The Effect of Water Deficit on Yield and Yield Component Variation in Winter Wheat

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Summary

The study was focused on the effect of limited water availability on yield and yield components of wheat. Soil water deficit is known to be one of the major factors limiting the productivity of cereals. Water deficit can affect plant growth and development in all stages, in early stages the rate of tiller appearance, leaf appearance and leaf area is reduced, later on the length of stems is reduced together with the number of grains per ear, and stress after anthesis shorten the duration of grain filling, thus reduces a grain size. The response of selected cultivars of winter wheat to water deficit was studied at the Field Research Station of the Mendel University, Brno, Czech Republic, in 2012/13, 2013/14, 2014/15 and 2015/16 growing seasons. A set of 26 cultivars was grown in two independent small plot experiments which were performed at two sites with different soil conditions, first site was characterised by loamy soil with good water retention and high yield potential, the second site was situated on drought prone sandy soil. Grain yield and primary yield components were determined: canopy density as the number of ears per area, and thousand grain weight as a parameter characterising grain size. The number of grains per ear was calculated using the grain yield, the number of ears per area and thousand grain weight.

All yield components were statistically significantly affected by site, year and cultivar factors.

Our results revealed that yield in all experiments was positively associated with high canopy density, but was not related to variations in grain weight. Under less favourable conditions association between yield and ear productivity was significant and grain weight was negatively correlated with number of ears and number of grains per ear. It suggested more severe competitiveness for resources.

Four yield-based indices of drought tolerance were calculated, i.e. Stress Tolerance Index, Tolerance Index, Drought Resistance Index and Superiority Measure. Correlation analysis and principle component analysis were performed using data from both sites to show the relationships among indices and grain yield and to identify superior cultivars.

Key words

winter wheat, yield components, drought tolerance indices, cultivars

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Introduction

Grain yield can be analysed in terms of three yield components, namely number of ears per area, number of grains per ear and mean grain weight. Compensation of components occurs as a result of competition for water and nutrients, particularly nitrogen (Miralles et al., 2000). The development of the components is sequential, later developing components are under control of earlier ones. The principles of yield formation in wheat are described in detail by many authors, e.g. Černý et al. (2012).

Recurrent periods of drought associated with climate change are considered as the principal constraint to crop productivity in some regions of the Czech Republic. Studying the relationship between the yield series and climate, Trnka et al. (2012) found out that climatic conditions during May and June played a key role in yield formation of wheat. Water deficit can affect plant growth and development in all stages. In early stages the rate of tiller appearance, leaf appearance and the reduction of the leaf area, while later the length of stems together with the number of grains per ear. The stress after anthesis shortens the duration of grain filling stage, thus reduces a grain size. The compensatory effects between yield components are much stronger under stress conditions than under favourable conditions (Blum, 2010; Moragues et al., 2006, Mwadzingeni et al., 2016).

Numerous efforts to mitigate water deficiency are underway, including water-saving conservation tillage, preferences of winter types of crops, and of more drought tolerant cultivars of such crops. Although the effect of water deficit in different stages of plant development on final yield is difficult to analyse due to yield component compensations, the farmers´ main criterion is the grain yield. Therefore, it seems reasonable to evaluate cultivars according to their performance under different conditions. Different measures of yield stability and reliability can be adopted to identify and select cultivars with stable yield even under stress conditions (Annicchiarico, 2002; Mohammadi and Amri, 2008; Nouri et al., 2011).

A set of popular winter wheat cultivars grown in the Czech Republic was tested at two sites with different water regimes in the soil (optimal conditions x water-limited conditions). The evaluation was focused on grain yield, its structure and relations among primary yield components. The aim was to identify cultivars which perform better under stress.

