate gluten-strength varieties, and volumes greater than 35 cm^3 indicate strong-gluten varieties. In our study, the sedimentation value varied within a narrow scale (20–27 cm^3). Thirteen accessions showed values between 25 cm^3 and 27.0 cm^3. Two accessions (BGR19034 and BGR32746) combined the highest sedimentation values with the highest wet and dry gluten contents. The mean value of bread-making strength index was 63.38 %. Fourteen accessions had an index above 70 %. The highest values were found in BGR32747 (91 %) and the lowest in BGR32748 (43.50 %). According Moudry & al. (2011), the varieties suitable for baking should attain high gluten index values (70) and high sedimentation values (50 ml). Their study showed that emmer varieties attained low gluten index and sedimentation values and were not suitable for baking. In our study, fourteen emmer landraces were characterized with high gluten index and low to medium sedimentation value. These results indicated that emmer may be difficult to use for common baking.

A Pelshenki test showed the highest significant differences between the investigated accessions (CV = 37.52 %) (Table 3). The variation of this character in evaluated samples of emmer wheat species ranged from 23 min to 100 min. The highest value of the Pelshenki test was observed in BGR26766 (100 min), while the lowest value was determined for BGR19039 (23 min) (Table 2).

Correlations between investigated characters

Pearson's correlation coefficients between 13 characters are presented in Table 4. Crude protein showed significant positive correlation with lysine (0.406), crude ash (0.502), wet gluten content (0.578) and dry gluten content (0.611). While being negative, it correlated with thousand kernel weight (–0.422). Lysine correlated positively with lysine towards protein content (0.622) and negatively both with thousand kernel weight (–0.631) and with sedimentation value (–0.374). Lysine towards protein percentage showed significant negative correlation with sedimentation value (–0.397). Crude fibre

Table 4. Significant correlations, *in bold*, between investigated characters in 38 emmer wheat.

	Crude protein, %	Lysine, %	Lysine % in protein	Crude fibre, %	Crude ash, %	Thousand kernel weight, g	Vitreous-ness, %	Sedimen-tation value, cm3	Pelshenki test, min	Wet gluten content, %	Gluten weakness, mm	Bread-making strength index	Dry gluten content, %
Crude protein, %	1												
Lysine,%	**0.406***	1											
Lysine % in protein	-0.032	**0.622****	1										
Crude fibre, %	0.218	0.305	0.072	1									
Crude ash, %	**0.502****	0.019	-0.086	0.226	1								
Thousand kernel weight, g	**-0.422****	**-0.631****	-0.261	**-0.443****	-0.175	1							
Vitreousness, %	-0.06	-0.272	-0.199	0.041	-0.092	0.039	1						
Sedimentation value, cm^3	-0.043	**-0.374***	**-0.397***	-0.194	-0.067	**0.489****	0.148	1					
Pelshenki test, min	0.144	-0.145	-0.083	0.198	0.164	-0.156	0.188	-0.275	1				
Wet gluten content, %	**0.578****	0.166	0.005	0.032	**0.331***	-0.235	0.192	0.121	0.212	1			
Gluten weakness, mm	0.049	0.192	0.004	0.123	-0.176	0.038	0.026	0.114	-0.282	-0.167	1		
Bread-making strength index	0.125	-0.163	-0.081	-0.013	**0.347***	-0.115	-0.023	-0.14	**0.330***	**0.398***	**-0.891****	1	
Dry gluten content, %	**0.611****	0.125	-0.028	0.042	**0.475****	-0.199	0.193	0.007	**0.350***	**0.904****	**-0.287**	**0.525****	1

*. Correlation is significant at the 0.05 level (2-tailed).
**. Correlation is significant at the 0.01 level (2-tailed).

content correlated negatively with thousand kernel weight (–0.443). Crude ash was in significant positive correlation with wet and dry gluten content and bread-making strength index (respectively, 0.331, 0.475 and 0.347). Thousand kernel weight correlated positively with sedimentation value (0.489). Wet gluten content showed significantly positive correlation with dry gluten content (0.350) and bread-making strength index (0330), while gluten weakness correlated negatively at the 0.01 level with bread-making strength index (–0.891). Bread-making strength index was in a significantly positive relationship with dry gluten content also at the 0.01 level (0.525).

