Agronomically important traits of emmer wheat

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ABSTRACT

Particular agronomic traits of six landraces of *Triticum diccocum* Schrank (Schuebl) were studied during three years in Prague and České Budějovice localities, Czech Republic. The analysis of tolerance to drought by using the method of ^{13}C discrimination (CID) was also focused on in the research. All the tested varieties were resistant to usual wheat diseases. An inclination of particular varieties to lodging and a low harvest index rate (0.33) were negative factors having a significant effect on the yield rate. Meanwhile, all the varieties contained a high percentage of proteins in grain (17.92%) which was an important advantage in low input conditions. The landraces of emmer wheat also proved to be more tolerant to drought (CID = 25.82‰) than check varieties of bread wheat (CID = 26.70‰). Results of the research showed that some of the emmer landraces may be successfully grown and used directly in low-input farming systems or in breeding programs focused on the breeding of suitable varieties for low-input farming.

Keywords: agronomic traits; drought tolerance; emmer; grain quality

Cultivated emmer wheat, *T. dicoccum* [syn. *T. turgidum* L. subsp. *dicoccon* (Schrank) Thell.], is a tetraploid species (BA-genomes) belonging to the *Triticum* L. genus (Zaharieva et al. 2010). Emmer wheat is one of the earliest domesticated plants and has been a staple crop over centuries (Troccoli and Codianni 2005). It has been grown, for example, in extreme montane conditions (Zaharieva et al. 2010). Breeding of emmer has rarely been given attention and its productivity does not usually achieve that of modern bread wheat cultivars (Vita et al. 2006). Meanwhile, some literature presents a similar productivity level of emmer and bread wheat, if varieties are grown in arid conditions (Marconni and Cubadda 2005) or with a lack of nitrogen in the soil (Trčková et al. 2005). Another advantage of emmer, published in the literature is a high quality of production (Zaharieva et al. 2010).

Further reason for growing and using emmer is presented in scientific literature as its tolerance to drought (Zaharieva et al. 2010), because a warmer climate and drought conditions (Márton et al. 2007) could become more frequent (Bucur and Savu 2006). An indirect method of discrimination of the isotope ^{13}C (CID) in photosynthesis could be applied in the evaluation of tolerance to drought (Araus et al. 2002). Two bread wheat varieties tolerant to drought, Drysdale and Rees demonstrate the succesfull use of this method in the modern breeding practice in Australia (Rebetzke et al. 2002).

Plants discriminate between ^{13}C and ^{12}C during photosynthesis, they discriminate against ^{13}C during diffusion of CO_2 through stomata and during the process of CO_2 fixation by ribulose-1,5 bisphosphate caroxylase (RUBISCO). If the plants have opened stomata, the discrimination of ^{13}C to ^{12}C becomes more important (the plants prefer ^{12}C to ^{13}C, the same as RUBISCO, because ^{12}C is by one protone lighter than ^{13}C) (Farquhar and Richards 1984). It was reported that there is a strong negative relationship between carbon isotopes discrimina-

Supported by the Ministry of Agriculture of the Czech Republic, Project No. QH82272.

tion (Δ) and water use efficiency of plants (WUE) (Ehdaie et al. 1991). The genotypes which close their stomata because of the changes in conditions (drought) are more sensitive to the drought stress factor and have better WUE (Rebetzke et al. 2002).

In normal conditions CID varies from 24‰ to 33‰ in the dry matter of C3 plants (O'Leary 1988). The resistant varieties may therefore be found among the genotypes characterised by lower values of CID (Farquhar and Richards 1984).

The objective of this study was to analyse the potential use of emmer wheat as an alternative crop in less favourable areas for agricultural practice. In this paper we report (1) the results of selected traits which strongly influenced yield, and (2) the results of CID as a tool for prediction of the drought tolerance of emmer in comparison with newly bred varieties of bread wheat.

MATERIAL AND METHODS

The evaluated varieties came from the Gene bank of the Crop Research Institute in Prague-Ruzyně (Czech Republic). Six genetic resources of emmer wheat (*Triticum dicoccum* Schrank) and two modern bread wheat varieties (*Triticum aestivum* L.), Vánek and SW Kadrilj (check), were chosen (Table 1). Varieties were sown in a randomized, complete block design in two replications on experimental plots in Prague and České Budějovice (CB) during 2007, 2008 and 2010. The seeding rate was adjusted for a density of 350 germinable grains per m^2. Rows were 125 mm wide. Each plot was 10 m^2 large. The years were characterised by differences in temperature compared to the mean year temperature and mean temperature in the growing season (Figure 1). In April 2007, there was a precipitation deficiency. 2008 was characterised by an average level of precipitation and 2010 by a precipitation rate in the growing period which was above average (Figure 2). The Prague location 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 CB locality was, meanwhile, characterised by N deficiency (NH_4-N + NO_3-N = 12 mg/kg) and pH = 6.41.