Material and methods

The response of selected cultivars of winter wheat to different growing conditions was studied at the Field Research Station Žabčice of the Mendel University in Brno, Czech Republic (49°01´N; 16°37´E; 179 m a.s.l.), in 2012/13, 2013/14, 2014/15 and 2015/16 seasons. Two independent small plot experiments were performed at two sites situated about 2 km apart. The site A was characterised by loamy soil with good water retention and high yield potential (gleyic fluvisol, 49-58 % of clayey particles). The site B was situated on drought prone sandy soil of chernozem type formed on a gravel terrace (20-28 % of clayley particles) and its yielding capacity was strongly dependant on precipitation rates during vegetation period. The average temperatures and sums of precipitation for all experimental seasons are given in Table 1, together with the long-term mean values valid for the Field Research Station (1961-1990). The data came from the agrometeorological station operated at the site A. The soil moisture content was continuously monitored using Volume soil moisture probes (VIRRIB®, FIEDLER AMS s.r.o., CZ) at both sites in the depth of 20 and 40 cm. At the site B the precipitation rates were measured using a rain gauge with data logger. The figures 1 and 2 displayed the changes in soil moisture and the cumulative rainfall in 2012/13 season. The measurement of soil moisture in autumn was not accurate due to disturbed soil structure, therefore the figures displayed the course from the beginning of January to July. The fields differed in water availability, high level of sub-soil water replenished from nearby river provided the plants at the site A with sufficient moisture even in the periods without rainfall. The soil moisture volume did not decrease below 40 % of water holding capacity (Fig. 1). The water availability at the site B had been restricted since the third decade of April (Fig. 2). Figures for further seasons are not shown, but the patterns were similar, the moisture volume at the site A increased with the depth and kept above wilting point regardless to precipitation rate. Sandy soil at the site B was prone to drying and the moisture volume decreased with the depth. At the site B the most favourable season was 2012/13, because the soil moisture volume did not drop to the wilting point. The 2013/14 and 2014/15 seasons were dry, the wilting point was reached at the beginning of May (2014) and at the beginning of June (2015). In the 2015/16 season the wilting point was also reached at the beginning of June (2016), but only in the depth of 40 cm. Limited moisture was still available in upper soil layers due to regular rainfall.

The experimental material consisted of 26 winter wheat cultivars commonly grown in the Czech Republic. The cultivars were tested using small plot experiments with three (site A) and four replications (site B). The randomisation was based on incomplete block design (alpha-design), the seeding rate was adjusted to 400 viable seeds per m^2. The plot size was 10.5 m^2 (12 rows, 0.125 m

Table 1. Average temperatures (T) and sums of precipitation (P) at the Field Research Station in Žabčice, years 2013-2016

FRS Žabčice	1961-1990		2012/2013		2013/2014		2014/2015		2015/2016	
	T (°C)	P (mm)	T (°C)	P (mm)	T (°C)	P (mm)	T (°C)	P (mm)	T (°C)	P (mm)
October-July (till 15.7.)	7,1	390	8,1	488	9,5	232	9,6	225	9,4	363
January	-2,0	25	-1,0	20	1,2	22	1,8	20	-1,2	15
February	0,2	25	0,7	42	2,8	13	1,8	7	5,1	63
March	4,3	24	1,9	41	8,5	6	5,4	28	5,4	29
April	9,6	33	10,6	20	11,8	11	10,1	9	9,8	41
May	14,6	63	14,8	109	14,4	63	14,7	34	15,6	41
June	17,7	69	18,3	147	18,8	43	19,1	22	19,8	35
July (till 15. 7.)	19,3	29	20,5	5	20,3	13	22,4	8	20,7	51
Jan.- July (till 15. 7.)	9,1	267	9,4	384	11,1	170	9,9	129	10,7	276

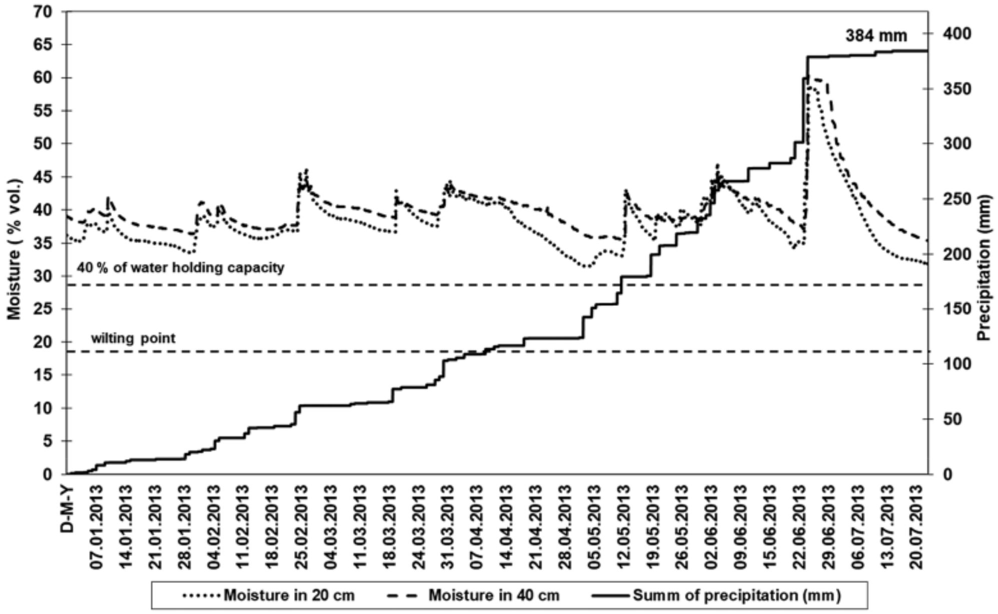

Figure 1.
Courses of soil moisture volume in the depth of 20 and 40 cm and cumulated precipitation at site A from 1st January to 20st July 2013

