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Greenhouse test for drought tolerance of the CORNET wheat variety set

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Abstract

In a greenhouse experiment the alteration of seven agronomic characters (heading time, plant height, straw dry matter yield, spike length, number of spikelets, seed number per main spike, grain yield) was evaluated under well watered and water withdrawal conditions. The two different water regimes had a significant effect on the seven characters. Heading time, plant height, seed number per main spike and grain yield were more sensitive to water withdrawal than the other three traits. For all parameters different genotypes ranked tolerant and/or sensitive to drought stress. For breeders and growers grain yield is the outstanding character. Lowest yield losses were observed for GK Kalász, GK Fény, GK Hunyad, Premio and Komárom. The most sensitive varieties were Robigus, Exklusiv, GK Szala and Capo when the well watered treatment was compared to the water withdrawal treatment.

Keywords

Abiotic stress, drought tolerance, *Triticum aestivum*, water withdrawal, yield

Introduction

Drought is the most significant environmental stress factor restricting plant production in major parts of worldwide agricultural production. Environmental stresses, such as drought, heat shock, high salinity and low temperature, have adverse effects on plant growth and seed production. Plants respond and adapt to these stresses through various biochemical and physiological processes, thereby acquiring stress tolerance (BOYER 1982). Depending on the agriculture areas, significant yield losses can be detected in abiotic stress-hit seasons (BRAY et al. 2000). Among abiotic stresses, drought is the most frequent abiotic stress in the area of East and Central Europe. In wheat (*Triticum aestivum* L.), yield loss can amount up to 80% of the yield potential realised under optimal environmental conditions (BRAY 1997, MAJER et al. 2008). Comparing the eight major crops (wheat, barley, corn, sorghum, soybean, oat, potato, sugar beet), wheat is the most sensitive to abiotic stresses involving drought (BRAY 1997). Improvement of yield stability under (drought) stress conditions requires the optimization of several physiological functions such as regulation of water status of tissues (BRODRIBB and HOLBROOK 2003, MARTINEZ et al. 2003), photosynthesis (LAWLOR 2002, MEDRANO et al. 2002), and translocation of assimilates (BRAY et al. 2000, LAWLOR 2002, PASSIOURA 2002).

Some plants are able to cope with arid environments by mechanisms that mitigate drought stress, such as stomatal closure, partial senescence of tissues, reduction of leaf growth, development of water storage organs, and increased root length and density, in order to use water more efficiently. Water flux through the plant can be reduced or water uptake can be increased by several physiological adaptations. These mechanisms allow plants to survive in arid environments by lessening the severity of drought stress, but they do not make these plants tolerate desiccation. In fact, with long periods of drought these plants will dehydrate and die (SCOTT 2000).

Drought and high temperature occur together in many regions of the world but they usually are investigated separately. The extent of thermal as well as drought induced disruption of grain development, however, is dependent on the genotype (KAUR et al. 2011). The interaction of high temperature and drought stress results in a stronger reduction of pericarp thickness and endosperm size than each stress alone (KAUR et al. 2011).

In rain-fed agricultural regions, limited rainfall and frequent unpredictable droughts result in low and variable wheat yields. Balanced water use between root water-uptake and remaining soil moisture is a key factor for drought adaptation. A significant negative correlation was found between root water-uptake ability and grain weight, suggesting that lower root water-uptaking ability was associated with higher grain weight (MORI et al. 2011).

Drought tolerance is a complex trait. Agronomic, phenological and physiological traits, which are connected to yield and yield parameters, can be used more or less for the prediction of yield parameters (PINTO et al. 2010). However, breeding programmes deal with thousands of lines every year. Hence, tests used in selection should be fast, easy-to-apply and cheap, like the water retention ability test of excised flag leaves (CLARKE and McCAIG 1982a,b), chemical desiccation method, irrigation tests (McCAIG and ROMAGOSA 1989) and canopy thermometry. Recently, important novel tools

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are used in drought breeding programs, like rain shelters in field experiments and complex stress diagnostic system in greenhouse experiments (MAJER et al. 2008).