Evaluation of the trials. The following traits were studied during the growing period: the degree of mildew infestation (DC 37, 51–61, 77) and brown rust infestation (DC 77) were expressed by a score in accordance with symptoms of a disease on plants (9 = no infestation); the index of lodging (combination of intensity and degree of lodging of the crop stand on each plot, mean of two measurements, after the heading – DC 59, before the harvest – DC 87); after harvest: grain yield, crude protein yield per hectare = (crude protein content/100) × grain yield; crude protein content was indicated by the method of Kjeldahl (ICC 105/2); harvest index was indicated during postharvest analyses of plants (30 stalks were chosen at random on each plot).

Drought tolerance. Samples of grains were dried until reaching a constant percentage of humidity, they were ground and burnt in an oxygenized atmosphere. The arising gases were separated, cleaned and reduced in elementar analyser EuroEA 3028-HT (EuroVector, Milan, Italy), their ratio was indicated there, too. The percentage of the ^{13}C isotope was indicated by the mass spectrometer (IRMS Isoprime, EuroVector, Milan, Italy) on the basis of molecular weight. The international stand-

Table 1. List of used varieties

Accession number[1]	Accession name	Origin	Taxon
Triticum dicoccum (Schrank) SCHUEBL			
01C0200117	Horny Tisovnik	CZE	var. *rufum* SCHUEBL
01C0200949	Ruzyně	CZE	var. *chevsuricum* DEKAPR.
01C0201262	Tapioszele 1	–	var. *serbicum* A. SCHULZ
01C0201282	Tapioszele 2	–	var. *rufum* SCHUEBL
01C0203989	Kahler Emmer	DEU	var. *dicoccum*
01C0204501	No. 8909	–	var. *dicoccum*
Check varieties of *Triticum aestivum* L.			
01C0204800	Vánek	DEU	var. *lutescens* MANSF.
01C0204877	SW Kadrilj	SWE	var. *lutescens* MANSF.

[1]http://genbank.vurv.cz/genetic/resources; – origin unknown

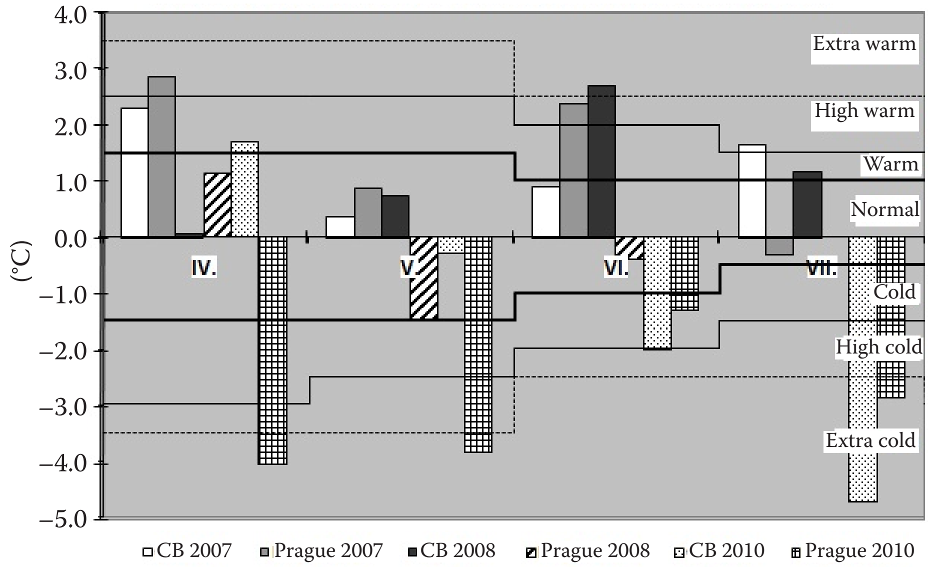


Figure 1. Temperature (°C) characteristics of the experimental stations – differences from long-term mean

ards, PeeDee Formation in South Carolina (derived from the Cretaceous marine fossil *Belemnitella americana*) (PDB) for $^{13}C/^{12}C$, were applied to identify isotopes in the samples. The detailed methodology of CID calculation is described in a paper by Konvalina et al. (2010).