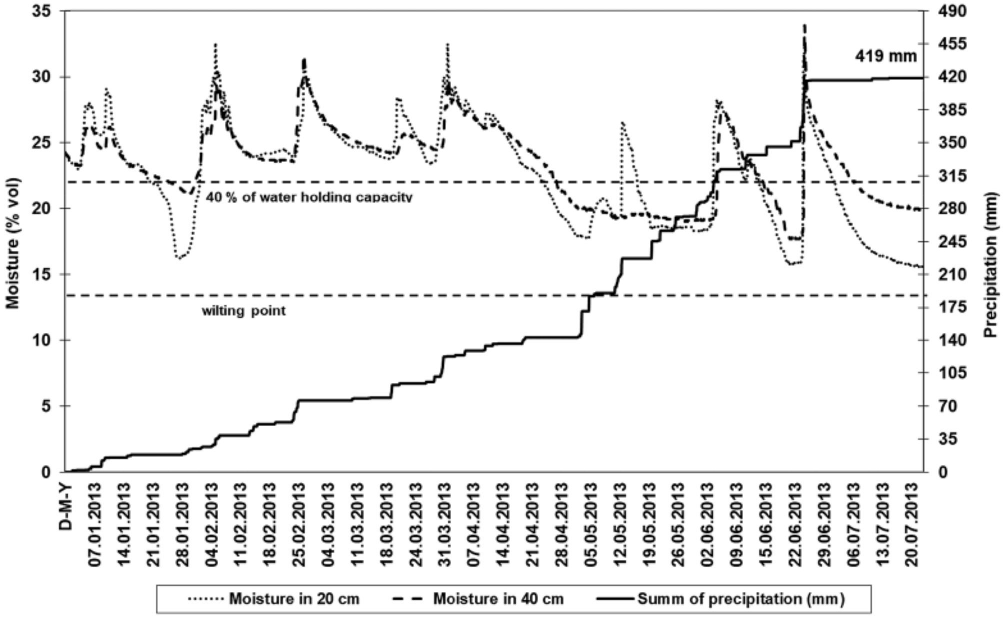

Figure 2.
Courses of soil moisture volume in the depth of 20 and 40 cm and cumulated precipitation at site B from 1st January to 20st July 2013

apart, 7 m length). The trial management followed common rules of experimental practice, the amount of fertilisers and chemical treatments were adjusted according to growing conditions and pest occurrence. Site A: pea was used as a forecrop, nitrogen (N) fertilisation was done three times (40, 50 and 40 kg of N/ha), two application of fungicides (flag leaf stage and heading stage), one application of growth regulator to reduce the risk of lodging. Site B: poppy, two doses of N fertilisers (40 and 50 kg of N/ha), no growth regulators and fungicide treatments. Trials at both sites were sown in October and mechanically harvested in July. Following agronomic traits were evaluated in all plots: grain yield (GY) expressed at 14% grain moisture content in tons per hectare and number of ears per square meter (EN/A). After harvest grain samples were taken from all replications per cultivar and site, bulked grain was cleaned using air/screen laboratory cleaner (Westrup A/S, DK) and thousand grain weight was assessed (1000-GW). The number of grains per ear (GN/E) was calculated using GY, 1000-GW and EN/A.

Statistical processing

A three-way analysis of variance for all characters (GY, 1000-GW, EN/A and GN/E) was applied to evaluate the effects of year, site and cultivar factors. Tukey´s honest significant differences (HSD) for groups of means were calculated at p=0,05. The relationship between parameters within each site was evaluated by using the Pearson correlation coefficients.

Drought tolerance indices based on grain yield of tested cultivars at A and B sites for four years were calculated as follows: Stress Tolerance Index (STI) suggested by Fernandez (1992), Tolerance Index (TOL) by Rossiele and Hamblin (1981), Drought Resistance Index (DRI) proposed by Fisher and Maurer (1978) and Superiority Measure (SPM) suggested by Lin and Binns (1988).

