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Responses of Different Wheat Genotypes to Drought Stress Applied at Different Growth Stages

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Abstract: Environmental stress especially drought stress can play an important role in the reduction of plant growth and development. In order to study the effects of drought stress on different growth stages of wheat, an experiment was conducted with five Iranian variety included Atrak, Red-Seed, Cross-Flat, Hirmand and Darab. A split plot design was used with drought treatment being the main plot and cultivar the subplot with three replications. Poorest yield were when drought stress was applied at flowering. It was shown that the most sensitive crop stage in terms of the total number of spikelets is at early stem elongation. Onset of the drought stress at flowering had the greatest damaging effect on seeds per spikelet. The most damaging to seed size was drought stresses applied at and just after flowering. Significant interactions occurred because Darab the highest yielding cultivar and Red-Seed the lowest yielding cultivar both showed an equal and great reduction in seed size under the drought stress while Hirmand was much less responsive. Morphological characters are likely to be affected by water stress. The results of this study indicate that if water for irrigation is scarce and needs to be conserve any saving should not be at the risk of causing drought stress around anthesis. Hirmand, while not the highest yielding cultivar is more stable over the range of moisture stresses applied and it could be considered as a parent to combine its stability with the higher yield potential of say, Darab.

Key words: Wheat genotypes, drought stress, morphological characters, yield

INTRODUCTION

Major challenge facing modern crop production is maintaining crop yield under adverse stress environmental condition. Drought is perhaps the main factor limiting crop production world wide (Jones and Corlett, 1992). In water deficient condition management practices can help to reduce yield loss, but great progress can also achieve through genetic improvement (White *et al*., 1994; Singh, 2001).

Plant responses to water stress include morphological and biochemical changes and later as water stress become more severe to functional damage and loss of plant parts (Chaves *et al*., 2002). Metabolic processes at all stages of crop growth are affected by water stress (Show and Burrows, 1966). Severe water deficit during the vegetative stage results in reduced leaf area and this in turn affects tillering and spike size (Mayaki *et al*., 1976; Sandha and Harton, 1977). Photosynthesis in the leaves, peduncle and spike is reduced resulting in decreased dry matter accumulation (Petinov, 1961; Evans *et al*., 1975; Nagarajan *et al*., 1999).

During meiosis cells are extremely sensitive to moisture content and a drought at this stage will cause pollen sterility and spikelet death and at anthesis drought can cause further reductions in seed set (Saini and Lalonde, 1998). Moisture stress reduces seeds set per spike (Turner and Jones, 1980; Ehdaie *et al*., 1988). Stresses after anthesis usually result in smaller seed size (Jamieson *et al*., 1995) both from direct effects on the grain but also because of accelerated flag leaf senescence (Evans *et al*., 1970; Hafsi *et al*., 2000).

Drought stress decreased amount of grain yield and Genotype x Environmental interaction for grain yield was significant (Shahryari *et al*., 2008). Plant height, spike lengths, grain number and total grain weight for well-watered and stress plants were compared by Majer *et al*. (2008).

Significant differences among cultivars and drought stress were found, with decrease in all traits as increase in stress levels (Jajarmi, 2009).

There are genotypic differences in the extent of these effects. It is important to know these differences for breeding wheat more tolerant of moisture stress and for advising farmers in their choice of suitable genotype.

MATERIALS AND METHODS

To investigate the effect of drought stress on different growth stages of wheat, five Iranian varieties were used. The varieties consist of: (1) Atrak with 85-90 cm height and 5.8 t ha^{-1} yield at research station. (2) Red-Seed with 90-110 cm height and 3.5-4.1 t ha^{-1} yield at research station. (3) Cross-Falat, with 95-110 cm height and 3.9-5.0 t ha^{-1} yield at research station. (4) Hirmand with 80-100 cm height and 3.2-4.8 t ha^{-1} yield at research station. (5) Darab with 85-90 cm height and 5.9 t ha^{-1} yield at research station.

A split plot design was used with drought treatments being the main plot and cultivars the subplots, with 3 replications. Six drought treatments were applied: a_1 control, irrigation as required throughout the growing season, a_2 no irrigation at tillering, a_3 no irrigation at commencement of stem elongation, a_4 no irrigation at anthesis, a_5 no irrigation at the milky dough stage and a_6 no irrigation after late dough and, as subplots the cultivars.

The experiment was conducted in Iran Research Station in an area where temperatures vary from 8 to 44°C, for one year. The area has a clay soil of pH between 6-8. Previously the area had been under alfalfa. As fertilizer 100 kg ha^{-1} ammonium phosphate and 65 kg ha^{-1} urea were applied with the seed and a further 35 kg ha^{-1} urea was applied at stem elongation. Crop density was between 200 to 300 plants m^{-2}. Plots were sampled at different growth stages, separated into various plant tissues and oven dried. Components of total biomass were then measured.

