Diversity of Evaluated Characters and HMW-*Glu* Alleles in Landraces and Cultivars of Emmer, Einkorn and Spelt Wheat

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ABSTRACT: Morphological and agronomical characters were studied in emmer (22), einkorn (10) and spelt (10) wheat cultivars in two seasons in Prague. Large diversity was recorded especially in emmer wheat, followed by einkorn and spelt. Spelt and emmer had tall stem (mean = 115 and 107 cm, respectively). Einkorn was shorter (85 cm), with good resistance to powdery mildew but low values of productivity characters. High spike productivity in spelt (mean grain mass per spike = 1.59 g) was conditioned by high TGW (mean 49 g), lower spike productivity was in emmer (mean 0.86 g, best cultivar 1.47 g). HMW-*Glu* allele 2* at 1A chromosome was rare in bread wheat (7%), absent in spelt and frequent in emmer (36% lines), allele 1 was prevailing in all species. At 1B, most common in wheat were subunits 7 + 9 (40%) and 7 + 8 (22%). Combination 6 + 8 was frequent in spelt (76%) and alleles 7 + 8 (41%) and 21 (21%) in emmer where also some rare alleles were found. Diversity of HMW-*Glu* subunits at 1D was lower.

Keywords: emmer; einkorn; spelt; bread wheat; agronomic and morphological characters; HMW-*Glu*-alleles

Bread wheat (*Triticum aestivum*) is one of most important crops feeding the World, followed by durum wheat (*T. durum*) in the range of importance of *Triticum* species. However, some other wheat species such as emmer, einkorn and spelt are of increasing interest of breeders and farmers because of their important biological and quality characters, which can be utilized in breeding these species as well as in bread wheat breeding. All the above wheat species are hulled wheats – their grain remains mostly closed in glumes after threshing. Specific grain quality is usually the main reason for growing these "neglected" species; because of their nutritious quality and low input demands they are often grown in low input systems. Only limited breeding efforts have been directed to these wheat species compared to bread wheat; nevertheless, interest about these crops increases, as reported e.g. by Vazzana and Heller (1996), Cubadda *et al.* (1996). Most gene bank accessions of the species are landraces and/or primitive cultivars, except for spelt for which advanced cultivars are more frequent. These materials can be utilized as a source of genetic diversity for crop improvement (Zou & Yang 1995); e.g. as donors of some important agronomical characters (adaptability, resistance to stresses, protein content – Wang *et al*. 1993).

Spelt is old cereal traditionally used in many European countries (Pena-Chocarro *et al*. 1998). Nowadays it is often recommended for organic farming systems (Chiorri *et al*. 1995). Because of its special grain quality, the area in which spelt wheat is grown has increased; its grain is largely used for production of bio-products.

Tetraploid emmer wheat is another hulled wheat with a long history of being grown and used for human nutrition. Despite this, the breeding of emmer has been marginal and at present mostly landraces or wild forms are available. However, owing to increasing demand for diversity and quality of food products, interest in this crop also increases (Hammer & Perrino 1995; Olsen 1998; Nielsen &

Mortensen 1998). High protein content in grain ranging from 15 to 20% (Sehnalová & Kostkanová 1990) is a typical trait of emmer wheat.

Diploid einkorn was not so widely utilized in the past. Increased interest has appeared recently owing to some its valuable properties such as grain quality and resistance to diseases. These characters are frequently utilized for improvement of widely grown bread and durum wheat species. For example, powdery mildew resistance genes were introduced into Czech cultivar Vlasta from einkorn. Rodriques-Quijano *et al*. (1998) suggest its utilization to improve grain quality.

Genetic markers are widely used for studies of genetic diversity within and between *Triticum* species. Gliadins and glutenins, like DNA markers, can be employed as a useful tool for characterization of cultivars (van Hintum & Elings 1991). Moreover, especially HMW glutenins in wheat are closely associated with differences in grain quality (Manley *et al*. 1992).