Table 2. MS and p-values indicating statistical significance of Year, Site and Cultivar effects and their interactions on GY, 1000-GW, NE/A and GN/E parameters tested by multifactorial ANOVA. Significant effects are indicated in bold (p<0,05)

Effect	Degrees of freedom	GY		1000-GW		EN/A		GN/E	
		MS	p	MS	p	MS	p	MS	p
Year	3	**23.9**	**0.000**	**381.0**	**0.000**	**214881**	**0.000**	**225.1**	**0.000**
Site	1	**1469.0**	**0.000**	**2634.4**	**0.000**	**1875380**	**0.000**	**1745.6**	**0.000**
Cultivar	25	**0.4**	**0.001**	**52.9**	**0.000**	**16873**	**0.000**	**61.2**	**0.000**
Year × Site	3	**29.7**	**0.000**	**138.1**	**0.000**	**167554**	**0.000**	**281.1**	**0.000**
Year × Cultivar	75	**0.3**	**0.002**	**6.0**	**0.000**	2829	0.276	9.3	0.062
Site × Cultivar	25	**0.5**	**0.000**	3.2	0.217	**6165**	**0.001**	**16.7**	**0.001**
Error	75	0.2		2.5		2465		6.5	

MS - mean square; p - probability value

Correlation analysis and Principal component analysis (PCA) were performed to show the relationships among the stress indices and grain yield and to identify superior cultivars.

All analyses were performed by using Statistica 12 (StatSoft, Tulsa, USA) and MS Excel, 2016.

Results and discussion

Analysis of variance showed that all evaluated characters were significantly influenced by all three factors. The interaction between year and site was significant for all characters, whereas the interaction between year and cultivar was significant for GY and 1000-GW and between site and cultivar for GY, EN/A and GN/E (Table 2). The group means for factors and values of Tukey´s HSD presented in Table 3 revealed significant differences between experimental sites and among years and cultivars. The means for the year x site interaction showed, that GY at the site A was significantly higher by 3.3; 6.8; 6.0 and 5.2 t.ha^{-1} compared to the site B. All differences between sites in 1000-GW were significant in all years, in 2015 and 2016 year the reduction in 1000-GW at the site B reached 10.1 and 9.5 g, respectively.

The difference in NE/A between sites was statistically significant in 2014, 2015 and 2016 years, mean canopy density at the site A was higher 258; 223 and 258 ears per square meter respectively. Wheats at the site A also had higher GN/E, particularly in 2013 (8 grains) and 2014 (11 grains). The difference between mean GN/E was smaller in 2015 (3 grains) and non-significant in 2016 (1 grain). Due to identical sowing rates and comparable plant densities at both sites after emergence (data not given), the observed differences in GY and yield components were caused by environmental factors during plant development. Both sides have similar characteristics in terms of temperature and rainfall, but they differed in terms of soil fertility and water retention. Results suggested that the conditions at the site B were consistently poorer for plant development.

NE/A depends on number of plants and number of fertile tillers which is strongly influenced by the availability of water and N (Černý et al., 2012). Sharma (1995) stated that in spring wheat the reproductive tiller number was positively correlated with grain yield and that genetic variation existed for tiller mortality. GN/E is given by number of spikelets and number of fertile florets per spikelet. Development of floral primordia happens during rapid vegetative growth, therefore in case of limited resources there may be competition between vegetative and floral organs. Miralles et al.

Table 3. Means for GY, 1000-GW, NE/A and GN/E parameters calculated for Year, Site and Cultivar effects. Tukey´s HSD is given for each group of means

Factor		N	GY	1000-GW	NE/A	GN/E
Year	2013	52	8.2	40	571	36
	2014	52	8.2	44	580	31
	2015	52	9.3	39	712	33
	2016	52	7.7	38	620	33
Tukey´s HSD			0.2	0.8	25.6	1.3
Site	Site A	104	11.0	44	716	36
	Site B	104	5.7	37	526	30
Tukey´s HSD			0.1	0.4	13.7	0.7
Cultivar	Aladin	8	8.3	41	665	30
	Baletka	8	8.1	36	627	34
	Bohemia	8	7.9	44	579	30
	Cimrmanova r.	8	8.2	40	646	32
	Dagmar	8	8.3	42	677	29
	Dulina	8	8.3	40	625	32
	Elan	8	8.4	40	619	33
	Elly	8	8.7	41	642	33
	Etana	8	8.4	42	570	34
	Fakir	8	8.3	40	587	34
	Forhand	8	7.9	42	632	29
	IS Conditor	8	8.6	37	708	32
	JB Asano	8	8.2	44	568	32
	KWS Ozon	8	8.5	41	573	35
	Lavantus	8	8.3	36	684	33
	Matchball	8	8.6	35	658	36
	Matylda	8	8.4	40	694	30
	Midas	8	8.3	40	612	34
	Patras	8	8.2	43	574	32
	Princeps	8	8.1	43	562	33
	Sailor	8	8.3	39	634	33
	SY Passport	8	8.5	37	540	42
	Tobak	8	8.9	38	601	37
	Turandot	8	8.2	44	630	29
	Vanessa	8	8.5	39	665	32
	Zeppelin	8	8.5	42	570	35
Tukey´s HSD			0.8	3.0	94.6	4.9