Cluster analysis

An analysis of genetic diversity for detection of similarity between accessions was carried out (Fig. 1). A cluster diagram based on squared Euclidean dissimilarity and Ward's method categorized the evaluated germplasm into five clusters at 10 % linkage distance. Cluster I included sixteen genotypes that represent 42.11 % of the studied accessions (BGR17306, BGR17308, BGR19035, BGR22611, BGR17310, BGR19043, BGR30019, BGR30018, BGR32748, BGR26767, BGR17309, BGR30016, BGR19044, BGR19048, BGR19039, and BGR31904). The average values for thousand kernel weight and gluten weakness of genotypes in this cluster were higher than the total means of all genotypes (Table 5). Six accessions were classified in the second cluster, which embraced 15.38 % of all genotypes. Genotypes in this group were in the highest rate with respect to lysine (0.46 %) and lysine percentage towards protein (2.48 %). The third cluster comprised eight genotypes: 20.51 % of the genotype batch (BGR19034, BGR17311, BGR19040, BGR30015, BGR19046, BGR19047, BGR19045, and BGR32746). The standard deviations of characters in this group (except for crude protein content) were lower than the calculated ones for the total batch. Values of five chemical characteristics (crude protein, lysine, lysine percentage towards protein, crude fibre and crude ash) in this cluster were lower in comparison to the total means of all genotypes. But genotypes in this group were at the highest rate with respect to sedimentation value (25.81 %). Seven genotypes were described in the fourth cluster, representing 17.95 % of all studied accessions (BGR 19037, BGR 17305, BGR 19036, BGR 32747, BGR 19041, BGR 19038, and BGR 10995). This cluster included accessions determined with high bread-making strength index (79.71) and low gluten weakness (6.04 mm). One accession was separated individually (BGR 26766) in Cluster V and characterized with the highest Pelschenke fermentation value (100 min).

