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Full Length Research Paper

Differences in yield parameters of emmer in comparison with old and new varieties of bread wheat

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Emmer wheat (*Triticum diccocum* Schrank) belonged to the most frequent species of cereals in the past. Nowadays, it is grown in arid and montane areas in particular. Interest in this cereal species has increased, as it is tolerant to biotic and abiotic stressing factors. Therefore, yield parameters were evaluated in three-year (2007, 2008 and 2010) trials that were carried out in two different localities in the Czech Republic. Results of the research were compared to characteristics of four old and two top modern bread wheat (*Triticum aestivum* L.) cultivars. The emmer wheat varieties were resistant to usual wheat diseases. They formed their yield by a quantity of productive tillers (2.5), whereas the varieties of bread wheat had less productive tillers (1.5) per one plant. The distribution of assimilates was worse in the emmer wheat plants and it provoked a lower harvest index (0.33) there. Grain yield of the emmer wheat varieties reached 58% of the yield level of the mean of control bread wheat varieties. High crude protein content in grain (17.91%) was an advantage of the emmer wheat varieties; the control bread wheat varieties reached 13.73%. Protein content was positively influenced (P < 0.01) by an ability of the emmer varieties to uptake as much nitrogen as possible from the soil during the flowering period. Adaptability to the land and climatic environmental conditions was another positive characteristic of the emmer wheat landraces in comparison with old and modern bread wheat varieties.

Key words: Emmer wheat, bread wheat, landraces, sustainable farming, yield formation.

INTRODUCTION

Wheat genetic resources are usually not as productive as modern bread cultivars (Ehdaie et al., 1991). However, they have become more interesting for farmers. These crops are less demanding and more adaptable to the environmental conditions (Kotschi, 2006). Tolerance to drought is one of the most important advantages of this cereal species (Zaharieva et al., 2010). It is an important aspect of the growing of such crop (Bucur et al., 2006, 2010). Therefore, they are suitable for low-input and organic farming systems. They provide lower but more stable yield levels, if being grown in less favoured areas for agriculture (Collins and Hawtin, 1999). In spite of a high quantity of available genetic resources, their use is still limited in a sustainable farming at the moment (Wolfe et al., 2008). The tetraploid emmer wheat cultivar, *Triticum dicoccum* (SCHRANK) SCHUEBL, is one of the model crops suitable for low-input and organic farming systems. It belongs to the hulled wheat cultivars and has been grown and used as a part of the human diet for a very long time (Marconi and Cubadda, 2005).

Nowadays, it is grown in some extreme montane conditions in Europe and Africa (Reddy et al., 1998). As the requirements for diversity and quality of food products have increased in the last few years, this wheat species has also become more interesting for farmers (Hammer and Perinno, 1995). It has gained a steady place in the

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Table 1. List of used varieties.

ECN[1]	BCHAR[2]	Name	Origin	Variety	R[3]
***Triticum dicoccum* (SCHRANK) SCHUEBL**					
01C0200117	412064	Horny Tisovnik	CZ	var. *rufum* SCHUEBL	-
01C0200947	412048	Ruzyne	-	var. *rufum* SCHUEBL	-
01C0201262	412051	Tapioszele 1	-	**var. *serbicum* A. SCHULZ**	**-**
01C0201282	412017	Tapioszele 2	-	var. *rufum* SCHUEBL	-
01C0203989	412013	Kahler Emmer	D	var. *dicoccum*	-
01C0204501	412013	No. 8909	-	var. *dicoccum*	-
Land races of *Triticum aestivum* L.					
01C0204158	635100	Kundan	IND	var. *meridionale* MANSF.	-
01C0200051	635104	Rosamova přesívka	CZ	*milturum* (ALEF.) MANSF.	1917
01C0200008	635090	Praga	CZ	*lutescens* (ALEF.) MANSF.	1968
01C0200100	635090	Jara	CZ	*lutescens* (ALEF.) MANSF.	1975
Control varieties of *Triticum aestivum* L.					
01C0204800	635090	Vanek	D	var. *lutescens* MANSF.	2005
01C0204877	635000	SW Kadrilj	S	var. *lutescens* MANSF.	2006