Table 4. Means for GY, 1000-GW, NE/A and GN/E parameters calculated for Year x Site interactions. Tukey´s HSD is given for each group of means. Differences represent relative reduction of values at site B in comparison with site A

Year	Site	N	GY	1000-GW	NE/A	GN/E
2013	Site A	26	9.8	43	582	40
2013	Site B	26	6.6	37	561	32
Difference			3.3	5.8	21	8
2014	Site A	26	11.5	46	709	36
2014	Site B	26	4.8	42	451	25
Difference			6.8	3.2	258	11
2015	Site A	26	12.3	44	823	34
2015	Site B	26	6.3	34	600	31
Difference			6.0	10.1	223	3
2016	Site A	26	10.3	42	749	33
2016	Site B	26	5.1	33	491	32
Difference			5.2	9.5	258	1
Tukey´s HSD			0.3	1	40	2

Table 5. Correlation coefficients between GY, 1000-GW, NE/A and GN/E calculated for 26 cultivars in four years within a site. Coefficients over 0.19 are statistically significant at p=0,05 and are indicated in bold

Site A	GY	1000-GW	NE/A
1000-GW	**0.22**	1	
NE/A	**0.53**	-0.13	1
GN/E	-0.03	**-0.25**	**-0.72**
Site B	GY	1000-GW	NE/A
1000-GW	-0.18	1	
NE/A	**0.65**	**-0.45**	1
GN/E	**0.47**	**-0.62**	0.03

(2000) suggested that extending the stem elongation period in cereals could be a way to reduce assimilate competition and thereby increase the number of fertile florets and grain yield.

Correlation coefficient calculated for four parameters within sites (Table 5) revealed that high GY at the site A was significantly associated with high NE/A (r=0.53). Significant negative relationship was found between GN/E and NE/A (r=-0.72). At the site B

