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SPIKE PRODUCTIVITY IN RELATION TO YIELD AS A CRITERION FOR EMMER WHEAT BREEDING

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ABSTRACT

Landraces, which are unbred cereal species, and include in particular the tetraploid emmer wheat, have become an important focus for the activities of local or organic farmers, processors and consumers of organic products. This study is based on analyses of the spike productivity, harvest index and grain yield of six emmer wheat landraces. It aims to find suitable criteria for the selection of cultivars and varieties which may contribute to the increase in the productivity of the emmer wheat. The cultivars and varieties most commonly used have short dense spikes which have a negative effect on the grain yield, as the spike density is negatively correlated with the weight of thousand grains (TGW), the weight of the grains in the spikes, the number of grains in spikelets and the proportion of hulls to the weight of the grains. Therefore, the selection of cultivars and varieties should focus on material having long lax spikes, and a high TGW, both of which would have a positive effect on the harvest index.

Key words: emmer, low-input and organic farming, spike productivity.

INTRODUCTION

Although older wheat genetic resources do not usually achieve the productivity of modern bred cultivars (Ehdaie et al., 1988; Ehdaie et al., 1991), they are becoming more interesting to functional food producers (Dotlačil, 2002). Such crops are less demanding and more adaptable to less favourable environmental conditions (Dengcai et al., 2003; Kotschi, 2006) and are therefore, suitable for low-input farming systems. They provide a lower but more stable yield, when grown in marginal areas (Collins and Hawtin, 1999).

The tetraploid emmer wheat - *Triticum dicoccum* (Schrank) Schuebl - is one of the crops considered suitable for low-input and organic farming systems. It is one of the hulled wheat species which have been grown and used as a part of the human diet for a very long time (Marconi and Cubadda, 2005). It has been domesticated more than once (Brown, 1999). It originates from the Levant region where its wild predecessor [*Triticum dicoccoides* (Koern. ex Aschers. et. Graeb.) Schweinf.] may still be found (Dotlačil, 2002). Nowdays, it is grown in extreme montane conditions in the Pyrenees and Alps (Bareš et al., 2002), Italy, Spain, and partly in the Balkans, Turkey, Caucasus, India and Ethiopia (Reddy et al., 1998). As people are paying more attention to the diversity and good quality of food products, they have become more interested in this cereal species (Hammer and Perinno, 1995; Olsen, 1998; Nielsen and Mortensen, 1998). Countries with intensive well-developed farming methods are likely to be more interested in this wheat species, whereas the total surface of emmer wheat has been reducing in those developing countries characterised also by a developing farming sector (Marconi and Cubadda, 2005). It plays an important role in the organic farming system, where it may develop potential as a less demanding crop, able to serve as a source of economic profit and material for high quality food products (Konvalina et al., 2008). Emmer wheat has never been bred; only landraces and the wild form of the emmer wheat are available at the moment.

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The emmer wheat landraces have a number of advantages which assure them an important place in the interest of farmers and consumers: they are resistant (tolerant) to drought (Davood et al., 2004); the root system is able to better absorb nitrogen (Trčková et al., 2005); the genetic resources of the wild emmer wheat may be used as a source of mycorrhizal dependency in wheat breeding (Yücel et al., 2009), and their resistance (tolerance) to wheat diseases is also often mentioned (Herrera-Foessel et al., 2005; Oliver et al., 2007). The emmer wheat is a suitable alternative crop to the durum wheat, which has similar characteristics and are also suitable for low-input farming systems (Akçura, 2009).

This paper presents the results of a study of emmer wheat genetic resources grown in low input, practically not certified organic farming conditions. It aims to emphasize the advantages of this unbred cereal species, to find the weaknesses of the emmer wheat varieties connected with yield formation and yield level, and to propose criteria for selection, based on the relation between the spike productivity and yield.