In the present study the drought tolerance of 25 commercial European (6 German, 9 Austrian, 8 Hungarian, 1 English, 1 French) wheat varieties was tested under well watered and water withdrawal conditions in a greenhouse experiment. Alteration of seven agronomic traits (i.e. heading date, plant height, dry matter yield of straw, spike length, number of spikelets per main spike, grain number per main spike, grain yield of main spike) were analysed. Results from the well watered treatment were compared to the water withdrawal treatment.

Material and methods

Plant material

Altogether 25 European winter wheat varieties were tested for their adaptability to drought stress within the COllective Research NETworking (CORNET) project "Wheat Stress". In detail, 4 varieties originated from Germany (2 of them were hybrid wheat varieties), 9 from Austria, 8 from Hungary and 1 from both France and Great Britain (*Table 1*).

Experimental condition

The drought tolerance experiment was carried out as pot experiment in the greenhouse. The seeds were sown into normal soil in 50×20 mm plastic pots. Two seeds were sown per pot. After germination the plantlets were vernalized for 6 weeks at 3-4°C in permanent dim light. After vernalization, the plantlets (2-3 leaves) were transplanted (4 plantlets per water regime) into black plastic pots filled with a special soil and fertilizer (1340 g sand, 526 g peat, 4 g Osmocote®).

Before starting the experiment the water capacity of the soil was determined. Two different water regimes, i.e. well watered and water withdrawal, were applied during the whole life cycle of the plants. In the well watered treatment 60% water capacity, in the water withdrawal treatment only 20% of the soil water capacity was kept for the whole run of the experiment, i.e. 4875 ml (1625 ml per plant) and 1550 ml (517 ml per plant) water were used for irrigation, respectively. Watering was done twice a week keeping permanent water conditions in the pots.

Trait evaluation

Seven agronomic traits were determined in both water treatments: heading time, plant height, dry matter yield of straw, spike length per main spike, number of spikelets per main spike, number of grains and grain dry matter yield per main spike. Dry matter was determined as follows: at harvest the above-ground biomass was harvested by scissors and dried at 48°C to permanent weight.

Statistical analysis

At least three replications were recorded for each entry and treatment. The collected data were analysed by ANOVA using MS Excel 2002 software (Microsoft Co., Redmond, WA).

Results and discussion

Heading time

One of the most significant effect of water withdrawal was the alteration of heading time. A group of 7 varieties, i.e. Eurojet, Tiger, Komárom, Hyland, Element, JB Assano and GK Kalász, headed some days) earlier in the severe drought stress treatment compared to the well watered treatment (*Figure 1*). These group was named the *rescue group* meaning that the physiology of these genotypes was accelerated by water withdrawal (*Figure 1*). Another group of varieties, i.e. GK Fény, GK Csongrád, GK Hunyad and GK Békés, form the *stable group*, showing no change in heading time between the well watered and water withdrawal treatment. The third and largest group included 14 varieties, i.e. GK Szala, Premio, Bitop, GK Petur, GK Rába, Tacitus, Brilliant, Hybred, Pegassos, Robigus, Midas, Capo, Eurofit and Exklusiv, which showed a later heading time under water withdrawal. This group was named the *lazy group.* These genotypes respond to water withdrawal by 1 to 20 days later heading.

Under severe drought stress the heading time is a very sensitive, simultaneously well detectable parameter to control the response to stress treatment(s). Similar observations were made by MAJER et al. (2008) under permanent and by KAUR and BEHL (2010) under partial drought stress during the life cycle of wheat plants, respectively.

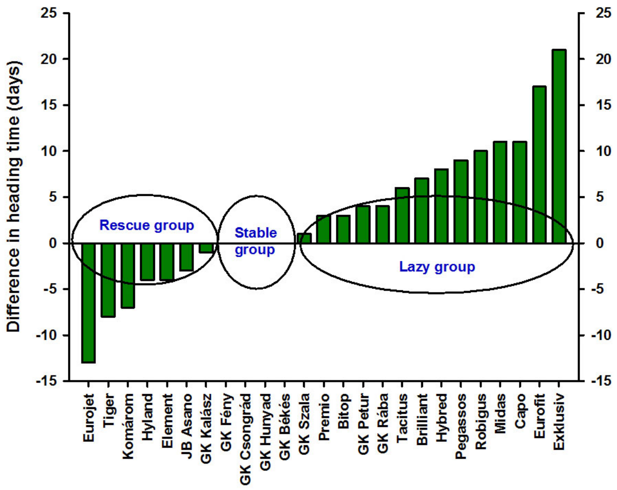

Figure 1: **Effect of two different water treatments on heading time of winter wheat: differences of the drought stress treatment compared to the well watered (control) treatment**