Statistical analysis of data. The significance of the effect of cultivar, year and location on the evaluated parametres was evaluated by an analysis of variance (ANOVA). The *LSD* test was used for division of the cultivars into statistically different groups. All statistical analyses were done using Statistica 9.0 software (StatSoft, Inc., Tulsa, USA).

RESULTS AND DISCUSSION

Results of the assessment of emmer wheat landraces compared to a group of modern bread wheat varieties gave a lot of interesting information on the differences between the landraces and modern varieties that separate the landraces advantageous or disadvantageous (and limited). Generally, all the emmer wheat landraces were absolutely resistant to mildew and brown rust if the plot attack of one of these pathogens was natural (Table 2). For that reason, it is interesting to breed the emmer wheat in order to enhance their resistance to the above-mentioned pathogens (Zaharieva et al. 2010).

The question of tolerance to drought is more important nowadays as wet and dry periods have been changing very fast and very often. The screening of carbon isotope discrimination (CID) explicitly confirmed a strong influence of the species as a factor ($P < 0.01$). The emmer wheat landraces reached more favourable values of CID (Table 2). Locality and year were the most important factors in a separate analysis of variance of the assessed species (Table 2). Kahler Emmer seems to be the most prospective accession. It reached a 5% positive difference to SW Kadrilj, a check variety, during three sequential years (Figure 3). Shirazi

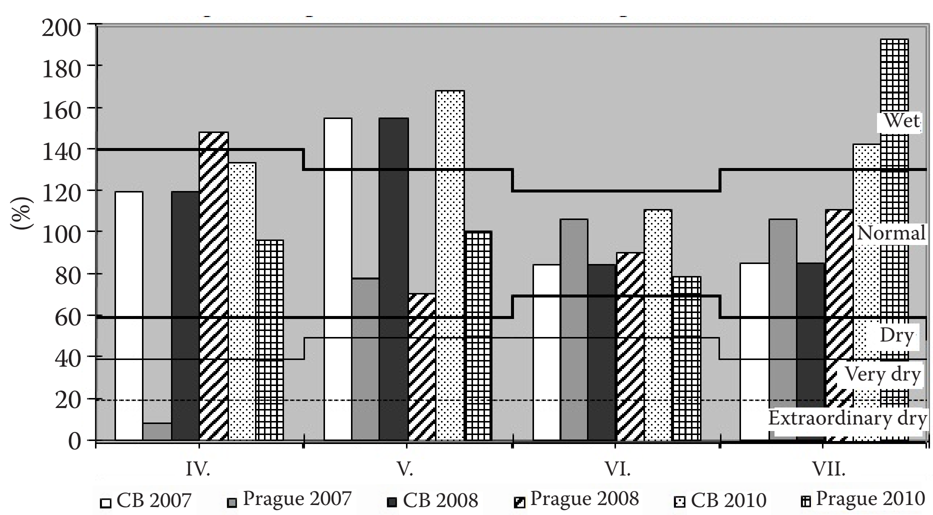


Figure 2. Precipitation characteristics of the experimental stations

Table 2. Particular emmer wheat agrotechnological traits related to yield formation (mean and standard error)