Remarks: [1] ECN = identifier; [2] BCHAR = taxonomical code; - = unknown; [3]registration.

organic farming system, where it may develop its potential as a less demanding crop. As it contains a high quantity of protein in grains, it may be used for the production of good-quality healthy local foodstuffs (Marconi and Cubadda, 2005). Emmer wheat has never been bred. Nowadays, only landraces and wild forms are available and are being grown. Several studies dealing with opportunities for growing emmer wheat have been published in the last few years. All of them have led to common conclusions and results; however, they have not answered all of the questions concerning the opportunities for growing and using the emmer wheat landraces in sustainable farming systems.

The yield level, indicated in particular literary sources, is lower compared to the bread or hard wheat cultivars (Marconi and Cubadda, 2005). Most of the emmer wheat landraces ripen later than the hard wheat cultivars (D´Antuono et al., 1998). Morphology of the spike is characterised by an inclination of the spike to breaking during the harvest. Some published studies (Stehno and Manev, 1999; Troccoli and Codianni, 2005) show that the plants are more than 100 cm long in average. Stallknecht et al. (1996) state that after selection of productive genotypes from genetic resources, the yield rate could be 48 to 84% of the spring bread wheat yield rate at the arid station. Some literary sources cite a comparable production rate of the emmer wheat landraces grown in conditions that are not suitable for the growing of bread wheat. The emmer wheat grains are much better quality (Marconi and Cubadda, 2005).

The objective of our study was to analyse the possibility and opportunity of using emmer wheat as an alternative crop in sustainable farming systems. In this paper, we reported the results of the analysis of the selected agronomically important traits in comparison with emmer wheat landraces, old and modern bread wheat varieties.

MATERIALS AND METHODS

Tested varieties come from the Gene Bank of the Research Institute of Crop Production in Prague (Prague). Six genetic resources of emmer wheat (*T. dicoccum* Schrank) were chosen. Four old varieties of bread wheat and two top bread wheat (*Triticum aestivum* L.) modern cultivars, Vanek (German origin) and SW Kadrilj (Swedish origin), were used as control cultivars there (Table 1). Varieties were sown in a randomized, complete block design on experimental parcels in Prague and České Budějovice (CB) during 2007, 2008 and 2010. The seeding rate was adjusted to a density of 350 germinable grains per m^2. Rows were 125 mm wide. Both of the years 2007 and 2008 were characterised higher than the usual mean temperatures in the growing season (Table 2). 2007 was the warmest year, whereas there were slightly higher temperatures at the Prague station in 2008 (1°C in July, in comparison to the 1961 to 1990 longtime mean). 2007 was characterised by a precipitation deficit during emergence, which led to a serious reduction of the field germinable rate. 2008 had common climate conditions. 2010 was wetter and warmer in both localities (Table 2). The Prague station was characterised by an abundance of nitrogen during flowering, DC 69 (NH_4-N + NO_3-N = 22 mg/kg) and pH = 7.36. The České Budějovice station was meanwhile characterised by a deficiency of nitrogen (NH_4-N + NO_3-N = 12 mg/kg) and weakly acidic - pH = 6.41 (Table 3).

Yield characteristics

These have been based on the methodology of the evaluation of cultivars, which respects a different character of wheat ideotypes

Table 2. Temperature and precipitation characteristics of the experimental stations.