RESULTS

Yield and its components: Analysis of variance results for character under investigation are tabulated in Table 1. As shown the cultivars used had significantly different attributes and that the main effects of the drought treatments gave significant responses in all attributes measured. Of more interest is that there were interactions, in that some cultivars were relatively more or less affected by the different moisture regimes than others with respect to seed yield and both numbers and size of seed.

Maximum yield was achieved under full irrigation (Fig. 1a), as expected. Poorest yields were when the drought stress was applied at flowering. Figure 2a shows that Darab (5) had the highest yields and Red-Seed (2) the lowest. Cross-Falat (3) and Hirmand (4) had a more stable seed yield across these drought treatments than the high yielding Darab explaining the significant interactions.

Most spikes were produced with full irrigation (Fig. 1b). Fewest spikes were produced when the drought stress was applied at the commencement of stem elongation. thus it can be concluded that the most sensitive crop stage in terms of the total number of spikelets is at early stem elongation. Spike emergence was delayed in some tillers and others tiller growth stopped completely in this treatment. Darab had the greatest number of spikes m^{-2}, Red-Seed the least (Fig. 2b).

There were significant main effects of drought stress and cultivar in the size of spikes produced (Fig. 2b, 3a). As well there were interactions and spike

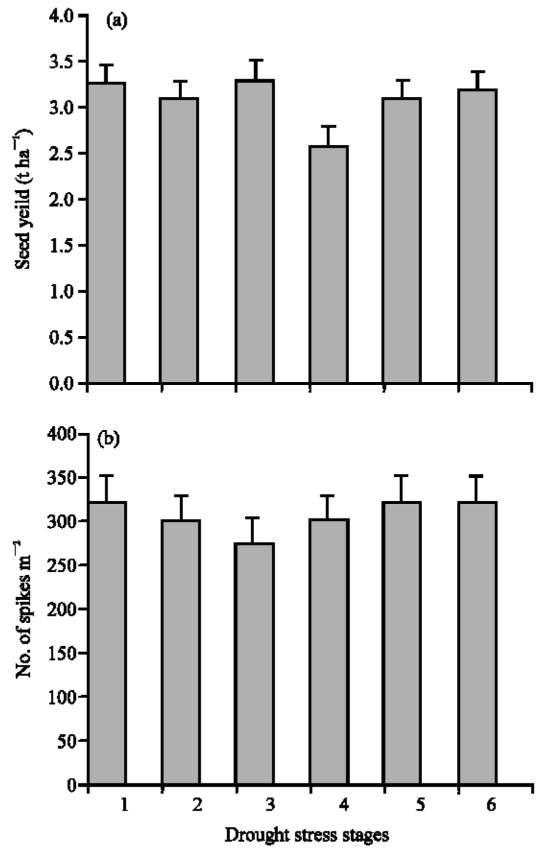

Fig. 1: (a) Effect of drought stress applied at different growth stages on seed yield and (b) number of spike m^{-2}

Table 1: Results of analysis of variance for characters under investigation

	Level of significance							
Source of variation	Seed yield	Spikes m^{-2}	Seeds spike^{-1}	1000-seed weight	Flag leaf length	Peduncle length	Biomass	Harvest index
Drought stress (D)	**	**	**	**	*	*	**	**
Cultivar (C)	**	**	**	**	**	**	**	**
Interaction (D×C)	**	**	**	**	ns	ns	ns	ns

