JKAU: Met., Env. & Arid Land Agric. Sci., **Vol. 21,** No.1, pp: 81-92 (2010 A.D./1431 A.H.)
DOI: 10.4197/Met. 21-1.6

Performance of Yield and Stability of Wheat Genotypes under High Stress Environments of the Central Region of Saudi Arabia

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Abstract. The current study aimed at assessing the heat tolerance of twelve wheat genotypes under four environmental conditions (two sowing dates and two years). Wheat genotypes were sown at two dates: December (favorable) and January (heat stress) during winter seasons of 2005/2006 and 2006/2007. The combined analysis of variance showed that plant height, spike length, number of kernels per spike, harvest index and grain yield were significantly influenced by years, sowing dates, and genotypes. The results showed that sowing at the first date increased plant height, grain yield, and harvest index. Highly significant genotype differences were recorded for all characters. In general, genotypes (YR-19 and YR-20) produced the highest grain yield in both seasons, while, local cultivar 'Sama' produced the lowest grain yield. Regarding the interaction effect between sowing dates and wheat genotypes on grain yield, YR-20 produced the highest grain yield under the first sowing date. The stability analysis revealed that genotypes YR-19 and YR-20 showed high and stable yielding. On the other hand, YR-2 and YR-3 showed below-average stability (b = 1.582 & 1.594). Also, the genotypes YR-20 and YR-19 were relatively heat resistant (HSI values < 1), while local cultivar 'Sama' and YR-2 were relatively heat susceptible (HSI > 1).

Introduction

Wheat (*Triticum aestivum* L.) is one of the most important crops of Saudi Arabia, and improvement in its productivity has played a key role in making the country self-sufficient in food production. However, in the past decade there has been marginal increase in the productivity of wheat, particularly under environments relatively favorable for growth and development of wheat (Joshi, *et al.*, 2007). On the other hand, there is substantial scope for improvement in productivity under unfavorable environments that are characterized by a significant presence of abiotic stresses such as high temperature (Aggarwal, 1991 and Joshi *et al.*, 2007).

Continuous high-temperature stress for wheat has been defined as when the mean average temperature of the coolest month is greater than 17.5° C (Fischer and Byerlee, 1991). Terminal heat stress largely refers to rise in temperatures at the time of grain growth. In wheat, high temperatures (>30° C) after anthesis can decrease the rate of grain-filling (Randall and Moss, 1990; Stone *et al.*, 1995; and Wardlaw and Moncur, 1995), while high temperatures imposed before anthesis can also decrease yield (Wardlaw *et al.*, 1989a). Under controlled experiments, grain yield of wheat per spike was reduced by 3 to 4% per 1° C increase in temperature over 15° C. (Wardlaw *et al.*, 1989 a, b). The effect of short periods of exposure to high temperatures (>30° C) on wheat grain yield are thought to be equivalent to a 2 to 3° C warming in the seasonal mean temperature (Wheeler *et al.*, 1996). Also up to a 23% reduction in grain yield has been reported from as little as 4 days of exposure to very high temperatures (Randall and Moss, 1990 and Stone and Nicolas, 1994).

According to an estimate, there are currently around 9 million ha of wheat in tropical or subtropical areas that experience yield losses due to high-temperature stress (Lillemo *et al.*, 2005). Intensity of high temperatures is likely to become much larger if current trends and future predictions about global warming continue (Kattenberg *et al.*, 1995). Furthermore, current recommendations for crop management practices that can reduce heat stress to plants rely heavily on additional inputs, especially irrigation water (Badaruddin *et al.*, 1999). This is an additional concern given that water resources around the globe are shrinking (World Meteorological Organization, 1997), and there is need of more sustainable and environmentally friendly approaches for increasing productivity.

Genotypes suited to late-sown environments having heat stress have been developed primarily through empirical selection with greater emphasis on grain yield and biotic stresses. Genotypes that perform better in highly stressed environments at one location may perform better at similar locations elsewhere (Reynolds *et al.*, 1994). High-yielding genotypes do not perform on par with abiotic stress–adapted genotypes when yield is depressed below a crossover point (Blum, 1996). Although, approaches other than that based on breeding for yield per se have been proposed (Reynolds *et al.*, 1998). Yield and yield traits continue to be important in measuring the success of a genotype in heat-stressed environments. A genotype with stable and high yield across the environments would be more suitable as a cultivar and also as a donor parent for further breeding in hot environments that vary over the years and within a particular year across locations.