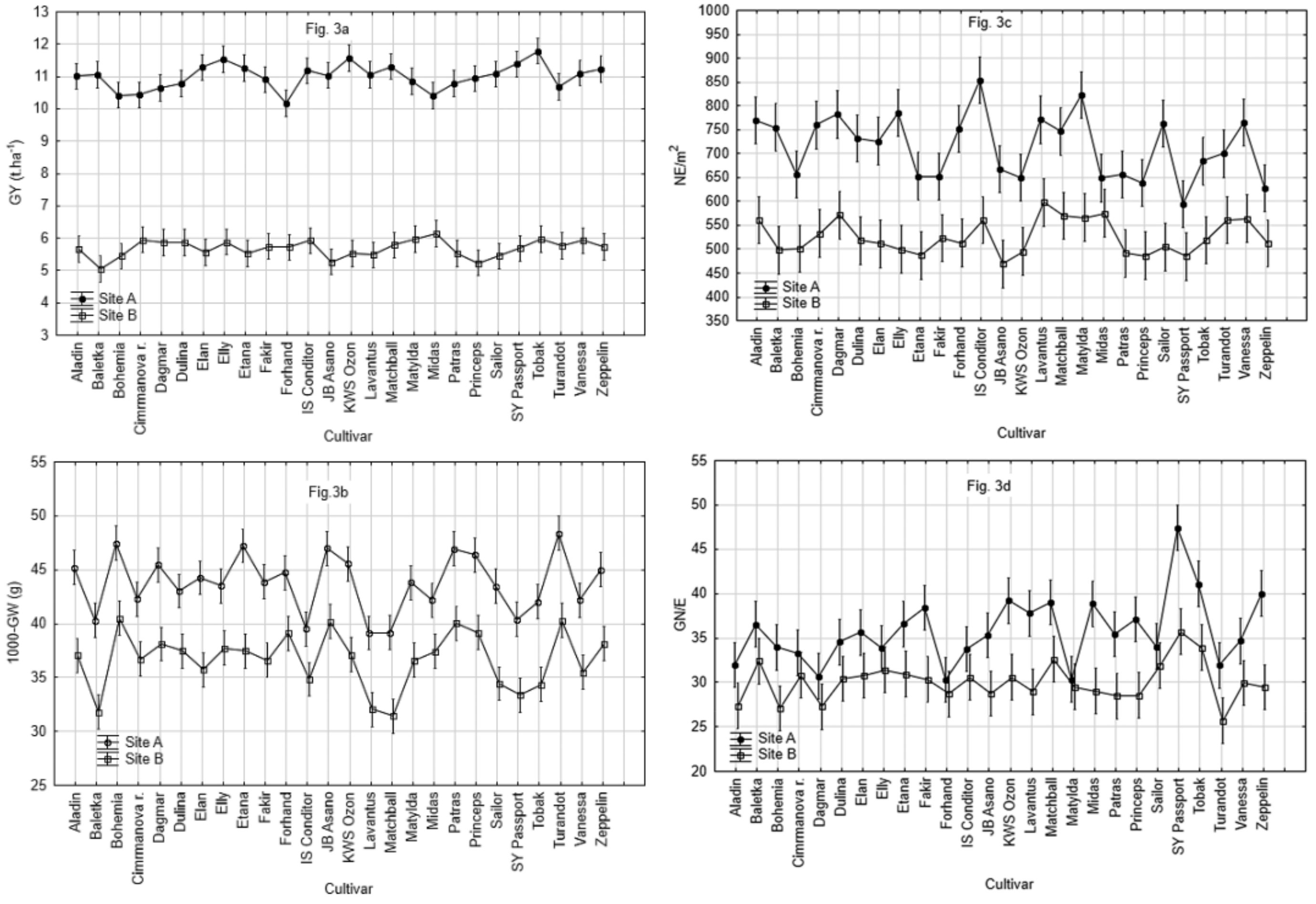

Figure 3. Group means for cultivar x site interaction. 3a displays GY, 3b is for 1000-GW, 3c for NEA and 3d for GN/E. Bars show confidence intervals for means based on MS error

Table 6. Correlation coefficients between drought tolerance indices, GY and the first and second factor of PCA calculated for 26 cultivars. Coefficients over 0.39 are statistically significant at p=0,05 and are indicated in bold

	STI	TOL	DRI	SPM	Site A GY	Site B GY
Site A GY	**0.57**	**0.85**	**-0.66**	**-0.91**		-0.10
Site B GY	**0.76**	**-0.61**	**0.81**	-0.23	-0.10	-
Factor 1	0.26	**0.97**	**-0.87**	**-0.77**	**0.94**	**-0.42**
Factor 2	**0.96**	-0.23	**0.49**	**-0.61**	0.33	**0.91**

GY was positively influenced by high NE/A (r=0.65) and GN/E (r=0.47). On the other hand, 1000-GW was negatively correlated with NE/A (r=-0.45) and GN/E (r=-0.62). Grain size is influenced by the rate and duration of the grain filling process (Simmonds et al. 2014). Under our conditions 1000-GW in the range between 40 and 50 g is considered as common and lower values signalise the presence of stress which accelerates ripening.

The comparison among cultivar performances at both sites is given using Figures 3a-d. According to ANOVA analysis, interactions between site and cultivar significantly influenced all parameters with the exception of 1000-GW (Fig. 3b). Zanke et al. (2014) stated that grain size is under strong genetic control with the heritability of H^2=0.89 and at the same time markedly influenced by the environment. The potential for bigger kernels is considered as an important selection criterion, particularly for less favourable conditions (Shpiler and Blum, 1991), although large grain size does not necessarily result in higher yields

Although the effect of water deficit in different stages of plant development on final yield is difficult to analyse due to yield component compensation, it is possible to compare cultivars according to the percentage of reduction of yield components and yield under stress conditions and consequently identify those, which respond distinctly to stress.

The improved yield under stress conditions can be either associated with high yielding potential of a genotype or with specific ability to cope with stress. Blum (2006) stated that yield under moderate stress conditions is highly dependent on the yield potential of the genotype and that moderate stress can be defined in terms of yield reduction of about 50%. With further yield reduction above that level yield potential becomes irrelevant and specific stress tolerance traits prevail.

Four yield-based drought tolerance indices were calculated for every cultivar and their values together with grain yield on normal and dry site were used for statistical evaluations. Correlation coefficients between indices and GY at both sites (Table 6) showed that GY at the site A was positively associated with STI (r=0.57) and TOL (r=0.85) and negatively associated with SPM (r=-0.91) and DRI (r=-0.66). The relationships between GY at the site B and indices were contrasting for TOL (r=-0.61) and DRI (r=0.81). The mean values for GY at both sites were not correlated (r=-0.10) which suggested different behaviour of tested cultivars under particular conditions. Mohammadi (2016) considered STI as superior indices for selection of genotypes combining high yield under both stress and optimal conditions. High values of TOL are associated with higher yield reduction under stress conditions, therefore TOL can be applied as an indicator of high sensitivity to stress (Sio-Se Mardeh et al., 2006).