Plant height

Reduced plant height is a well-known symptom of drought stress. Under limited water supply, all plant species alter their green mass production (SCOTT 2000). In our experiment only a moderate effect of water withdrawal on plant height was observed for 3 varieties, i.e. GK Kalász, Premio and Komárom. These varieties tolerated water withdrawal the best of all varieties. For GK Kalász relative plant height realised under drought stress was significantly higher compared to the majority of varieties (*Table 1*). Most of the varieties were significantly not different from Hybred and Tacitus, the varieties with the highest depression (>50%) of plant height. Therefore, it can be concluded that the effect of drought stress on plant height does not lead to a good differentiation between genotypes which was also observed in a previous study (CSEUZ et al. 2009). Contrary significant differences were observed for the number of seeds per main spike and for grain yield higher (see later results) demonstrating that small grain cereals were mainly improved in regard to seed production (increase in harvest index) and not for stalk (plant height) productivity (BRAY 1997).

Table 1: **Plant height (cm) under two different water regimes and relative plant height (%) of the water withdrawal treatment compared to the control (well watered) treatment** (Varieties with the same letters are not significantly different at P=0.05, $LSD_{5\%}$=10.39)

Variety	Origin	Control (*Ctrl*)	Water withdrawal (*Wat-*)	Relative plant height (*Wat-×100/Ctrl*)
GK Kalász	HU	54.5	42.0	77.06 [a]
Premio	FR	61.5	44.3	72.08 [ab]
Komárom	AT	56.0	39.3	70.23 [ab]
Tiger	DE	85.5	56.7	66.27 [b]
Capo	AT	66.5	41.7	62.65 [bc]
Bitop	AT	84.5	52.3	61.93 [bc]
Element	AT	72.5	44.7	61.60 [bc]
Brilliant	DE	71.0	43.3	61.03 [bc]
GK Szala	HU	63.5	38.0	59.84 [bc]
JB Asano	DE	79.0	47.0	59.49 [bc]
GK Hunyad	HU	88.5	52.5	59.32 [bc]
GK Petur	HU	59.5	35.0	58.82 [bc]
GK Fény	HU	79.0	46.3	58.65 [bc]
GK Békés	HU	77.0	44.7	58.00 [bc]
Eurojet	AT	79.5	45.3	57.02 [bc]
Eurofit	AT	84.0	46.3	55.15 [c]
Hyland	DE	81.0	44.7	55.14 [c]
GK Rába	HU	75.0	41.0	54.67 [c]
Midas	AT	85.5	46.7	54.57 [c]
GK Csongrád	HU	62.0	33.7	54.29 [c]
Pegassos	DE	93.0	50.0	53.76 [c]
Robigus	UK	55.0	29.5	53.56 [c]
Exklusiv	AT	70.0	37.0	52.86 [c]
Tacitus	AT	79.5	39.7	49.89 [c]
Hybred	DE	81.5	40.3	49.48 [c]

Dry matter yield of straw

During dry seasons the quantitative difference between varieties in regard to green biomass production is clearly visible and can be evaluated by visual scoring. In the present experiment dry matter production of different yield components were determined after harvest. The dry matter yield of straw (spikes were removed) showed an interesting trend. GK Hunyad reduced its straw production only for 34.6% in the water withdrawal treatment compared to the control treatment. GK Hunyad seems to be a biomass producing genotype (vegetative type) producing a significantly higher quantity of straw. The other 24 varieties did not show significant differences in comparison with each other. However, the mean values of Hybred, Tiger, Element, GK Békés, GK Szala, GK Kalász and Exklusiv were significantly not different from GK Hunyad (*Table 2*). In regard to straw dry matter yield the same tendency was obtained as for plant height: the differences between the genotypes in both the well watered and the water withdrawal treatment were not outstanding to allow efficient selection. Similar results were obtained by other authors (BRAY 1997, CLARKE and McCAIG 1982a, MORI et al. 2011).