MATERIAL AND METHODS

Landraces and some cultivars of emmer (22 accessions of *Triticum dicoccon*), einkorn (10 accessions of *Triticum monococcum*), and spelt (10 accessions of *Triticum spelta*) were studied for 13 morphological and agronomic characters in two years' field trials (2003, 2004) using 2 m^2 plots. Two modern spring bread wheat cvs. Sandra and Munk (*Triticum aestivum*) were used as check cultivars. Characteristics of spike and harvest index (HI) were measured on 30 stems from each cultivar randomly sampled before harvest. In emmer and spelt wheat also HMW-*Glu* alleles were identified and frequencies of the particular alleles were compared to those in the set of previously analyzed 120 winter wheat landraces and obsolete cultivars (*T. aestivum*). HMW-*Glu* patterns were characterized in 100 randomly sampled grains from each cultivar by means of standard SDS-PAGE technique for wheat. Glutenin patterns were evaluated by means of densitometry (Image Master DTS); classification by Payne and Lavrence (1983) was implemented for identification of HMW-*Glu* alleles.

RESULTS AND DISCUSSION

Among 22 tested accessions of emmer wheat (Table 1), only 6 can be considered as selected materials, the rest were landraces. The plant height was rather variable (88–135 cm), mean value (107 cm) reached 137% of that in check cultivars. However, short stem was not always linked to lodging resistance (e.g. some short-stem cvs. of 93–98 cm) were more susceptible to lodging than those accessions of 115 cm and more. Lower diversity in plant height as well as lodging resistance was found in einkorn (shorter stem of 71–88 cm by mean value 73 cm, good lodging resistance). Spelt had the longest stem (mean plant height 115 cm ranging from 108 to 123 cm) but better lodging resistance (mean value 7.7) than in emmer. Nevertheless, even in emmer wheat the accessions with acceptable resistance to lodging rated 8 could be found.

Among spring wheat, emmer was late in flowering (by 1–16 days to bread wheat, mean of cvs. was 9 days) and also in maturity (up to 17 days, mean difference was 6 days). Relatively late maturity of emmer is mentioned also by D'Antuono *et al*. (1998). Emmer was even later than einkorn (in average by 13 days in flowering and 8 days in maturity when compared to bread wheat). Nevertheless, some emmer wheat accessions (Krajova from Horny Tisovnik; Bajonettfoermiger begrante emmer; Poering Jarma; Khapli; *T. dicoccon*, Brno) matured as early as spring bread wheat (91 to 93 days). Among einkorn, cv. Escana was the earliest to mature (93 days). Winter spelt was relatively late-maturing compared to winter wheat.

Resistance to powdery mildew was good in most of the einkorn accessions evaluated (rating 7–8); the rating in other species rating did not exceed 6 (except for a few emmer cultivars,a landrace from Tabor, and sample No. 8910).

Short spikes were typical for einkorn (mean value = 5.5 cm), whereas long spikes were typical for spelt (mean = 12.0 cm). However, the numbers of spikelets per spike were not linked to the spike length and mean values of this character were higher in emmer (21) and einkorn (22) than in spelt (19) and bread wheat (19).

The highest spike productivity has been found in spelt (mean grain weight per spike was 1.59 g, that is by 22.3% more than in bread wheat cvs.); spelt cvs. Franckenkorn and Oberkulmer Rotkorn proved the highest grain mass per spike (1.91 g and 1.94 g, respectively). This high spike productivity in spelt was determined mainly by very high weight of 1000 grains (TGW, mean value was 49 g), whereas number of grains per spikelet (mean value = 1.7) and per spike (mean value = 33) were relatively lower. There were also found distinctive

Table 1. Values of measured characters in emmer (22), einkorn (10) and spelt (10) wheat cultivars and two check cultivars of common wheat