MATERIAL AND METHODS

Studied varieties

The genetic resources of emmer wheat and modern control bread wheat seeds (Table 1) were provided by the Research Institute of Plant Production in Prague-Ruzyne (Prague). Exact small-parcel experiments were established at two localities (in 2007-2008): Prague (research area of gene bank) and in České Budějovice (research area of University of South Bohemia).

Table 1. List of the genetic resources/cultivars

Identificator	Taxonomic code	Name	Origin	Botanical variety
Triticum dicoccum (Schrank) Schuebl				
01C0200117	412064	Horny Tisovnik (D1)	CZ	var. *rufum* Schuebl
01C0200947	412048	Ruzyne (D2)	-	var. *rufum* Schuebl
01C0201262	412051	Tapioszele 1 (D3)	-	var. *serbicum* A. Schulz
01C0201282	412017	Tapioszele 2 (D4)	-	var. *rufum* Schuebl
01C0203989	412013	Kahler Emmer (D7)	D	var. *dicoccum*
01C0204501	412013	No. 8909 (D10)	-	var. *dicoccum*
Triticum aestivum L.				
01C0204800	635090	Vánek (M6)	D	var. *lutescens* Mansf.
01C0204877	635000	SW Kadrilj (M10)	S	var. *lutescens* Mansf.

The soil and climatic characteristics

Station 1: Prague - at an altitude of 340 metres above sea level; with mean annual temperature of 7.9°C; and a mean annual precipitation rate of 472 mm. The proportion of mineral nitrogen was sufficient (1.8 mg.kg^{-1}N-NH$_4$ and 22.0 mg.kg^{-1}N-NO$_3$), phosphorus (77 mg.kg^{-1}) and magnesium (152 mg.kg^{-1}) in the soil were satisfactory; pH was alkaline (7.3), and the proportion of potassium was good (191 mg.kg^{-1}). Station 2: JU ZF in České Budějovice (CB), altitude of 388 metres above the sea level; mean annual temperature of 8.2°C, and mean annual precipitation rate of 620 mm. The proportion of mineral nitrogen was low (2.3 mg.kg^{-1}N-NH$_4$ and 10.2 mg.kg^{-1} N-NO$_3$), the pH was slightly acidic (6.3), and the proportions of phosphorus (108 mg.kg^{-1}), magnesium (138 mg.kg^{-1}) and potassium (125 mg.kg^{-1}) were satisfactory. The temperature variation was characterised by an increased mean annual temperature and mean temperature in the growing season. A dry spring in 2007 caused a serious reduction in the field emergence.

Evaluation of experiments

Samples (30 plants) were taken from each plot before the harvest and were analysed according to the methodology developed by Konvalina et al. (2008). The following characteristics were examined: spike length, spike density, TGW, number of grains in spike, number of spikelets in spike, number of grains in spikelet, proportion of grains in hulled spike and harvest index. The yield was recalculated to a humidity of 14%.

Statistical data processing

The statistical data processing was carried out by the basic analysis and analysis of variance, including the assessment of effect of each factor (ANOVA), with the Statistica 9.1 program. The regression and correlation analyses were also applied (for the assessment of interdependence). The homogenous groups of cultivars were evaluated by the LSD test.

RESULTS

The emmer wheat had short spikes (4.61-5.78 cm), less variable than those of the modern control cultivars' (7.04-7.30 cm) (Table 2). The emmer wheat cultivars compensated for their short spikes by the density of their spikes; the spikes were by one third denser than those of the control common wheat cultivars (28.00-30.75 spikelets 10 cm^{-1} spike's length).