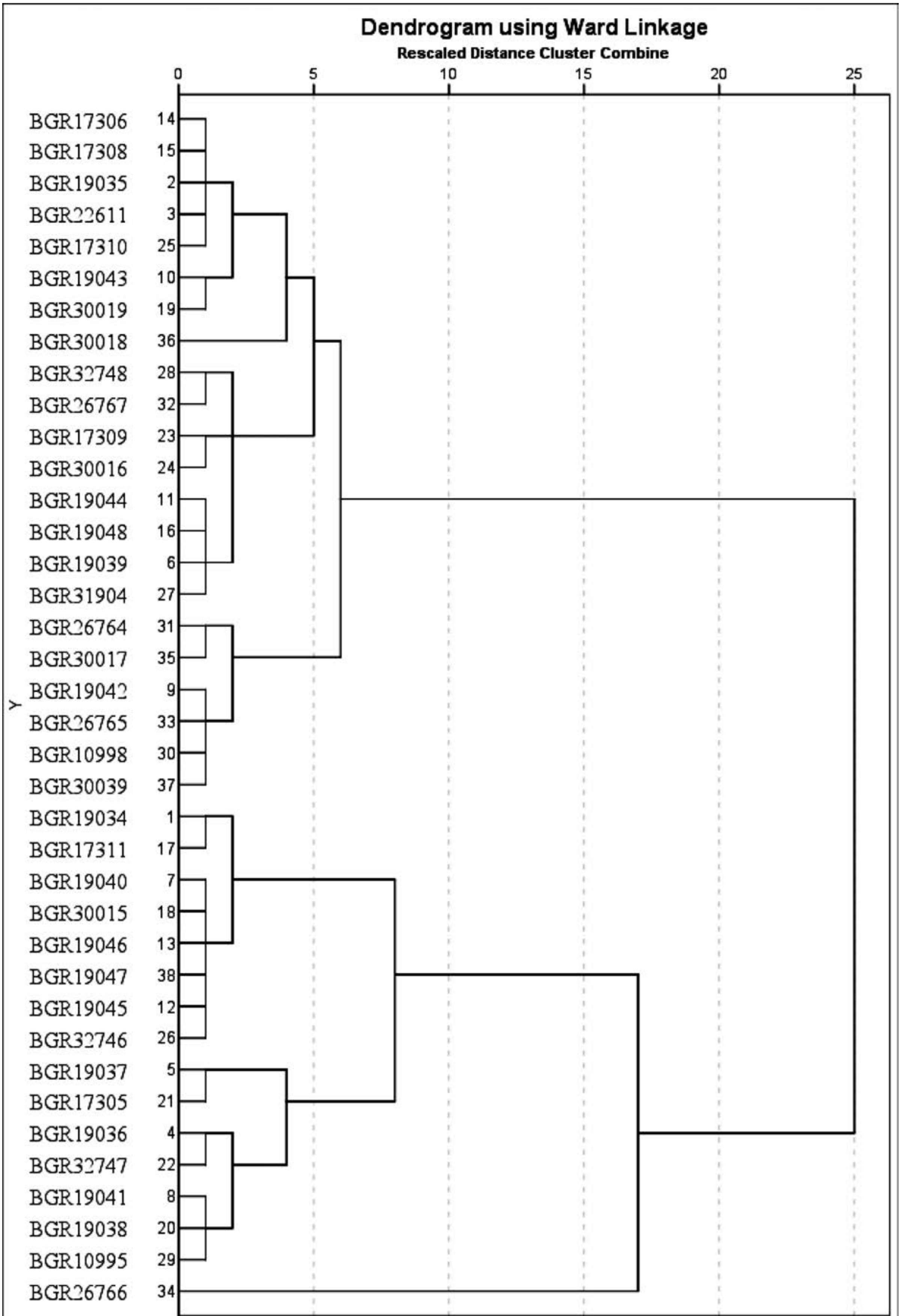

Fig. 1. Tree diagram of 38 genotypes for 14 studied variables using the hierarchical cluster analysis (Ward's method and square Euclidean distance).

Table 5. Mean and standard deviation of five clusters for fourteen characters.

Characters	Means/Stand. deviation	Clusters					Total mean/ total SD for all genotypes
		I	II	III	IV	V	
Crude protein, %	Means	17.56	18.48	17.60	18.50	**19.17**	17.93
	SD	2.07	0.90	1.88	0.88	0.04	1.70
Lysine, %	Means	0.37	**0.46**	0.35	0.39	0.35	0.38
	SD	0.05	0.09	0.04	0.05	0.00	0.06
Lysine, % in protein	Means	1.98	**2.48**	1.83	2.09	1.83	2.04
	SD	0.52	0.57	0.44	0.24	0.01	0.49
Crude fibre, %	Means	1.60	1.79	1.56	1.68	**1.94**	1.64
	SD	0.16	0.32	0.09	0.19	0.02	0.20
Crude ash, %	Means	1.95	2.03	1.97	**2.08**	2.04	1.99
	SD	0.16	0.18	0.12	0.11	0.05	0.15
Thousand kernel weight, g	Means	**40.08**	27.77	39.10	31.31	29.20	36.03
	SD	5.41	6.10	6.35	1.77	0.40	7.12
Vitreousness, %	Means	83.47	89.17	93.31	78.00	**96.50**	85.78
	SD	6.55	7.81	4.51	8.16	1.50	8.44
Sedimentation value, cm3	Means	24.13	23.00	**25.81**	21.71	21.00	23.78
	SD	1.47	1.79	1.03	1.78	0.00	2.02
Pelshenki test, min	Means	32.00	28.50	33.56	42.50	**100.00**	35.50
	SD	7.06	3.45	3.98	10.19	0.00	13.32
Wet gluten content, %	Means	32.77	39.76	38.54	35.43	**41.00**	35.80
	SD	6.50	3.56	5.45	6.32	1.00	6.31
Gluten weakness, mm	Means	**10.91**	10.50	6.97	6.04	7.25	9.02
	SD	2.28	1.52	0.70	0.86	0.25	2.68
Bread-making strength index	Means	53.19	57.33	73.00	**79.71**	71.50	63.38
	SD	6.55	5.24	4.85	7.79	1.50	12.59
Dry gluten content, %	Means	11.33	13.43	13.59	13.16	**14.86**	12.57
	SD	2.31	1.20	1.74	1.95	0.26	2.18

Conclusion

The results show that the kernel physical characteristics and the chemical characteristics of emmer varied significantly among the evaluated accessions. The **crude protein** content ranged from 14.14 % to 20.71 %, lysine varied from 0.30 % to 0.58 %, crude ash was between 1.66 % and 2.77 %, while crude fibre content was from 1.23 % to 2.17 %. ***Wet gluten*** ranged within a wide scale from 22.60 % to 45.80 %.

This confirms that emmer genotypes are characterized by high content of protein and wet gluten contents, but lower sedimentation values. This relates to specific practical decisions for preparing bread of emmer.

A significant positive correlation was obtained between crude protein and five characters: lysine, crude ash, wet gluten content, and dry gluten content. On the other hand, this correlated negatively with thousand kernel weight. Wet gluten content showed a significantly positive correlation with dry gluten content and bread-making strength index, while gluten weakness correlated negatively with bread-making strength index. Bread-making strength index was in a significantly positive relationship with dry gluten content.

A cluster analysis carried out allowed dispensation of the genotype patterns. A group of genotypes possessing high lysine content was determined. Accessions bearing useful traits for baking were assigned with a high bread-making strength index and low gluten weakness, one accession with extremely high Pelshenke fermentation value was indicated. This approach promotes a further utilization improvement of the existing emmer collection both for breeders needs and for direct use by the food industry.

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