Variety	Mildew (points)	Brown rust (points)	$\Delta^{13}C$ (‰)	Index of lodging	Harvest index	Grain yield (t/ha)	Protein content (%)	Protein yield (t/ha)
Horny Tisovnik	9 ± 0.0^{b}	9 ± 0.0^{c}	26.01 ± 0.5^{ab}	5.0 ± 1.4^{b}	0.36 ± 0.1^{de}	3.293 ± 0.8^{a}	16.96 ± 1.6^{bc}	0.453 ± 0.1^{a}
Ruzyně	9 ± 0.0^{b}	9 ± 0.0^{c}	25.63 ± 0.8^{a}	7.7 ± 0.5^{a}	0.32 ± 0.0^{bc}	2.579 ± 1.2^{a}	18.59 ± 2.2^{d}	0.362 ± 0.2^{a}
Tapioszele 1	9 ± 0.0^{b}	9 ± 0.0^{c}	26.08 ± 0.3^{ab}	4.6 ± 0.5^{b}	0.37 ± 0.1^{e}	3.022 ± 1.0^{a}	16.05 ± 0.8^{b}	0.384 ± 0.2^{a}
Tapioszele 2	9 ± 0.0^{b}	9 ± 0.0^{c}	25.91 ± 0.8^{a}	7.4 ± 0.9^{a}	0.29 ± 0.1^{a}	2.822 ± 1.0^{a}	19.00 ± 1.6^{d}	0.394 ± 0.1^{a}
Kahler Emmer	9 ± 0.0^{b}	9 ± 0.0^{c}	25.53 ± 1.5^{a}	7.8 ± 2.2^{a}	0.31 ± 0.0^{ab}	2.870 ± 0.7^{a}	18.86 ± 2.9^{d}	0.407 ± 0.2^{a}
No. 8909	9 ± 0.0^{b}	9 ± 0.0^{c}	25.74 ± 1.5^{a}	7.4 ± 2.0^{a}	0.34 ± 0.0^{cd}	2.956 ± 0.3^{a}	18.04 ± 3.0^{cd}	0.408 ± 0.1^{a}
Vánek	7 ± 1.1^{a}	7 ± 0.7^{b}	26.60 ± 1.1^{bc}	8.7 ± 0.7^{c}	0.46 ± 0.0^{f}	4.853 ± 1.7^{b}	13.90 ± 1.2^{a}	0.667 ± 0.3^{b}
SW Kadrilj	7 ± 0.8^{a}	6 ± 1.2^{a}	26.80 ± 0.9^{c}	8.9 ± 1.0^{c}	0.46 ± 0.0^{f}	5.186 ± 1.9^{b}	13.55 ± 1.8^{a}	0.697 ± 0.3^{b}

Different letters document statistical differences between varieties for the *LSD* test, α = 0.05

et al. (2010) state the fact that the difference of 5–10% of the CID values between varieties allows a classification of more or less tolerant varieties to drought if they are grown in the same conditions. A variety reaching a lower CID value in dry conditions reaches lower CID values in abundant precipitation as well (Farquhar and Richards 1984). All the assessed varieties proved to have a weak variability of the CID values (Table 2, Figure 3). Therefore, negative CID values reached by the check bread wheat varieties are stable. For that reason, growing of modern spring wheat varieties in dry conditions may be considered as a risk. Aspects of their possible tolerance to drought was not taken into account in the breeding process.

Concerning other assessed factors influencing the total yield rate of the emmer wheat, nutritional status of the locality and run of year are very important too ($P < 0.01$) (Table 3). Resistance to lodging reduced in a wet year and in a locality characterised by abundant precipitation (Figure 2, Table 3). For that reason, varieties having firm and robust stalks should be chosen and grown there (e.g. Kahler emmer, Ruzyně) although they may reach lower harvest index values (0.31–0.32) (Table 2). Long and firm stalks are also more competitive to weeds (Cudney et al. 1991). The grain yield rate of the emmer wheat landraces reached 58% of the one of the check bread wheat varieties (Table 2, Figure 4). A high proportion of protein in grains