Cultivar/population	Lod ging	Plant height (cm)	Days to flowe ring	Days to maturity	Powdery mildew	Spike length (cm)	Spikelets per spike	Grains per spike	Grains in spikelet	Grain mass per spike (g)	TGW (g)	HI	% of glumes
Sandra (*T. aestivum*) – CZE CHECK	9	78	58	91	5	9	19	42	2.2	1.36	33	0.50	
Munk (*T. aestivum*) – CZE CHECK	9	78	62	93	6	9	18	40	2.2	1.21	30	0.46	
Mean value (bred wheat)	9.0	78	60	92	5.5	9.0	19	41	2.2	1.30	32	**0.48**	
Krajova-Horny Tisovnik (Malov, CZE)	6	93	67	92	6	6	18	19	1.0	0.56	30	0.40	19
T. dicoccon (Ruzyne, CZE)	8	110	70	101	6	8	23	30	1.3	0.95	32	0.39	23
T. dicoccon (Szeged, HUN)	7	108	72	101	6	8	24	33	1.3	0.97	29	0.38	25
T. dicoccon (Kew)	7	100	70	96	3	7	21	29	1.4	1.02	35	0.38	25
Khapli (Indie)	8	110	61	93	4	8	15	26	1.7	1.17	46	0.39	18
T. dicoccon (Tapioszele, HUN)	4	95	65	94	6	6	18	20	1.1	0.59	29	0.46	24
T. dicoccon (Tapioszele, HUN)	8	118	71	100	7	9	23	28	1.2	0.90	32	0.26	28
T. dicoccon (Tapioszele, HUN)	8	105	73	102	6	8	23	26	1.2	0.84	32	0.33	30
Mestnaja (Gruzie) (GEO)	8	100	69	100	5	5	17	16	0.9	0.48	30	0.33	31
T. dicoccon (Kromeriz)	7	115	76	107	4	11	23	27	1.2	0.77	29	0.22	44
Bajonettfoermiger begr. Emmer (SWE)	6	103	62	93	3	7	20	27	1.4	1.26	46	0.37	27
Kahler Emmer (GER)	8	108	73	100	6	8	23	30	1.3	0.96	32	0.38	22
May-Emmer (CHE)	7	118	71	99	6	8	22	25	1.2	0.74	29	0.30	28
Weisser Sommer (GER)	7	118	73	100	6	8	23	28	1.3	0.83	29	0.36	26
Poering Jaarma (Nachitchevan, AZE)	4	98	61	91	6	6	16	20	1.3	0.73	37	0.41	23
T. dicoccon (CZE)	7	120	71	99	6	8	23	30	1.3	0.93	30	0.34	26
T. dicoccon (Sort. Schiemann, DEU)	3	135	81	109	4	11	26	33	1.3	1.47	44	0.30	24
T. dicoccon (Dagestan, RUS)	5	103	64	94	6	7	17	24	1.4	0.96	40	0.43	18
T. dicoccon (Brno, CZE)	6	95	66	93	6	6	17	18	1.1	0.56	31	0.45	23
T. dicoccon (Schlanstedt, DEU)	7	88	65	95	6	6	20	21	1.1	0.68	32	0.41	21
T. dicoccum (Tabor, CZE)	7	105	75	102	7	7	22	28	1.2	0.82	30	0.38	21
T. dicoccum No. 8909 (Unknown)	8	110	72	97	7	8	24	29	1.2	0.79	27	0.34	28
Mean value (Emmer)	6.6	107	69	98	5.6	7.5	21	26	1.2	0.86	33	0.36	**25**