Year	Locality	Month 4	Month 5	Month 6	Month 7	Month 8	Year	Growing season[1]
		Temperature characteristics (℃)						
Longtime normal (1961 – 1990)	Prague	7.7	12.7	15.9	17.5	17.0	7.9	14.2
	CB	8.1	12.0	16.2	17.7	17.1	8.2	14.2
2007	Prague	11.7	15.1	18.6	18.7	18.3	9.9	16.5
	CB	11.8	15.2	19.6	19.7	18.4	10.2	16.9
2008	Prague	8.2	14.1	17.7	18.5	18.2	9.4	15.3
	CB	9.2	15.0	18.7	18.9	18.6	9.8	16.1
2010	Prague	9.0	11.8	17.2	20.9	17.7		15.3
	CB	9.1	13.0	17.6	20.9	18.1		15.7
		Precipitation characteristics (mm)						
Longtime normal (1961 – 1990)	Prague	38.2	77.2	72.7	66.2	69.6	525.9	323.9
	CB	46.5	70.1	93.0	77.8	78.8	582.8	366.2
2007	Prague	3.2	60.2	77.3	70.8	82.5	503.4	294.0
	CB	1.9	85.3	66.6	80.5	116.2	718.5	350.5
2008	Prague	56.8	54.9	66.0	73.7	67.8	492.1	319.2
	CB	55.7	108.8	78.4	66.2	60.0	469.3	369.1
2010	Prague	37.0	78.3	57.6	128.0	123.5		424.4
	CB	61.1	117.9	103.8	111.0	110.9		504.7

Remark: [1]Growing season – April to August.

Table 3. Agrochemical analysis of soil.

Locality	Year	N-NH_4 [mg.kg^{-1}]	N-NO_3 [mg.kg^{-1}]	pH ($CaCl_2$)	P[mg.kg^{-1}]	K [mg.kg^{-1}]	Mg [mg.kg^{-1}]	Ca [mg.kg^{-1}]
Prague	2007	2.31	23.32	7.30	78	210	148	4360
	2008	1.38	20.6	7.35	75.4	171	156	3211
	2010	4.64	12.15	7.43	109	380	183	5277
CB	2007	2.89	7.17	6.27	138	155	163	1557
	2008	1.75	13.3	6.30	77	94	112	1186
	2010	2.42	7.3	6.67	111	100	137	2027

Remarks: Proportion of mineral nitrogen (NH_4 + NO_3) 20 - 50 mg.kg^{-1} (optimum value of fertile arable land).

suitable for sustainable farming systems (Konvalina et al., 2010). The following traits were studied during the growing period: length of the plant (at the end of the flowering stadium – DC 69); the index of lodging (a combination of intensity and degree of lodging of the crop stand on each parcel, mean of two measurements (DC 59 and DC 87) (Van Waes, 2006); the degree of powdery mildew resistance (mean of measurements in growing stages DC 37, DC 61 and DC 77) and brown rust resistance (DC 77) were expressed by a score in accordance with symptoms of a disease on plants (9 = resistance).

A number of productive tillers (a sample of 10 plants at the end of the flowering stadium – DC 69) were evaluated: The nitrogen content in the plant fytomass during the flowering period (DC 69) was determined by an organic analyses of plants. The crude protein content in grain was analysed by the Kjeldahl method (ICC 105/2). Concerning the economic characteristics, the yield rate, crude

Table 4. Differences in selected agronomically important traits in different groups of varieties (mean + SD of three years, two localities).