**p<0.01, *p<0.05, ns: Not significant

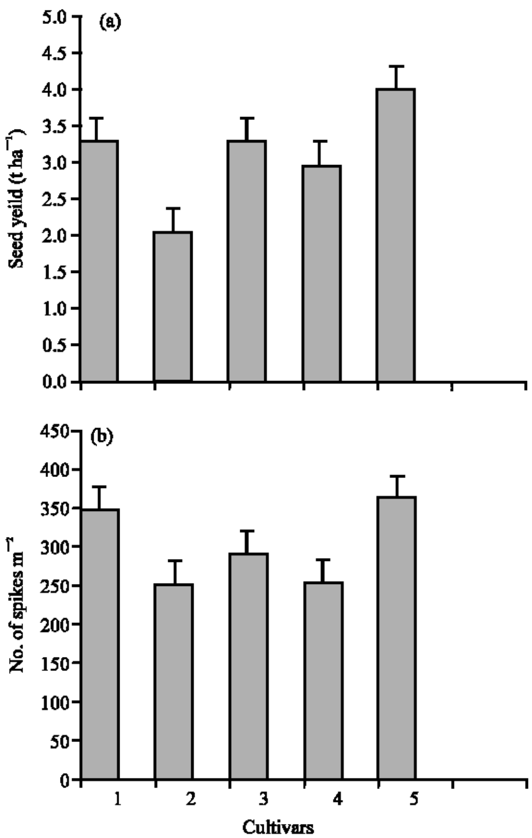

Fig. 2: (a) Cultivar effect on seed yield and (b) number of spike m^{-2}

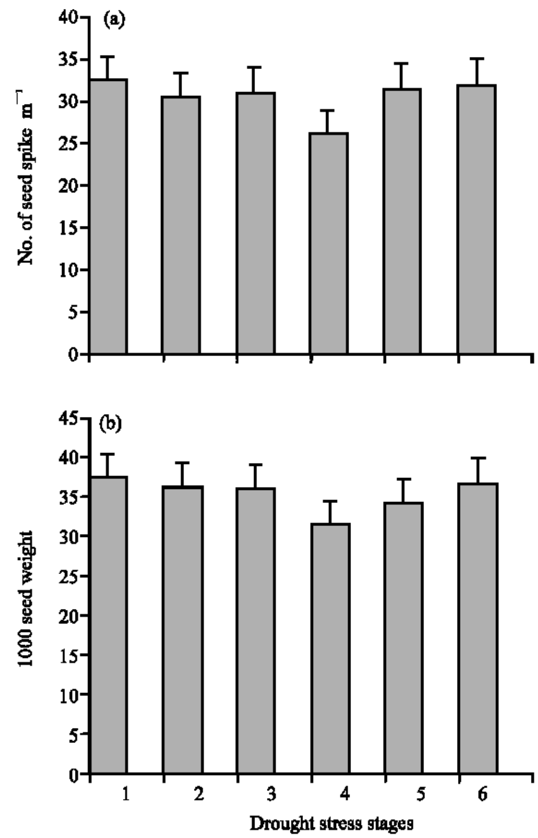

Fig. 3: (a) Effect of drought stress applied at different growth stages on number of seed per spike and (b) 1000 seed weight

size of cultivars Darab and Red-Seed was severely damaged by drought stress, while Hirmand was more stable. Overall the onset of the drought stress at flowering had the greatest damaging effect on seeds per spikelet.

Atrak had the highest mean number of seeds per spike and Cross-Falat the lowest.

The number of seeds spike^{-1} and the size of those seeds determines yield. There were significant differences in way in which the seed size of cultivars varied with different drought treatments. Overall drought stresses applied at and just after flowering were the most damaging to seed size, stages 4 and 5 in Fig. 3b. Significant interactions occurred (Table 1) because Darab the highest yielding cultivar and Red-Seed the lowest yielding cultivar both showed an equal and great reduction in seed size under the drought stresses 4 and 5, while Hirmand was much less responsive.

It can be seen (Fig. 2b, 4a, b) that the cultivars in this study reach their yields by different combinations of spike number, spike size and seed size. Cross-Flat for example has the largest seed but because its spikes are smaller its yield was less than that of Darab. Red-Seed has poor spike size and seed size so its yield is poor.

Morphological characters: The results from measuring and analyzing morphological attributes are shown in Table 2. Characters such as flag leaf length, peduncle length, total biomass and harvest index, characters which from other research are likely to be affected by drought stress and could explain responses to seed yield. There was no D×C interactions (Table 1).

Flag leaf length was significantly affected by moisture stress but the differences were too small to help explain changes in seed yield. Red-Seed had a much smaller flag leaf than other cultivars.

Peduncle length was also statistically affected by some drought stresses but again these changes were quite small. Red-Seed had the shortest peduncle.

Biological yield, total biomass, is important for use of a crop as livestock feed, but if grain is the only economical yield, then its reduction is not important unless it affects grain yield. There were big differences caused by drought stress most marked in those stresses applied after anthesis. All cultivars had their biomass similarly suppressed by late droughts. Once again Red-Seed showed up as being different to other cultivars by having a much lower biomass at harvest.

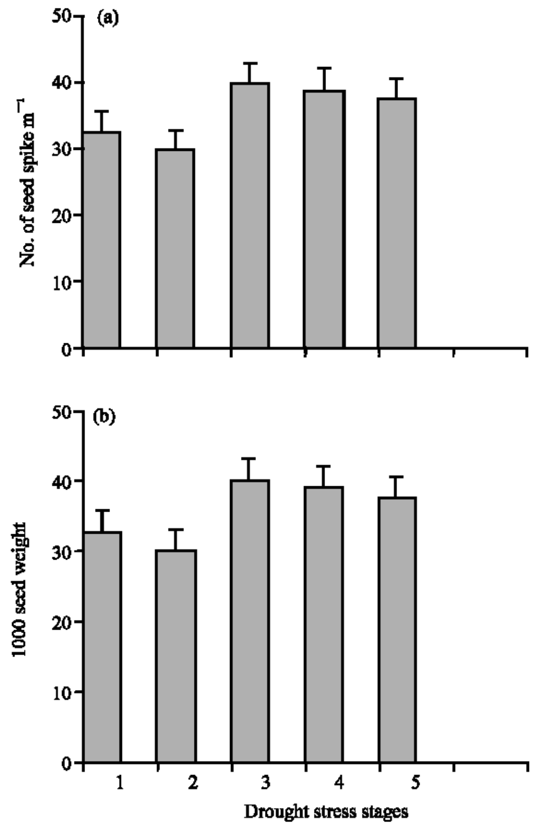

Fig. 4: (a) Cultivar effect on number of seed spike^{-1} and (b) 1000 seed weight