Cultivar/population	Lod ging	Plant height (cm)	Days to flowe ring	Days to maturity	Powdery mildew	Spike length (cm)	Spikelets per spike	Grains per spike	Grains in spikelet	Grain mass per spike (g)	TGW (g)	HI	% of glumes
Escana (*T. monococcum*) (ESP)	9	88	67	93	8	6	21	19	0.9	0.49	25	0.36	29
T. monococcum (GEO)	8	85	73	98	7	6	25	16	0.6	0.34	20	0.32	27
T. monococcum (ALB)	7	85	73	98	7	5	19	14	0.7	0.34	24	0.32	29
T. monococcum (ARM)	9	80	70	100	8	6	21	15	0.8	0.36	23	0.31	29
T. monococcum (Klein Asien)	9	78	68	95	7	5	20	16	0.8	0.39	24	0.39	26
T. monococcum (ALB)	8	88	71	98	7	6	21	17	0.8	0.40	23	0.33	29
Schwedisches Einkorn (SWE)	9	68	77	106	8	5	21	15	0.7	0.30	19	0.31	29
T. monococcum (GEO)	8	93	73	98	7	5	22	15	0.7	0.30	20	0.28	27
T. monococcum (Tabor, CZE)	9	100	81	109	7	6	24	18	0.8	0.42	23	0.29	30
T. monococcum No.8910 (GEO)	9	88	77	100	8	5	22	16	0.7	0.30	19	0.31	27
Mean value (Eincorn)	9.0	85	73	100	7.4	5.5	22	16	0.8	0.36	22	0.32	**28**
T. spelta (Kromeriz, CZE)	7	110	163	199	6	11	18	26	1.4	1.13	43	0.40	22
Fuggers Babenhauser Zuchtw.(DEU)	8	123	161	198	4	12	19	35	1.9	1.68	48	0.37	27
T. spelta (Uhrineves, CZE)	6	110	164	198	3	11	18	30	1.7	1.08	36	0.38	25
Baulaender Spelz (DEU)	7	113	163	199	5	11	18	28	1.6	1.32	48	0.40	24
Ostro (CHE)	8	118	163	203	4	13	19	29	1.6	1.67	57	0.35	29
Altgold (CHE)	8	115	162	199	3	11	20	30	1.6	1.61	54	0.38	27
Oberkulmer Rotkorn (CHE)	8	123	164	202	4	13	20	35	1.8	1.94	55	0.36	31
Redoute (BEL)	9	113	166	200	4	14	21	35	1.6	1.75	51	0.36	31
Rubiota (CZE)	8	120	161	198	3	13	19	38	2.0	1.85	48	0.37	27
Franckenkorn (DEU)	8	108	163	198	4	11	19	41	2.2	1.91	47	0.40	25
Mean value (Spelt wheat)	7.7	115	163	199	4.0	12.0	19	33	1.7	1.59	49	0.38	**27**

Table 2. Diversity of HMW-*Glu* alleles in landraces and cultivars of spelt (*Triticum spelta*) and emmer (*Triticum dicoccon*) when compared to European winter wheat (*Triticum aestivum*) landraces and obsolete cultivars

Chromosome	Alleles	*T. aestivum*		*T. spelta*		*T. dicoccum*	
		n	%	*n*	%	*n*	%
	0	100	44.6	3	17,6	6	9.1
1A	1	109	48.7	14	82,4	36	54.5
	2*	15	6.7			24	36.6
	6+8	36	16.1	13	76.5	12	18.2
	7+8	51	22.3			27	40.9
	7+9	88	39.7				
	6	2	0.9				
	7	7	3.1			2	3.0
	8	1	0.4				
	9	3	1.3				
1B	20	27	12.1				
	13+16	4	1.8			2	3.0
	17+18	5	2.2	1	5.9		
	21					14	21.2
	14+15			3	17.6	3	4.5
	6,7					2	3.0
	22					2	3.0
	0					2	3.0
	2+12	142	63	12	71		
1D	3+12	8	4		0		
	5+10	74	33	5	29		
Number of cultivars		123		10		36	
Number of identified *Glu*-lines		224		17		66	
Mean number of *Glu*-lines per cultivar		1,82		1.70		1.83	

characteristics in spike productivity between two local landraces (from Kroměříž and from Uhříněves) and other bred spelt cvs. Landrace from Uhříněves had the lowest TGW (36 g) and consequently also poor spike productivity (1.08 g). Extensive diversity of productivity characters in spelt referred also Porfiri *et al*. (1998).