Parameter	Group of varieties		
	Emmer landraces	Bread wheat	
		Old varieties	New varieties
Mildew resistance (0-9 = resistant)	9.00±0.00[a]	7.24±0.77[c]	8.03±0.89[b]
Rust resistance (0-9 = resistant)	9.00±0.00[a]	7.02±1.27[b]	7.33±1.01[b]
Plant length (cm)	114.65±16.08[a]	99.67±18.07[b]	89.42±13.14[c]
Index of lodging	6.65±1.95[b]	8.14±1.01[a]	8.81±0.45[a]
Number of tillers	2.48±0.87[a]	1.62±0.51[b]	1.52±0.49[b]
N content in plant (%)	1.54±0.31[a]	1.72±0.42[a]	1.77±0.55[a]
N content in grain (%)	17.91±2.26[a]	15.08±1.66[b]	13.73±1.22[c]
Yield ($t.ha^{-1}$)	2.92±1.14[c]	4.24±1.74[b]	5.02±2.29[a]
Grain/husks (%)	76.56±4.07[b]	100.00±0.00[a]	100.00±0.00[a]
Yield of dehulled grain ($t.ha^{-1}$)	2.25±0.89[c]	4.24±1.74[b]	5.02±2.29[a]
Yield of protein ($t.ha^{-1}$)	0.401±0.17[b]	0.629±0.24[a]	0.682±0.31[a]
Harvest index	0.33±0.05[c]	0.40±0.05[b]	0.46±0.03[a]
Thousand grain weight (g)	31.41±3.16[c]	39.55±7.51[b]	43.13±4.70[a]

Different letters are statistical differences between varieties for Tukey HSD test, $P < 0.05$.

protein yield per hectare = (crude protein content/100) x grain yield, harvest index (HI) and weight of one thousand grains (TGW), grain/husks ratio were analysed too.

Statistical data analysis

All statistical analyses were done using Statistica 9.0 software (StatSoft, Inc.). Instruments of basic statistics, an analysis of variance and the evaluation of a potential influence of individual factors (ANOVA) were applied there. The Tukey *HSD* test was used for division of the cultivars into statistically different groups.

RESULTS AND DISCUSSION

During the three year study the differences of yield formation between landraces of emmer [*T. diccocum* (Schrank) Schuebl] and old and modern varieties of bread wheat (*T. aestivum* L.) were analysed. From Table 4, it was evident that all the emmer wheat landraces were resistant to powdery mildew (*Blumeria graminis*) and brown rust (*Puccinia recondita*). On the other hand, all the bread wheat varieties were affected by the aforementioned diseases. If we carefully select resistant varieties of emmer from genetic resources, we may expect a minimum yield loss caused by common wheat diseases (Lammerts van Bueren, 2002). The emmer wheat landraces were also used as donors of resistance to wheat diseases in many breeding programmes (Herrera-Foessel et al., 2005).

The regulation of weeds is a serious problem connected with sustainable farming systems which aim to limit all chemical inputs (Wolfe et al., 2008). Therefore, the length of plants could be a positive factor as it assures a higher competitiveness to weeds (Cudney et al., 1991). All the tested emmer wheat varieties were 25 cm longer (higher) than the control varieties and 15 cm longer (higher) than the old bread wheat varieties (Table 4). On the other hand, some authors (e.g. Lammerts van Bueren, 2002) state the fact that the length of plants can be connected with a low resistance to lodging. This fact has not been confirmed by our tests as the longer material was less lodged than the shorter one. The lodging resistance is among others, influenced by the width of stalks (Stehno et al., 2010). The resistance to lodging is also a factor that influenced the total grain yield rate of all the tested varieties in the research (Table 5). The negative correlation was weaker in the emmer wheat landraces (r= -0.58) and stronger in control bread wheat varieties (r= -0.62).

The yield formation of emmer depends on a higher tillering capacity (2.48 tillers per plant) than for old (1.64 tillers per plant) and control (1.52 tillers per plant) bread wheat varieties (Table 4). Higher variability of tillering capacity has been noticed among the emmer wheat landraces (SD = 0.87). It was because of an individual reaction of each variety to the different conditions of each locality and year. The number of productive tillers did not have a statistically significant effect on the total yield rate (Table 5). We have also studied the ability to uptake nitrogen (expressed as the quantity of nitrogen in the plant fytomass during the flowering period) because the low-input farming system is usually characterised by a lower quantity of accessible nitrogen (Lammerts van Bueren, 2002). Bread wheat varieties had better and more efficient nutrient-management at the more fertile locality.

Table 5. Correlation coefficients between selected agronomically important traits.