Table 2. Mean values of the evaluated characteristics and statistically homogenous groups of cultivars (LSD test)

Cultivar	Spike's length (cm)	Spike's density (pc.10cm^{-1})	TGW (g)	Weight of grain in spike (g)	Number of grains in spike
D1	4.6±0.32b	28.8±1.04ab	33.6±2.67b	0.6±0.09b	17.8±1.91c
D2	5.3±0.31a	29.0±1.41abc	29.6±5.28a	0.8±0.22ac	25.1±4.61b
D3	4.9±0.30b	28.0±1.07a	32.7±1.53ab	0.7±0.12bc	19.3±2.19c
D4	5.3±0.37a	30.0±1.31cd	31.6±1.47ab	0.8±0.08a	26.6±2.01ab
D7	5.8±0.25c	29.5±1.20bc	30.8±2.80ab	0.8±0.17a	26.9±4.16ab
D10	5.4±0.21ac	30.8±0.71d	30.7±3.85ab	0.9±0.13a	29.0±3.24a
M6	7.3±0.60d	20.9±0.99e	44.1±5.02d	1.3±0.15d	28.6±3.10a
M10	7.0±0.57d	22.6±0.74f	40.7±2.15c	1.1± 0.11d	28.0±2.69ab

Cultivar	Number of spikelets in spike	Number of grains in spikelet	Share of grains to hulls (%)	Harvest index	Yield ($t.ha^{-1}$)
D1	11.0±1.06d	1.6±0.14a	78.8±3.66c	0.35±0.04c	3.24±1.30ab
D2	15.3±1.64ab	1.6±0.15a	72.6±4.87a	0.29±0.07ab	2.06±1.05a
D3	11.8±1.17d	1.6±0.09a	78.3±2.61c	0.38±0.02c	3.20±1.16ab
D4	15.5±1.27ac	1.7±0.08a	73.5±4.11ab	0.29±0.03a	2.69±1.44ab
D7	15.8±1.68ac	1.7±0.12a	74.1±4.12ab	0.31±0.04ab	2.52±1.45a
D10	16.7±1.48c	1.7±0.09a	76.1±2.30bc	0.34±0.06bc	2.83±1.54ab
M6	14.0±0.94b	2.0±0.20b	-	0.45±0.03d	4.30±2.53b
M10	14.5±0.62ab	1.9±0.19b	-	0.46±0.03d	4.40±2.62b

Difference between values followed by the same letter are not statistically significant at $p < 0.05$

The emmer wheat cultivars and the control cultivars could be divided into a number homogenous groups according to their similarity in respect of the two characteristics studied and evaluated. The emmer wheat spike length was statistically and obviously ($p < 0.01$) influenced by the cultivar (43.4%), whereas the emmer wheat spike's density was mostly influenced by the locality (59.7%) (Table 3).

The TGW of the emmer wheat cultivars was by one third lower (29.59-33.55 g) than that of the control cultivars (Table 2) and it was positively correlated (r = 0.76) to the weight of grain in the spike (Table 5). The TGW was influenced by all the factors studied and evaluated (cultivar, locality, year) ($p < 0.05$) and the interaction of the factors (Table 3). The weight of grain in the spike of the emmer wheat cultivar was lower (0.60-0.86 g) than that of the control cultivars (1.14-1.26 g).

The number of grains and spikelets in the spikes of the emmer wheat cultivars was variable and statistically and obviously ($p < 0.01$) influenced by the cultivar (48.8%, resp. 60.6%) (Table 3). The number of grains in the spikes of Tapioszele 2, Kahler Emmer and No.8909 cultivars belong to the same homogenous group (p = 0.05) as the control cultivars (Table 2).

The cultivars were also divided into homogenous groups according to the number of spikelets in the spikes (Ruzyne and Vanek, SW Kadrilj resp. Tapioszele 2, Kahler Emmer and SW Kadrilj). Two of the studied characteristics form a high positive correlation one to each other (r = 0.84) (Table 5).

The number of grains in the emmer wheat two-flower spikelets was 1.63 to 1.72, being less variable than in the control cultivars (Vanek and SW Kadrilj), where the number of grains in the spikelets was highly influenced by the locality (29.7%) and year (56.7%) (Table 2).