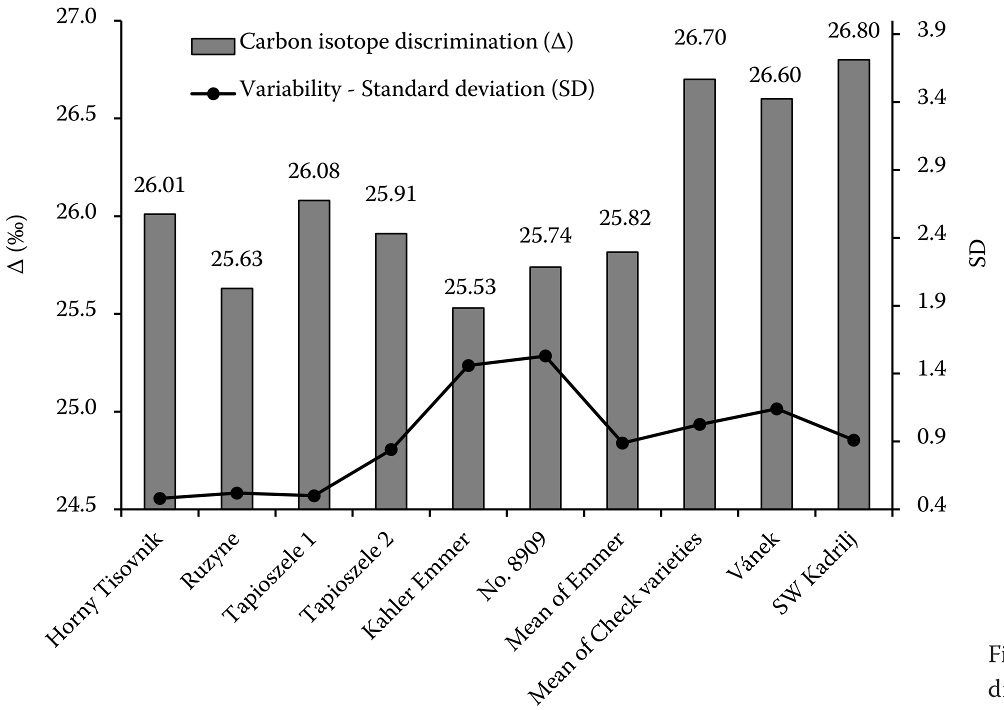


Figure 3. Carbon isotope discrimination (△) (‰)

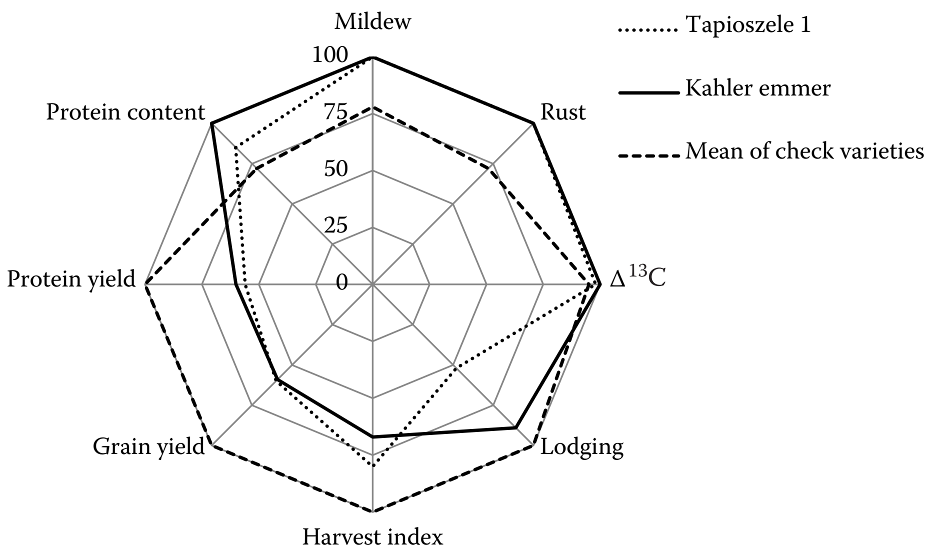
Table 3. Effect of main factors on selected agronomic parameters of tested varieties (ANOVA)

Factor	*df*	*F*-ratio					
		$\Delta^{13}C$	index of lodging	harvest index	grain yield	protein content	protein yield
All varieties							
Species	1	20.08^{**}	43.01^{**}	222.99^{**}	52.28^{**}	112.12^{**}	46.54^{**}
Emmer wheat (landraces)							
Variety	5	1.60^{ns}	37.82^{**}	17.34^{**}	2.76^{*}	19.44^{**}	2.64^{*}
Locality	1	62.80^{**}	23.30^{**}	11.44^{**}	45.87^{**}	208.33^{**}	156.03^{**}
Year	2	35.00^{**}	49.20^{**}	21.19^{**}	111.74^{**}	10.45^{**}	105.13^{**}
Bread wheat (check)							
Variety	1	1.60^{ns}	3.35^{ns}	0.87^{ns}	2.99^{ns}	8.17^{**}	1.42^{ns}
Locality	1	17.30^{**}	10.87^{**}	21.84^{**}	170.93^{**}	133.18^{**}	277.28^{**}
Year	2	28.50^{**}	7.65^{**}	38.48^{**}	172.94^{**}	107.67^{**}	143.10^{**}

$^{ns}P > 0.05$; $^{*}P \leq 0.05$; $^{**}P \leq 0.01$

was an advantage of the assessed emmer wheat landraces: Kahler emmer – 18.86% (an emmer wheat landrace) whereas SW Kadrilj – 13.55% (a check bread wheat variety). The assessed varieties may be divided into two different groups. The varieties characterised by a lower proportion of crude protein in grains, more favourable harvest index values and a lower resistance to lodging (Horny Tisovnik, Tapioszele 1) belong to the first group. On the other hand, the varieties characterised by a higher proportion of crude protein content in grains, lower harvest index values and higher resistance to lodging (e.g. Kahler Emmer) belong to the second group (Table 2). The proportion of crude protein in emmer wheat grains was influenced ($P < 0.01$) by the nutritional status of the locality (Table 3), as the emmer wheat root system was able to absorb nutrients from less accessible soil bonds (Trčková et al. 2005).