Parameter	Emmer landraces			Bread wheat – old varieties			Bread wheat – control varieties		
	Protein content	Grain yield	Protein yield	Protein content	Grain yield	Protein yield	Protein content	Grain yield	Protein yield
Mildew resistance	-	-	-	-0.40^{ns}	-0.53*	-0.68**	-0.20^{ns}	-0.77*	-0.30^{ns}
Rust resistance	-	-	-	0.15^{ns}	0.02^{ns}	0.03^{ns}	0.42^{ns}	-0.81*	-0.24^{ns}
Plant length	-0.35^{ns}	0.51*	0.31^{ns}	-0.48^{ns}	0.63**	0.56*	-0.56^{ns}	0.81*	0.74*
Index of lodging	0.17^{ns}	-0.58**	-0.59**	-0.26^{ns}	-0.62*	-0.75*	-0.20^{ns}	-0.68*	-0.73*
Number of tillers	-0.34^{ns}	-0.37^{ns}	-0.41*	0.15^{ns}	0.07^{ns}	0.10^{ns}	0.12^{ns}	0.21^{ns}	0.23^{ns}
N content in plant	0.76*	0.02^{ns}	0.32^{ns}	0.40*	0.41^{ns}	0.54*	0.77*	0.26^{ns}	0.39^{ns}
Grain/husks	-0.07^{ns}	0.19^{ns}	0.33^{ns}	-	-	-	-	-	-
Harvest index	-0.44*	0.31^{ns}	0.23^{ns}	-0.23^{ns}	0.25^{ns}	0.20^{ns}	0.78*	-0.54^{ns}	-0.43^{ns}
TGW	-0.56**	0.28^{ns}	0.20^{ns}	-0.06^{ns}	0.22^{ns}	0.18^{ns}	-0.15^{ns}	0.54^{ns}	0.53^{ns}

*P < 0.05; **P < 0.01; ^{ns}not significant.

Table 6. Effect of experimental factors on selected agronomically important traits of Emmer (ANOVA).

Factor		df	Protein content		Grain yield		Protein yield	
			MS	%TV	MS	%TV	MS	%TV
Variety	(1)	5	24.97**	7	1.00**	2	0.02**	1
locality	(2)	1	267.62**	76	16.68**	25	1.00**	56
year	(3)	2	13.43**	4	40.64**	62	0.67**	37
1x2		5	1.34**	0	0.45**	1	0.01**	1
1x3		10	2.69**	1	1.54**	2	0.03**	2
2x3		2	43.30**	12	5.13**	8	0.05**	3
1x2x3		10	0.68**	0	0.37**	1	0.01**	1
error		72	0.00	0	0.06	0	0.00	0

*P < 0.05; **P < 0.01; ^{ns}not significant; MS = mean square; %TV = percentage of total variability.

On the other hand, emmer wheat varieties were characterised by higher and more stable nitrogen uptake when it was grown in a location with a deficit of nitrogen (Table 4). Trčková et al. (2005) have also confirmed such findings. They have proven a more efficient uptake of NO_3 by emmer wheat plants. Correlation analysis (Table 5) has also proven a connection between the quantity of nitrogen in the plant phytomass during the flowering period (DC 61) and the total quantity of nitrogen in the grains of emmer wheat (r = 0.76) and bread wheat (r = 0.77). Low values of the harvest index (0.33) in the case of emmer, also confirm an unsuitable distribution of assimilates in plants. Variability of the harvest index was minimum (Table 4). The thousand grain weight (TGW) of emmer was low (31.41 g), in comparison with the old (39.55 g) and control (43.12 g) bread wheat varieties. A low level of TGW is another reason for lower productivity of some varieties of emmer. Because emmer wheat is a hulled wheat species (Marconi and Cubadda, 2005), after dehulling grains represented 76.56% of the production (Table 4). There were minimum differences between the emmer wheat varieties.