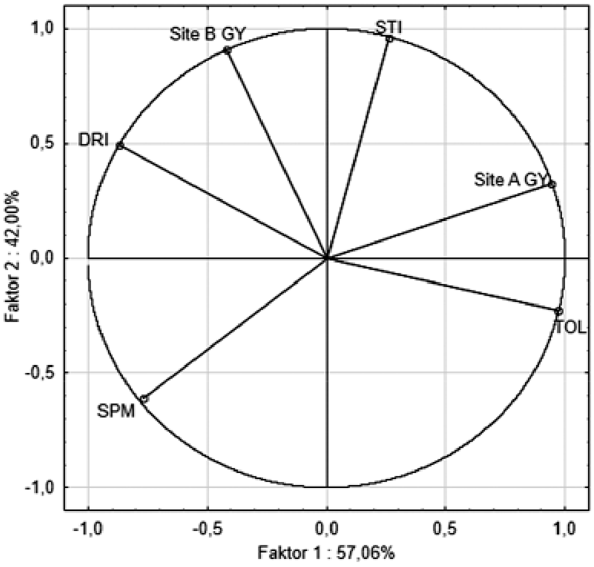

Figure 4. Biplot of factor coordinates of 4 drought tolerance indices and GY for 26 cultivars (STI - Stress Tolerance Index; TOL - Tolerance Index; DRI - Drought Resistance Index; SPM - Superiority Measure, Site A GY- grain yield at the site A; Site B GY- grain yield at the site B)

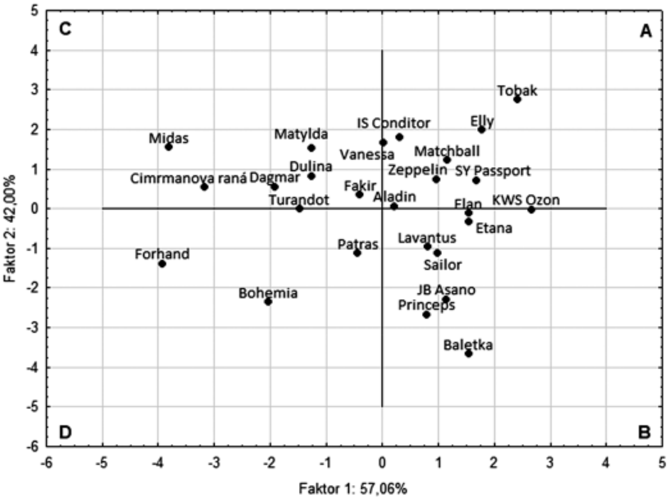

Figure 5. Projection of 26 cultivars according to their factor coordinates

Principal component analysis is commonly applied in studies focused on responses of crops to stress conditions, e.g. Drikvand et al. (2012) and Mohammadi (2016). Using our data, the analysis revealed that our 6 variables could be reduced to 2 factors, first factor explained 57 % of the total variation and the second factor added 42 %. Factor 1 was positively related to TOL (r=0.97) and GY at the site A (r=0.94) and negatively to DRI (r=-0.87), SPM (r=-0.77). Factor 2 presented variation in STI (r=0.96) and in GY at the site B (r=0.91), associations with DRI (r=0.49) and SPM (r=-0.61) were weaker (Table 6). The graphs were plotted to provide visual aid for the classification of variables and cases. Figure 4 displayed the relationships among the indices and GY. Figure 5 showed the variation among cultivars and identified those with similar characteristics with respect to the coordinate system defined by the two factors dimensions. Tested cultivars were positioned according to their yield performance into 4 groups named A-D. Group A included cultivars high-yielding at both sites, group B identified cultivars with superior performance at the site A and cultivars in C group could be noted for water-limited conditions. Cultivars in D group were inferior from the viewpoint of yield at both sites. The information about cultivar performance under stress can help farmers in selection of cultivars suitable for their conditions.

Conclusion

The study was focused on effects of growing conditions on yield parameters in wheat. One of the main factors was limited water availability which significantly reduced GY, 1000-GW, EN/A and GN/E in most seasons. High EN/A resulted in high GY regardless of conditions, whereas high GN/E was positively associated with GY only in less productive environment. Significant negative correlations between 1000-GW weight, EN/A and GN/E were found in stressed conditions only.