Table 2: **Straw dry matter yield (g) under two different water regimes and relative straw yield (%) of the water withdrawal treatment compared to the control (well watered) treatment** (Varieties with the same letters are not significantly different at P=0.05, $LSD_{5\%}$= 10.39)

Variety	Control (*Ctrl*)	Water withdrawal (*Wat-*)	Relative straw yield (*Wat-×100/Ctrl*)
GK Hunyad	5.96	2.06	34.56 [a]
Hybred	4.84	1.35	27.89 [ab]
Tiger	5.71	1.59	27.85 [ab]
Element	5.33	1.48	27.77 [ab]
GK Békés	5.21	1.43	27.45 [ab]
GK Szala	5.15	1.39	26.99 [ab]
GK Kalász	4.77	1.27	26.62 [ab]
Exklusiv	4.83	1.28	26.50 [ab]
Bitop	5.72	1.49	26.15 [b]
Eurojet	5.43	1.42	26.12 [b]
Capo	5.51	1.39	25.23 [b]
Robigus	4.83	1.21	25.05 [b]
Komárom	5.92	1.45	24.49 [b]
Tacitus	5.86	1.43	24.40 [b]
Pegassos	6.14	1.48	24.10 [b]
Eurofit	6.26	1.49	23.80 [b]
Midas	6.58	1.55	23.56 [b]
Brilliant	5.89	1.38	23.43 [b]
GK Csongrád	5.21	1.21	23.22 [b]
Hyland	6.52	1.47	22.55 [b]
Premio	6.83	1.51	22.11 [b]
GK Petur	5.71	1.26	22.07 [b]
GK Fény	5.90	1.24	21.02 [b]
JB Asano	7.43	1.55	20.86 [b]
GK Rába	5.72	1.18	20.63 [b]

Spike length

In view of spike length the differences among the tested varieties were limited. The lowest reduction in spike length in the stress treatment was achieved by Element (82.71% relative spike length), while 23 varieties from Midas to Robigus did not show significant differences (*Table 3*). Exklusiv and Robigus showed the highest reduction. The effect of drought from the first day of transplantation of plantlets into pots until harvest caused significant spike length reduction, but this depression did not depend on the genetic character of spike length (long or short spikes). There were some varieties with long spikes, e.g. Pegassos and JB Asano, which reduced their spike length only moderately, whereas on the other hand there were some genotypes with short spikes, e.g. GK Petur and Robigus, which reduced their spike length significantly. In regard to grain yield no correlation between the decrease in spike length and grain yield was observed (r_S=0.29, P=0.15). From our results it can be concluded that spike length and its reduction by drought stress is not an important character playing to be looked at. Other characters like seed number per main spike etc. have more significant effects on grain yield.

Table 3: **Spike length (mm) under two different water regimes and relative spike length (%) of the water withdrawal treatment compared to the control (well watered) treatment** (Varieties with the same letters are not significantly different at P=0.05, $LSD_{5\%}$= 10.39)

Variety	Control (*Ctrl*)	Water withdrawal (*Wat-*)	Relative spike length (*Wat-×100/Ctrl*)
Element	118.0	97.6	82.71 [a]
Midas	119.0	96.3	80.92 [ab]
GK Hunyad	112.0	88.0	78.57 [ab]
Tiger	123.5	95.0	76.92 [ab]
GK Petur	73.5	55.6	75.65 [ab]
GK Rába	106.5	79.3	74.46 [ab]
Brilliant	138.5	102.6	74.08 [ab]
Pegassos	139.5	103.0	73.84 [ab]
GK Békés	88.5	64.3	72.66 [ab]
GK Szala	99.0	69.3	70.00 [ab]
Bitop	115.0	79.6	69.22 [ab]
JB Asano	142.5	98.0	68.77 [ab]
GK Kalász	81.5	56.0	68.71 [ab]
GK Csongrád	81.0	55.3	68.27 [ab]
Premio	82.5	55.6	67.39 [ab]
GK Fény	81.5	54.3	66.63 [ab]
Eurojet	144.0	93.0	64.58 [ab]
Tacitus	120.5	75.6	62.74 [ab]
Hybred	128.0	79.3	61.95 [ab]
Hyland	126.5	75.6	59.76 [ab]
Komárom	129.0	77.0	59.69 [ab]
Capo	127.0	64.0	50.39 [b]
Eurofit	165.0	81.6	49.45 [b]
Robigus	93.5	28.3	30.27 [bc]
Exklusiv	105.0	15.0	14.29 [c]