The yield level of emmer wheat varieties was 58% of the yield level of the control cultivars (SW Kadrilj, Vanek) and 69% of the yield level of old varieties of bread wheat. The total hectare crude protein yield was at the same level of difference as grain yield (comparison of varieties). On the other hand, the emmer wheat landraces were characterised by a higher crude protein content in grain (17.91%) than the old (15.08%) and control (13.73%) bread wheat varieties. The grain and protein yield were more stable in the case of the emmer wheat cultivars (Table 4). Evaluation of the impact of each factor and its interactions (ANOVA) have revealed significant differences between varieties.

Concerning emmer wheat (Table 6), the protein content was influenced (P < 0.01) by locality (76%), and the grain yield rate (P < 0.01) were influenced by the year factor (62%). Both factors - locality (56%) and year (37%), influenced the total crude protein content (P < 0.01). Concerning the old (Table 7) and control (Table 8) bread wheat varieties, the results were different. The crude protein content, crude protein yield and grain yield were influenced (P < 0.01) by both factors at the same time.

Table 7. Effect of experimental factors on selected agronomically important traits of old varieties of bread wheat (four varietes) (ANOVA).

Factor		df	Protein content		Grain yield		Protein yield	
			MS	%TV	MS	%TV	MS	%TV
variety	(1)	3	12.49**	12	8.50**	7	0.09**	3
locality	(2)	1	45.10**	44	52.43**	43	1.77**	63
year	(3)	2	35.92**	35	47.49**	39	0.71**	25
1x2		3	4.63**	5	2.46**	2	0.03**	1
1x3		6	2.59**	3	2.97**	2	0.05**	2
2x3		2	0.35**	0	6.73**	6	0.17**	6
1x2x3		6	1.64**	2	0.19*	0	0.00^{ns}	0
Error		48	0.00	0	0.07	0	0.00	0

*P < 0.05; **P < 0.01; ^{ns}not significant; MS = mean squere; %TV = percentage of total variability.

Table 8. Effect of experimental factors on selected agronomically important traits of control varieties of bread wheat (two varieties) (ANOVA).

Factor		df	Protein content		Grain yield		Protein yield	
			MS	%TV	MS	%TV	MS	%TV
variety	(1)	1	1.10**	3	0.99**	1	0.01**	0
locality	(2)	1	17.98**	49	56.84**	47	1.59**	64
year	(3)	2	14.53**	40	57.51**	48	0.82**	33
1x2		1	1.31**	4	1.91**	2	0.01**	0
1x3		2	0.20**	1	0.52**	0	0.01**	0
2x3		2	0.85**	2	2.53**	2	0.06**	2
1x2x3		2	0.37**	1	0.54**	0	0.00*	0
Error		24	0.00	0	0.05	0	0.00	0

*P < 0.05; **P < 0.01; ^{ns}not significant; MS = mean squere; %TV = percentage of total variability.

These results have indicated the fact that the emmer wheat landraces were more adaptable to different climate characteristics of year and different levels of nitrogen content in the soil than the bread wheat varieties.

Conclusion

The emmer wheat landraces may be grown, if selected carefully, in low input or organic farming systems and in less favourable areas for agriculture too. Emmer wheat is able to become competitive against weeds and other biotic (diseases) and abiotic (e.g. low level of nitrogen fertilization) stressing factors. This advantage may be reduced by the low resistance of some varieties to lodging. Therefore, because of the high variability of the tested varieties, there is the possibility to select resistant varieties.

Furthermore, the total yield level was reduced by the placement of assimilates in straw and a less efficient distribution of grains. On the other hand, this fact may not be disadvantageous if a farmer needs a lot of straw. Adaptability of the emmer wheat landraces to the land and climatic environmental conditions was another positive aspect (the emmer wheat landraces were much more adaptable than the modern bread wheat varieties). High crude protein content in grain was an advantage of the emmer wheat cultivars from the point of view of grain quality and processing. The aforementioned reasons suggest that after careful selection, emmer could be an alternative crop for low input agricultural systems.

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