Grain yield stability is one of the most important needs of agriculture. The ideal wheat (*Triticum aestivum* L.) genotype should be high yielding under any environmental conditions. But as genetic effects are not independent of environmental effects, most genotypes do not perform satisfactorily in all environments (Carvalho *et al.*, 1983). When interaction between genotype and environment occurs, the relative ranking of cultivars for yield often differs when genotypes are compared over a series of environments and/or years. This poses a serious problem for selecting genotypes significantly superior in grain yield (Stafford, 1982).

Various statistical techniques have been developed to identify systematic variation in individual genotypic responses. Among these, Eberhart and Russell (1966) model has been widely used in studies of adaptability and stability of plant materials (Carvalho *et al.*, 1983, and Espitia-Rangel *et al.*, 1999). The effectiveness of each method depends on the proportion of the genotype by environment interaction that each analysis can explain (Shorter *et al.*, 1991). Therefore, the choice of an adequate model to measure the stability of different genotypes is a question to be resolved by researchers. According to Crossa *et al.* (1988), the selection of superior genotypes in a plant-breeding program is based mainly on their yield potential and stable performance over a range of environmental conditions.

This study was conducted to investigate a set of 10 wheat genotypes and their parent cultivar 'Yeocra Rojo', and the local cultivar 'Sama' to identify genotypes with high yield stability under high-temperature environments that occur due to delay in planting.

Material and Methods

Field Trials

Field experiments were conducted at the Agricultural Research Station, College of Agriculture and Veterinary Medicine, Al-Qassim University, Saudi Arabia, during 2005/2006 and 2006/2007 winter seasons. The experiments were sown in two dates in both seasons. The first sowing date was 2nd and 4th of December (favorable) and the second date was 1st and 4th of January (heat stress), in both seasons, respectively. The field design was a randomized complete block in a split-plot arrangement of treatments, with three replications. Sowing dates were allocated to the main plots and wheat genotypes to the subplots. The experiments included wheat cultivars Sama and Yeocra Rojo, and the ten selected genotypes originating from immature embryos culture of cultivar Yeocra Rojo under salt stress (Barakat and Abdel-Latif, 1996). The plot size was 4x3 m with row to row spacing of 25 cm. The recommended fertilizer requirements of wheat in Al- Qassim region, Saudi Arabia, as NPK, were 200, 200 and 100 kg/ha, respectively for a growing season of 120 days on wheat, according to Bashour and Al-Jaloud (1984).

Yield and Other Measurements

At harvesting time, ten plants were randomly chosen to measure plant height, spike length, and the number of grains per spike. Harvest index was calculated as the grain mass divided by the total above ground mass

The heat susceptibility index (HSI) was used as a measure of heat tolerance in terms of minimization of the reduction in yield caused by unfavorable versus favorable environments. HSI was calculated for each genotype according to the formulae of Fisher and Maurer (1978):

$$HSI = (1 - yh/yp)/H.$$

Where: yh = mean yield in heat environment, Yp= mean yield in normal condition = potential yield, H = heat stress intensity = 1 - (mean yh of all genotypes / mean yp of all genotypes).

Statistical Analysis

Data of the two seasons were submitted to analysis of variance (ANOVA) for one factor and combined over sowing dates following

Gomez and Gomez (1984). The means of treatments were compared using the Least Significant Difference (LSD) method at 5% of probability. Statistical analysis was performed using "MSTATC" microcomputer program (MSTATC, 1990).

Stability analysis of grain yield of the tested genotypes was done for the four environmental conditions (2-sowing dates and 2-years). Stability was defined as a function of slope and deviation from the regression of cultivar yield on an environmental index. Yield stability was analyzed similar to that suggested by Eberhart and Russell (1966).