The share of grains to hulls varied between 72.63% and 78.75% in the case of the emmer wheat landraces. The cultivars are divided into three groups ($p < 0.05$): the influence of a factor achieves 21.7%. The locality (in particular the nutritive value of the soil) had the most important effect on the proportion of grain (43.7%), which showed a positive correlation ($p < 0.05$) to the spike's length (0.80), TGW (0.83) and the weight of grain in the spike (0.71). On the other hand, it was strongly negatively correlated to the spike density (r = -0.90).

Table 3. Influence of factors (cultivar, locality, year) on the spike productivity parameters by ANOVA

Species	Factor	DF	Spike's length		Spike's density		TGW		Grain weight in spike		No grains in spike	
			MS	% TV	MS	% TV	MS	% TV	MS	% TV	MS	% TV
Emmer wheat (six cultivars)	cultivar (1)	5	1.34**	43.4	7.53**	21.1	16.83*	10.1	0.08**	16.7	162.47**	48.8
	locality (2)	1	0.44**	14.2	21.33**	59.7	42.94*	25.7	0.34**	70.8	124.81**	37.5
	year (3)	1	0.80**	25.9	0.08ns	0.2	36.75*	22.0	0.00**	0.0	1.47ns	0.4
	1 x 2	5	0.22**	7.1	1.93**	5.4	13.06ns	7.8	0.02ns	4.2	7.63ns	2.3
	1 x 3	5	0.08*	2.6	1.88**	5.3	16.51*	9.9	0.02ns	4.2	23.02**	6.9
	2 x 3	1	0.10**	3.2	2.08*	5.8	26.11*	15.6	0.00ns	0.0	2.71ns	0.8
	1 x 2 x 3	5	0.09**	2.9	0.48ns	1.3	9.30*	5.6	0.01ns	2.1	5.68ns	1.7
	Error	24	0.02	0.6	0.42	1.2	5.63	3.4	0.01	2.1	4.99	1.5
Control cultivars of common wheat (two cultivars)	cultivar (1)	1	0.28*	5.8	12.25**	72.6	46.24**	19.9	0.06ns	31.6	1.38ns	1.6
	locality (2)	1	0.14ns	2.9	1.00ns	5.9	28.09*	12.1	0.04ns	21.1	58.91**	67.5
	year (3)	1	1.16**	23.9	0.25ns	1.5	90.25**	38.8	0.01ns	5.3	13.51ns	15.5
	1 x 2	1	0.03ns	0.6	0.25ns	1.5	2.25ns	1.0	0.00ns	0.0	3.33ns	3.8
	1 x 3	1	0.77**	15.9	1.00ns	5.9	60.84**	26.1	0.06ns	31.6	0.77ns	0.9
	2 x 3	1	1.50**	30.9	0.25ns	1.5	1.69ns	0.7	0.00ns	0.0	0.08ns	0.1
	1 x 2 x 3	1	0.95**	19.6	1.00ns	5.9	0.25ns	0.1	0.00ns	0.0	4.73ns	5.4
	Error	8	0.023	0.5	0.88	5.2	3.18	1.4	0.02ns	10.5	4.58ns	5.2

* = statistically significant $p < 0.05$; ** = statistically significant $p < 0.01$; ns = statistically not significant.

The emmer wheat cultivars' harvest index was lower than that of the control cultivar. The cultivars studied are divided into four homogenous groups according to the LSD test results ($p < 0.05$) (Table 2): Tapioszele 2 (0.29), Horny Tisovnik (0.35) and Tapioszele 1 (0.38) belong to separate groups; the control cultivars Vanek (0.45) and SW Kadrilj (0.46) belong to the same group. The harvest index of each group was influenced by the year (in emmer wheat cultivars - 71.7%; in common wheat cultivars - 77.4%). The higher harvest index level was connected with the higher grain proportion in hulled spikelets ($r = 0.78$) (Table 5) and had a negative correlation with spike density ($r = -0.71$).