Table 2: Changes induced by the effects of cultivars and drought stress at different growth stages on morphological characteristics

Cultivar	Flag leaf length (cm)	Peduncle length (cm)	Biomass t ha^{-1}	Harvest index (%)
Atrak	30.48	18.32	15.98	23.50
Red-Seed	25.70	15.21	12.50	19.20
Cross-Falat	29.95	17.35	14.95	23.80
Hirmand	28.89	16.22	13.35	22.50
Darab	29.98	19.60	17.00	23.88
SE	0.21	0.30	0.12	0.65
Times of stress				
No stress	29.87	18.98	16.31	26.52
Tillering	28.95	18.25	15.98	20.58
Stem elongation	28.28	17.21	15.62	20.00
Anthesis	29.00	17.21	14.95	17.85
Milky dough	29.50	17.00	13.75	24.00
Late dough	29.50	17.21	12.51	30.00
SE	0.32	0.33	0.17	1.02

Maximum harvest index, that portion of biological yield which forms the economic yield, was attained with the late application of moisture stress, late dough stage. Red-Seed had the lowest harvest index.

DISCUSSION

Cultivars used had significantly different attributes and of more interest was that there were interactions for cultivars and drought stress since. Darab (5) had the highest yields and Red-Seed (2) the lowest. Cross-Falat (3) and Hirmand (4) had a more stable seed yield across these drought treatments than the high yielding Darab explaining the significant interactions. Highly significant genotype x water stress interaction was also reported (Sial *et al*., 2009).

Under full irrigation maximum yield was achieved and poorest when the drought stress was applied at flowering (Pirayvatlou, 2001; Mirbahar *et al*., 2009). Differences in drought tolerant of wheat cultivar presented by Akram *et al.* (2004). It was also reported that high yielded variety affected more under stress condition than low yield one (Lizana *et al*., 2006).

Fewest spikes were produced when the drought stress was applied at the commencement of stem elongation. Spike emergence was delayed in some tillers and others tiller growth stopped completely in this treatment, agreeing with observations by Henckel (1964). Cultivars which are more free tillering such as Darab can produce more spikes if there are no constraints (Shabestary and Mojtahedi, 1989). Thus, it can be concluded that the most sensitive crop stage in terms of the total number of spikelets is at early stem elongation.

Spike size of cultivars Darab and Red-Seed was severely damaged by drought stress, while Hirmand was more stable. Overall, the onset of the drought stress at flowering had the greatest damaging effect on seeds per spikelet, again agreeing with published data (Canny, 1960).

Drought stresses applied at and just after flowering were the most damaging to seed size, the same results were found by Mirbahar *et al.* (2009).

Cultivars in this study reached their yields by different combinations of spike number, spike size and seed size. The different yield components of these cultivars and the relative stability of Hirmand across the drought treatments challenges breeders to wonder whether it is possible to combine the best of these attributes into a new improved cultivar.

Morphological characters such as flag leaf length, Peduncle length were statistically affected by some drought stresses but these changes were quite small to help explain changes in seed yield. Red-Seed had a much smaller flag leaf and peduncle than other cultivars.

There were big differences in total biomass, caused by drought stress, applied after anthesis. It is surprising that there were no interactions between cultivar and the timing of the stress as this was expected from work by Nagarajan *et al.* (1999).

Maximum harvest index was attained with the late application of moisture stress, late dough stage. Translocation from senescing leaves to the seed is sped up at this stage and because the plant and grain are drying out faster than if irrigated there is less loss of biomass by continued transpiration. Minimum harvest index resulted from moisture stress applied at flowering due mainly to reduce seed set and so a smaller sink for photosynthates. Red-Seed had the lowest harvest index.

It is essential to develop drought stress tolerant wheat genotypes to ensure sustainable and productive wheat production under changed climate conditions. The results of this study indicate that if water for irrigation is scarce and needs to be conserved any saving should not be at the risk of causing drought stress around anthesis. Cultivar Red-Seed is very different to the other cultivars being more prone to drought stress. Hirmand, while not the highest yielding cultivar is more stable over the range of moisture stresses applied and it could be considered as a parent to combine its stability with the higher yield potential of say, Darab.

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