Results and Discussion

Effects of Sowing Dates and Genotypes on Plant Height, Spike Length, Grain Number per Spike, Grain Yield and Harvest Index

The combined analysis of variance (Table 1) revealed highly significant differences between genotypes, sowing dates, and years for all studied traits except spike length. Also, the ANOVA indicated that substantial variation existed for year x genotype x sowing date for yield, yield components, and plant height of genotypes. These results indicate that studied genotypes responded differently to the different environmental conditions suggesting the importance of the assessment of genotypes under different environments in order to identify the best genetic make up for a particular environment. Similar results were obtained by El-Morshidy *et al.* (2001), Abd-El-Majeed *et al.* (2005), Tawfelis (2006) and Menshawy (2007).

Table 1. Analysis of variance "*p*" values for selected sources of variation for characters measured on 12 wheat genotypes with two sowing date for 2-years.

SOV	Plant height	Spike Length	Kernels Spike^{-1}	Grain yield (gm^{-2})	Harvest index
Year (Y)	0.000	0.000	0.007	0.000	0.000
Sowing date (S)	0.000	0.211	0.002	0.000	0.000
YS	0.000	0.116	-	0.000	0.000
Genotype (G)	0.000	0.000	0.000	0.000	0.000
YG	0.015	0.000	0.001	0.000	0.000
SG	0.001	0.200	0430	0.000	0.229
YSG	0.004	0.031	0.012	0.000	0.000
CV %	7.89	8.44	13.45	17.37	11.68

Plant height, grain yield, and harvest index were decreased in the second sowing date. Spike length and kernels per spike were the yield parameters not affected by the sowing date treatments (Table 2). The reduction of grain yield by delaying sowing date could be attributed to grain–filling process that is harmfully affected by high temperatures and kernels reaching to maturity stage before complete filling (Menshawy, 2007). Tawfelis (2006) found significant variation in yield and yield component among wheat genotypes under favorable and late planting.

Highly significant genotype differences were recorded for all characters (Table 1). These variations among genotypes might partially reflect their different genetic backgrounds. Data in Table 2 illustrate plant height, grain yield and yield components of the tested 12 wheat genotypes. Local cultivar 'Sama' exhibited the tallest plants (97.8 and 97.7cm) while the shortest plants were for cultivar 'Yeocra Rojo' (62.3 and 61.8cm) in both seasons, respectively. YR-11 had the longest spikes (11.2 and 11.8cm) and the most kernels per spike (40.0 and 44.9), in both seasons, respectively. Grain yield is the end result of many complex morphological and physiological processes occurring during the growth and development of crop. The grain yield differed among wheat genotypes (Table 2). In general, genotypes (YR-19 and YR-20) produced the highest grain yield (254.8 and 270.8g/m^2) and (149.3 and 160.8 g/m^2) in both seasons, respectively.

These genotypes produced higher grain yield than its parent cultivar Yeocra Rojo. While, local cultivar 'Sama' produced the lowest grain yield (123.3 and 84.2 g/m^2) in both seasons, respectively. Also, the last genotype gave the lowest harvest index (23.1 and 30.9%) in both seasons, respectively.

Regarding the interaction effect between sowing dates and wheat genotypes on grain yield, YR-20 produced the highest grain yield under the first sowing date (Table 3). The last genotype, YR-3 and YR-19 gave the highest yield under late sowing in the first season. Moreover, YR-20 produced a high grain yield (283.7 and 118.7gm^{-2}) under the first and second sowing dates, in the second season. A possible explanation can be that the photothermal non responsive genotypes were always late in heading which occurred in time irrespective of sowing dates (Kumar *et al*., 1995). Such genotypes could tolerate high temperature and are suitable for early sowing. These results are in agreement with those of Menshawy, *et al*. (2007).

Table 2. Effect of Sowing date (S1 and S2), genotypes and their interaction on studied characters for 2005/06 and 2006/07 seasons.