Much lower spike productivity (mean grain mass per spike = 0.86 g, that is only 66.2% of that in check cvs.) was found in emmer. Nevetheless, some emmer cultivars had much higher values (Khapli 1.17 g, Bajonettfoermiger begr. emmer 1.26 g, and *T. dicoccum*-Sort Schiemann 1.47 g). The three best landraces provided grain mass per spike only about 1 g. Lower spike productivity was mainly due to the low mean number of grains per spikelet (1.2) and per spike (26) when TGW fluctuated in wide range 29–46 g (cv. Khapli) and its mean value was similar as in bread wheat. Lower spike productivity than in spring wheat was due to the lower number of grains per spike and per spikelet; it reflects also in low harvest index (HI = 0.26–0.46, mean value 0.36). Similar results for emmer were published by Pisante *et al.* (1996). These results indicate that research and breeding of emmer could bring promising results.

Very low spike productivity in einkorn (mean = 0.36 g per spike, that is only 27.7% of grain mass per spike in bread wheat) results from relatively low values of all spike productivity characters. Also very low harvest index provides evidence on extensive character of einkorn. On the other hand einkorn can be utilized as donor of other valuable characters (e.g. resistance to powdery mildew, grain quality).

Share of glumes on the grain mass was rather variable in emmer (18–44%) and more constant in spelt (22–31%) and einkorn (26–30%). Emmer wheat cultivars with low share of glumes were (18–19%) were Khapli, *T. dicoccoides* – Brno and Krajova – Horny Tisovnik.

Spelt wheat and especially emmer wheat showed also significant diversity in HMW-*Glu* alleles and some characteristic differences to bread wheat were ascertained (Table 2). At 1 A chromosome allele 1 was the most common in all examined species and occurred in 48.7% isolated *Glu*-lines of bread wheat, 82.4% *Glu*-lines of spelt and 54.5% *Glu*-lines of emmer wheat, respectively. The absence of HMW-*Glu* subunit (0) in this locus was common in bread wheat (45.5%) and relatively seldom in spelt (17.6%) and especially in emmer (9.1%). Allele 2* was rare in bread wheat (6.7% isolated lines), much more frequent in emmer (36.6%) and quite missing in the examined spelt cultivars.

Similarly, only three allelic combinations were identified at 1D, when allelic combination 2 + 12 was the most common in bread wheat (63% *Glu*-lines) and especially in spelt (71.0%), followed by 5 + 10 combination which has about half frequency of incidence in bread wheat (33%) and slightly lower in spelt (29%). Allelic combination 3 + 12 was observed only in 5 bread wheat cultivars (3.6%).

Much more diversity has been recorded at 1B chromosome in bread wheat (10 different alleles and/or their combinations) and in emmer (9 alleles and/or their combinations) whereas only three patterns could be identified in spelt. The only allelic combination 6 + 8 occurring relatively frequently in the all three species (16.1% in bread wheat, 18.2% in emmer) is dominant in spelt (76.5%). Allelic combination 14 + 15 was rather frequent in spelt (17.6%); it occurred rarely in emmer (4.5%) and was not found in bread wheat. Combination of *Glu*-alleles 7 + 8 was the most common in emmer, it was followed by allele 21 which was identified exclusively in this species, similarly as rare allele 22 (3.0%). Also alleles 6, 7 and combination 13 + 16 were rare (up to 3%) and did not occur in spelt.

CONCLUSIONS

Considerable diversity of morphological and agronomical characters has been found in einkorn and emmer; lower diversity was found within spelt cultivars. It seems that research and breeding, especially in emmer, could bring significant progress in genetic improvement of these crops. Specific differences in HMW-*Glu* subunits' composition among examined species as well as differences to common wheat were found, too.

Acknowledgement: The research has been carried out in the framework of the Grant 521/03/1201 of the Czech Grant Agency.

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