The yield level of emmer wheat landraces was lower (2.06-3.24 $t.ha^{-1}$) than that of the control cultivars (4.30-4.40 $t.ha^{-1}$). The LSD test results show that the emmer wheat cultivars (a - Ruzyne and Kahler Emmer) are divided into different homogenous groups according to the influence of cultivar, locality and year factors, the same as the control cultivars (b). Four emmer wheat cultivars (Horny Tisovnik, Tapioszele 1, Tapioszele 2 and No. 8909) are represented in two homogenous groups (Table 2). The yield level was tested by analysis of variance (ANOVA); it is statistically influenced (at $p < 0.01$) by the year (emmer wheat - 71.7%; common wheat - 77.4%). The influence and interaction of the other factors was negligible.

The total grain yield of the emmer wheat cultivars showed a positive correlation to the proportion of grain ($r = 0.78$), TGW ($r = 0.71$) and spike's length ($r = 0.55$). The spike density was negatively correlated ($r = -0.71$) with grain yield (Table 5).

Table 4. Influence of factors (cultivar, locality, year) on the spike productivity's parameters, harvest index and yield by ANOVA

Species	Factor	DF	Number of spikelets in spike		Number of grains in spikelet		Share of grains to hulls		Harvest index		Yield	
			MS	% TV	MS	% TV	MS	% TV	MS	% TV	MS	% TV
Emmer wheat (six cultivars)	cultivar (1)	5	44.22**	60.6	0.01ns	4.5	52.2**	21.7	1.56**	2.2	1.56**	2.2
	locality (2)	1	14.38**	19.7	0.10**	31.8	105.0**	43.7	11.55**	16.5	11.55**	16.5
	year (3)	1	0.36ns	0.5	0.05*	14.6	25.5ns	10.6	50.10**	71.7	50.10**	71.7
	1 x 2	5	1.75ns	2.4	0.01ns	3.3	21.7ns	9.0	0.17ns	0.2	0.17ns	0.2
	1 x 3	5	4.92**	6.7	0.02*	5.4	11.7ns	4.9	0.66**	0.9	0.66**	0.9
	2 x 3	1	3.81ns	5.2	0.12**	37.9	7.5ns	3.1	5.46**	7.8	5.46**	7.8
	1 x 2 x 3	5	2.23ns	3.1	0.00ns	0.6	6.7ns	2.8	0.29*	0.4	0.29*	0.4
	Error	24	1.26	1.7	0.01	2.0	10.1	4.2	0.08	0.1	0.08	0.1
Control cultivars of common wheat (two cultivars)	cultivar (1)	1	1.05ns	14.6	0.05*	9.1	-	-	0.00ns	6.5	0.04ns	0.0
	locality (2)	1	0.86ns	11.9	0.15**	29.7	-	-	0.00ns	9.7	35.64**	38.8
	year (3)	1	4.31*	59.7	0.29**	56.7	-	-	0.01**	77.4	55.02**	59.9
	1 x 2	1	0.11ns	1.5	0.01ns	1.3	-	-	0.00ns	0.7	0.19ns	0.2
	1 x 3	1	0.33ns	4.6	0.00ns	0.2	-	-	0.00ns	0.1	0.04ns	0.0
	2 x 3	1	0.03ns	0.4	0.00ns	0.3	-	-	0.00ns	0.7	0.70*	0.8
	1 x 2 x 3	1	0.14ns	2.0	0.01ns	0.9	-	-	0.00ns	2.0	0.02ns	0.0
	Error	8	0.39	5.4	0.01	1.7	-	-	0.00	2.8	0.13	0.1

* = statistically significant $p < 0.05$; ** = statistically significant $p < 0.01$; ns = statistically not significant.