Table 4: **Number of spikelets per main spike under two different water regimes and relative spikelet number (%) of the water withdrawal treatment compared to the control (well watered) treatment** (Varieties with the same letters are not significantly different at P=0.05, $LSD_{5\%}$= 10.39)

Variety	Control (*Ctrl*)	Water withdrawal (*Wat-*)	Relative spiklet number (*Wat-×100/Ctrl*)
GK Petur	14.0	12.3	88.07 [a]
GK Kalász	16.0	12.3	77.06 [ab]
Tiger	23.0	17.3	75.35 [ab]
GK Hunyad	20.0	14.0	70.00 [ab]
Midas	23.0	16.0	69.57 [ab]
Pegassos	25.0	16.7	66.64 [ab]
Tacitus	24.0	15.7	65.25 [ab]
Brilliant	22.5	14.7	65.16 [ab]
Eurojet	24.5	15.7	63.92 [ab]
GKCsongrád	19.0	12.0	63.16 [b]
GK Békés	22.0	13.7	62.09 [b]
JB Asano	20.0	12.3	61.65 [b]
Komárom	19.5	11.7	59.80 [b]
Premio	15.5	9.0	58.06 [b]
Hybred	23.5	13.7	58.13 [b]
Bitop	19.5	11.0	56.41 [b]
GK Fény	21.5	12.0	55.81 [b]
GK Rába	23.5	13.0	55.32 [b]
Element	23.5	13.0	55.32 [b]
GK Szala	19.5	10.7	54.67 [b]
Hyland	24.5	11.7	47.59 [bc]
Eurofit	29.0	12.3	42.52 [bc]
Capo	22.5	9.0	40.00 [bc]
Robigus	21.5	5.0	23.26 [c]
Exklusiv	25.5	1.7	6.51 [c]

Number of spikelets

The number of spikelets per spike was counted for each genotype in each treatment. The drought stress influenced significantly the number of spikelets. However, the differences were not so pronounced. GK Petur showed the smallest decrease in number of spikelets, while the means of the following 22 varieties were significantly not different. The highest decrease in spikelet number in the stress treatment was observed for Robigus and Exklusiv (*Table 4*). The results in spikelet number were associated with the results in regard to spike length. It can be concluded that Robigus and Exklusiv were the two varieties most sensitive to drought in regard to these two spike parameters. Regarding the relative number of spikelets the range of values is very demonstrative. According to these relative values some genotypes can be described as tolerant in keeping their number of spikelets under drought, e.g. GK Petur, GK Kalász and Tiger. On the other hand some genotypes, e.g. Hyland, Eurofit, Capo, Robigus and Exklusiv, lost more than half of their spikelets under drought stress which had a significant effect on grain production.

Seed number per main spike

The number of seeds per spike is one of the agronomic most important yield component. Significant differences were detected among tested varieties. The significantly lowest reduction was measured for GK Kalász (relative mean value 61.44 %) and GK Hunyad (49.11%), while 3 varieties, i.e. Exklusiv, GK Szala and Capo, showed extreme sensitivity to water withdrawal and did not produce any seeds (*Table 5*). Seed number per (main) spike is one of the most important yield components. Big differences between genotypes were observed in the present nursery: 2 Hungarian varieties, i.e. GK Kalász and GK Hunyad, showed a moderate reduction in seeds number in the stress treatment, whereas 3 other varieties could not produce any seeds in their main spike. They showed no tolerance to the applied drought stress at all.