Using yield-based stress tolerance indices 26 winter wheat cultivars were compared according to their response to stress and non-stress conditions. The results showed that even among cultivars which had not been specifically bred for drought tolerance was possible to identify those with better performance under stress conditions. Such information can be helpful to farmers to improve the yield and its stability in drought-prone areas.

References

Annicchiarico P. (2002). Genotype x environment interactions. Challenges and opportunities for plant breeding and cultivar recommendations. FAO Plant production and protection paper, 174, pp 105, Rome, Italy

Blum A. (2006). Drought Adaptation in Cereal Crops: A Prologue. pp 3-15. In Ribaut JM (editor) Drought Adaptation in Cereals. Food Products Press, Binghamton, NY.

Blum A. (2010). Plant Breeding for Water-Limited Environments. Springer, London

Černý V., Hruška L., Petr J. (2012). Yield Formation in the Main Field Crops. pp. 337. Elsevier Science Publishers B.V., Netherlands

Drikvand R., Doosty B., Hosseinpour T. (2012). Response of Rainfed Wheat Genotypes to Drought Stress Using Drought Tolerance Indices. J Agric Sci. 4(7): 126-131

Fernandez G.C.J. (1992). Effective selection criteria for assessing plant stress tolerance. Proceedings of the International Symposium on Adaptation of vegetables and other food crops in temperature and water stress. AVRDC Publication. Tainan. Taiwan

Fischer R.A., Maurer R. (1978). Drought resistance in spring wheat cultivars. I. Grain yield response. Aust J Agric Res. 29: 897-907

Lin S., Binns M.R. (1988). A superiority measure of cultivar performance for cultivar x location data. Can J Plant Sci. 68: 193-198

Moragues M., García del Moral L.F., Moralejo M., Royo C. (2006). Yield formation strategies of durum wheat landraces with distinct pattern of dispersal within the Mediterranean basin I: Yield components, Field Crops Res. 95 (2-3): 194-205

Miralles D., Richards R., Slafer G. (2000). Duration of stem elongation period influences the number of fertile florets in wheat and barley. Aust J Plant Physiol. 27: 931-940

Mohammadi R. (2016). Efficiency of yield-based drought tolerance indices to identify tolerant genotypes in durum wheat. Euphytica. 211: 71-89

Mohammadi R., Amri A. (2008). Comparison of parametric and non–parametric methods for selecting stable and adapted durum wheat genotypes in variable environments. Euphytica, 159: 419-432

Mwadzingeni L., Shimelis H., Dube E., Laing M. D., Tsilo T. J. (2016). Breeding wheat for drought tolerance: Progress and technologies. J Integr Agric 15 (5): 935-943

Nouri A., Etminan A., Teixeira da Silva J.A., Mohammadi R. (2011). Assessment of yield, yield–related traits and drought tolerance of durum wheat genotypes (Triticum turgidum var. durum Desf.). Aust J Crop Sci 5 (1):8-16

Rosielle A.A., Hamblin J. (1981). Theoretical aspects of selection for yield in stress and non-stress environment. Crop Sci 21: 943-946. In: Mohammadi R. (2016). Efficiency of yield-based drought tolerance indices to identify tolerant genotypes in durum wheat. Euphytica. 211: 71-89

Sharma R.C. (1995). Tiller mortality and its relationship to grain yield in spring wheat. Field Crops Res. 41: 55-60

Shpiler L., Blum A. (1991). Heat tolerance for yield and its components in different wheat cultivars. Euphytica. 51 (3): 257-263

Sio-Se Mardeh A., Ahmadi A., Poustini K., Mohammadi V. (2006). Evaluation of drought resistance indices under various environmental conditions. Field Crop Res. 98: 222-229

Simmonds J., Scott P., Leverington-Waite M. et al. 2014. Identification and independent validation of a stable yield and thousand grain weight QTL on chromosome 6A of hexaploid wheat (*Triticum aestivum* L.). BMC Plant Biol. 14: 191

Talebi R., Fayaz F., Naji A.M. (2009). Effective selection criteria for assessing drought stress tolerance in durum wheat (Triticum durum Desf.). General and Appl Plant Phys. 35 (1/2): 64-74

Trnka M., Brázdil R., Olesen J.E. et al. (2012). Could the changes in regional crop yields be a pointer of climatic change? Agric for Meteorol. 166: 62-71

Zanke C.D., Ling J., Plieske J. et al. (2015). Analysis of main effect QTL for thousand grain weight in European winter wheat (*Triticum aestivum* L.) by genome-wide association mapping. Front Plant Sci. 6: 644

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