Kahler emmer, a prospective emmer wheat landrace, and Tapioszele 1, were taken as examples; all the assessed characteristics were compared to mean values of the check bread wheat varieties and a beam graph was drawn out (Figure 4). It shows the resistance of the landraces to mildew and brown rust. On the other hand, it also shows the lower harvest index values (e.g. Tapioszele 2) and the weaker resistance to lodging of several varieties. A high proportion of protein in grains (varying from 16.05 to 19.00%) is one the most important advantages. The emmer wheat is also more predisposed to a tolerance to drought as



of level of evaluated pa-
ariaties (%)

it reaches lower CID values than the other two check bread wheat varieties. The emmer wheat is considered a prospective alternative crop for growing in low-input farming systems. It may also be used in a many breeding programs.

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 grains have big potential for production of many new products, because of high protein content and other nutritional aspects. At this time it is a crop especially for small scale farming with a connection to local food processing.

REFERENCES

Araus J.L., Slafer G.A., Reynolds M.P., Rovo C. (2002): Plant breeding and drought in C-3 cereals: What should we breed for? Annals of Botany, *89*: 925–940.

Bucur D., Savu P. (2006): Considerations for the design of intercepting drainage for collecting water from seep areas. Journal of Irrigation and Drainage Engineering, *132*: 597–599.

Cudney D.W., Jordan L.S., Hall A.E. (1991): Effect of wild oat (*Avena fatua*) infestations on light interception and growth rate of wheat (*Triticum aestivum*). Weed Science, *39*: 175–179.

Ehdaie B., Hall A.E., Fagquahar G.D., Nguyen H.T., Waines J.G. (1991): Water-use efficiency and carbon isotope discrimination in wheat. Crop Science, *31*: 1282–1288.

Farquhar G.D., Richards R.A. (1984): Isotopic composition of plant carbon correlates with water use efficiency of wheat. Australian Journal of Plant Physiology, *11*: 539–552.

Konvalina P., Moudrý J., Dotlačil L., Stehno Z., Moudrý jr. J. (2010): Drought tolerance of landraces of emmer wheat in comparison to soft wheat. Cereal Research Communications, *38*: 429–439.

Márton L., Pilar P.M., Grewal M.S. (2007): Long term studies of crop yields with changing rainfall and fertilization. Agricultural Engineering Research, *13*: 37–47.

Marconi M., Cubadda R. (2005): Emmer Wheat. In: Abdel-Aal E.-S.M., Wood P. (eds.): Speciality Grains for Food and Feed. American Association of Cereal Chemists, St. Paul, 63–108.

O'Leary M.H. (1988): Carbon isotopes in photosynthesis. BioScience, *38*: 328–336.

Rebetzke G.J., Condon A.G., Richards R.A., Farquhar G.D. (2002): Selection for reduced carbon isotope discrimination increases aerial biomass and grain yield of rainfed bread wheat. Crop Science, *42*: 739–745.

Shirazi M.U., Gyamfi J.A., Ram T., Bachiri H., Rasyid B., Rehman A., Khan M.A., Mujtaba S.M., Ali M., Shreen A., Mumtaz S. (2010): Selection of some suitable drought tolerant wheat genotypes using carbon isotopes discrimination (CID) technique. Pakistan Journal of Botany, *42*: 3639–3644.

Trčková M., Raimanová I., Stehno Z. (2005): Differences among *Triticum dicoccum*, *T. monococcum* and *T. spelta* in rate of nitrate uptake. Czech Journal of Genetics and Plant Breeding, *41*: 322–324.

Troccoli A., Codianni P. (2005): Appropriate seeding rate for einkorn, emmer, and spelt grown under rainfed conditions in southern Italy. European Journal of Agronomy, *22*: 293–300.

Vita P., Riefolo C., Codianni P., Cattivelli L., Fares C. (2006): Agronomic and qualitative traits of *T. turgidum* ssp. *dicoccum* genotypes cultivated in Italy. Euphytica, *150*: 195–205.

Zaharieva M., Ayana N.G., Al Hakimi A., Misra S.C., Monneveux P. (2010): Cultivated emmer wheat (*Triticum diccocum* Schrank), an old crop with a promising future: a review. Genetics Resources and Crop Evolution, *57*: 937–962.

Received on April 4, 2011

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