Grain yield

Significant differences among genotypes were obtained for grain yield losses. For all tested varieties grain yield reduction was >50% in the stress treatment. However, 3 varieties, i.e. GK Kalász, GK Fény and GK Hunyad, showed significantly lower yield losses than the majority of varieties. The highest yield losses were observed for 13 varieties, i.e. JB Asano, Midas, Tiger, Element, Pegassos, Brilliant, Eurofit, Eurojet, Hybred, Robigus, Exklusiv, GK Szala and Capo. As already mentioned above Exklusiv, GK Szala and Capo were not able to produce any seeds under the applied water withdrawal treatment (*Table 6*). From the results it is obvious that the applied life long drought stress had a very strong effect on grain production which was observed also in other studies (BOYER 1982, BRAY 1997, KAUR and BEHL 2010). The most tolerant genotype GK Kalász lost only about 50% of its grain yield, whereas the other genotypes reduced their grain yield significantly and 3 genotypes did not realise any grain yield. Grain yield loss was mainly influenced by the reduction in the number of seeds (r_s=0.89, P<0.0001).

Table 5: **Number of seeds per main spike under two different water regimes and relative seeds number (%) of the water withdrawal treatment compared to the control (well watered) treatment** (Varieties with the same letters are not significantly different at P=0.05, $LSD_{5\%}$= 10.39)

Variety	Control (*Ctrl*)	Water withdrawal (*Wat-*)	Relative seeds number (*Wat-×100/Ctrl*)
GK Kalász	32.0	19.7	61.44 [a]
GK Hunyad	56.0	27.5	49.11 [ab]
Midas	59.5	21.3	35.85 [b]
Komárom	46.5	16.3	35.12 [b]
Premio	56.0	18.7	33.32 [bc]
GK Fény	64.5	21.3	33.07 [bc]
GK Csongrád	56.5	18.3	32.44 [bc]
Element	51.5	15.7	30.41 [bc]
GK Békés	62.5	18.7	29.86 [bc]
Bitop	51.5	15.3	29.77 [bc]
Hyland	81.0	24.0	29.63 [bc]
Tacitus	76.5	21.3	27.88 [bc]
GK Rába	66.0	18.3	27.77 [bc]
Tiger	36.5	9.0	24.66 [bc]
GK Petur	50.5	9.0	17.82 [c]
Brilliant	58.0	8.3	14.36 [cd]
JB Asano	58.5	7.0	11.97 [cd]
Pegassos	57.5	6.3	11.01 [cd]
Hybred	47.0	4.3	9.21 [cd]
Eurojet	49.0	3.3	6.80 [cd]
Eurofit	62.5	3.0	4.80 [cd]
Robigus	55.0	1.3	2.42 [cd]
Exklusiv	44.0	0.0	0.00 [d]
GK Szala	14.5	0.0	0.00 [d]
Capo	27.5	0.0	0.00 [d]

Table 6: **Grain yield per plant (g) under two different water regimes and relative grain yield (%) of the water withdrawal treatment compared to the control (well watered) treatment** (Varieties with the same letters are not significantly different at P=0.05, $LSD_{5\%}$= 10.39)

Variety	Control (*Ctrl*)	Water withdrawal (*Wat-*)	Relative grain yield (*Wat-×100/Ctrl*)
GK Kalász	1.56	0.67	42.95 [a]
GK Fény	2.35	0.78	33.19 [ab]
GK Hunyad	2.71	0.87	32.10 [ab]
Premio	2.37	0.74	31.22 [b]
Komárom	1.68	0.50	29.76 [b]
GK Csongrád	1.95	0.57	29.23 [bc]
GK Békés	2.67	0.64	23.97 [bc]
Hyland	2.75	0.64	23.27 [bc]
GK Rába	2.73	0.59	21.61 [bc]
Bitop	2.01	0.42	20.90 [bc]
GK Petur	1.86	0.38	20.43 [bc]
Tacitus	2.74	0.49	17.88 [c]
JB Asano	2.13	0.33	15.49 [cd]
Midas	2.01	0.27	13.43 [cd]
Tiger	1.72	0.22	12.79 [cd]
Element	1.41	0.18	12.77 [cd]
Pegassos	1.73	0.10	5.78 [d]
Brilliant	1.80	0.09	5.00 [d]
Eurofit	1.72	0.08	4.65 [d]
Eurojet	1.33	0.06	4.51 [d]
Hybred	1.16	0.05	4.31 [d]
Robigus	1.52	0.02	1.32 [d]
Exklusiv	1.30	0.00	0.00 [d]
GK Szala	0.67	0.00	0.00 [d]
Capo	0.68	0.00	0.00 [d]

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