Table 5. Correlation analysis of the evaluated characteristics (6 emmer wheat cultivars)

Characteristics		1	2	3	4	5	6	7	8	9	10
Spike's length	(1)	1.00									
Spike's density	(2)	-0.78**	1.00								
TGW	(3)	0.63**	-0.72**	1.00							
Weight of grain in spike	(4)	0.79**	-0.61**	0.76**	1.00						
No grains in spike	(5)	0.55**	-0.15ns	0.25**	0.77**	1.00					
No spikelets in spike	(6)	0.22ns	0.22ns	-0.08ns	0.45**	0.84**	1.00				
No grains in spikelet	(7)	0.71**	-0.59**	0.57**	0.75**	0.61**	0.10ns	1.00			
Share of grains to hulls	(8)	0.80**	-0.90**	0.83**	0.71**	0.26*	-0.14ns	0.68**	1.00		
Yield	(9)	0.16ns	-0.37**	0.57**	0.17ns	-0.15ns	-0.14ns	-0.09ns	0.41**	1.00	
Harvest index	(10)	0.55**	-0.71**	0.71**	0.56**	0.13ns	-0.21ns	0.53**	0.78**	0.38**	1.00

* = statistically significant p < 0.05; ** = statistically significant p < 0.01; ns = statistically not significant.

DISCUSSION

In relation to spike productivity, the emmer wheat cultivars are characterised by a lower number of grains in the spike and lower weight of spike than the modern common wheat cultivars (Konvalina, 2009). Their spikes are dense and short; the lower grain's weight in spike is partially compensated for by a higher number of productive stalks per area unit (Stehno et al., 2008). The positive correlation between the number of grains in the spike and the spike weight may contribute to an enhancement of spike productivity. The TGW is influenced by the interaction of the genotype and the environment (Petr, 1980). The TGW of the emmer wheat cultivar is lower than that of the modern common and durum wheat cultivar (Marconi and Cubadda, 2005); the common wheat TGW increased from 31-38 g to 42-47 g during the breeding process (Lekeš, 1997). An increase in TGW is desirable and favourable, as it is positively correlated to other spike productivity characteristics and to the total yield level.

The number of spikelets in the spike of the emmer wheat cultivar varied from 11.0 to 16.7, whereas the number of grains varied from 1.6 to 1.7 grains/two-flower spikelet. The number of spikelets in the spike of the control soft wheat cultivar was low; the same as the number of grains in the three-flower spikelet - SW Kadrilj (1.9) and Vanek (2.0). The spike productivity of modern cultivars was reduced, as it responded to the nutritive conditions of the plots (Krejčířová et al., 2006; Capouchová et al., 2008; Krejčířová et al., 2008). The station with more nutritive soil was characterised by a higher number of grains in the spikelets in the growing season, but a lower number of grains in spikelets in the post-flowering period. This is confirmed by Petr (1980). The emmer wheat landraces proved to be better able to express their yield potential in the low-input farming systems.

The emmer wheat cultivars had a relatively high harvest index level (0.29-0.38 on average), but not at the level of the bred common (Sehnalová, 1990) or durum (Marconi and Cubbada, 2005) wheat cultivars. The harvest index level of control cultivars (0.45, resp. 0.46) was reduced by the lack of nutrients in the period of grain filling (Baresel, 2006, in Wolfe et al., 2008) and a lower efficiency of root system (Trčková et al., 2005). Therefore, the emmer wheat could be a suitable crop for marginal areas and low-input farming systems (Castagna et al., 1996; Merezhko et al., 1997; Marconi and Cubadda, 2005).

CONCLUSIONS

The study and evaluation of the emmer wheat landraces identified possible ways of improvement in spike productivity in relation to yield level. The studied landraces had short dense spikes; this is important, as it is negatively correlated to the grain yield. An examination of the correlations shows that the more dense the spike is, the more the TGW, the weight of grain in spike, the number of grains in spikelet, and the share of grains to hulls are reduced. It also has an important effect on the reduction of the yield level. Therefore, the breeding of cultivars should focus on the selection of material having long lax spikes and a higher TGW.

The yield level was seriously reduced by a lower ability to use the assimilates for the growth of generative organs, which is reflected by the lower harvest index. Our research shows the selection of the cultivars having long lax spikes, high TGW, high weight of grain in spike and high number of grains in spike could have a positive effect on the harvest index level.

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