Treatment	Plant height		Spike length		Kernels spike^{-1}		Grain yield (gm^{-2})		Harvest index	
	05/06	06/07	05/06	06/07	05/06	06/07	05/06	06/07	05/06	06/07
Sowing dates										
S1	72.9	75.6	9.6	8.3	36.3	34.6	211.6	165.2	45.4	34.7
S2	73.9	62.6	10.0	8.2	39.6	36.7	167.2	84.8	41.3	22.4
F test	NS	**	NS	NS	NS	NS	**	**	*	**
Genotypes										
Local	97.8	97.7	9.1	9.0	37.6	35.5	123.3	84.2	23.1	30.9
YR2	68.2	62.5	9.2	9.0	35.0	38.1	193.3	94.3	32.4	34.0
YR3	69.2	65.7	9.1	9.2	32.2	38.4	189.3	133.1	32.9	39.3
YR4	67.2	62.0	8.7	9.2	34.8	41.4	213.8	119.4	38.8	38.8
YR5	68.8	68.0	8.7	9.1	35.4	38.4	190.5	136.4	36.9	39.1
YR6	72.7	66.5	9.3	9.5	35.5	37.0	183.7	130.5	34.0	41.8
YR7	68.5	65.7	9.0	8.2	36.4	40.2	144.5	121.6	35.1	41.8
YR11	73.2	65.0	11.2	11.8	40.0	44.9	197.3	138.5	35.5	38.9
YR12	71.8	58.3	8.3	8.3	31.2	32.1	115.7	100.8	31.3	34.4
YR19	82.7	76.3	8.5	8.2	36.7	41.7	254.8	149.3	37.7	38.7
YR20	88.8	69.3	8.5	8.8	36.8	38.2	270.8	160.8	34.7	37.5
YR	62.3	61.8	7.7	8.8	33.9	31.9	183.1	143.1	34.1	40.6
LSD	3.8	8.4	0.6	1.1	6.4	4.9	26.0	36.6	4.11	5.5
Interaction										
G×S	NS	**	**	NS	NS	*	**	**	**	NS
CV%	4.46	10.5	5.7	11.1	14.6	12.0	11.8	25.1	8.2	16.6

*, ** Significant at 0.05 and 0.01 levels of probability, respectively

Table 3. Effect of interaction between sowing date and genotypes on grain yield in two seasons.

Genotypes	Grain yield (gm^{-2})			
	05/06		06/07	
	S1	S2	S1	S2
Local	115.0	104.7	131.7	63.67
YR2	250.0	148.0	136.6	40.67
YR3	247.3	219.5	131.3	46.67
YR4	250.0	169.8	177.7	69.0
YR5	249.3	189.4	131.7	83.3
YR6	218.3	187.7	149.0	73.3
YR7	152.3	152.0	136.7	91.2
YR11	259.0	197.0	135.7	80.0
YR12	105.0	101.7	126.3	100.0
YR19	220.0	193.0	289.7	105.7
YR20	258.0	203.0	283.7	118.7
YR	214.0	140.0	151.8	145.7
LSD at 0.05	36.8		36.6	

Heat Susceptibility Index and Stability Analysis

The combined analysis of variance of grain yield is given in Table 4. There were significant differences for environments (E), genotypes (G), and genotype by environment (G×E). Highly significant genotype × environment interactions for many wheat traits were previously reported (Kheiralla *et al*. 2004, and Mahmoud 2006). Singh and Narayanan (2000) reported that, if G × E interaction is found to be significant, the stability analysis can be carried out.

The values of grain yield and regression coefficient (b) and regression deviation (S2d) of 12 genotypes are given in Table 4. According to the Eberhart and Russell (1966) model, a stable cultivar is one with a high mean yield, unit regression coefficient (b=1) and deviation from regressions as small as possible (S2d = 0).

Table 4. Mean squares of combined analysis of variance for grain yield.

Source of variation	df	Mean squares
Environments (E)	3	100275.5**
Rep/E	8	2365.3
Genotypes (G)	11	12830.0**
E×G	33	46086.7**
Error	88	745.1

*, ** Significant at 0.05 and 0.01 levels of probability, respectively

In the analysis of 4 environments, the genotypes YR-19 and YR-20 gave high mean yields and regression coefficient (b) not significantly different from the unit. On the other hand, YR-2 and YR-3 showed below-average stability (b = 1.582 & 1.594) indicating that these genotypes perform well under favorable conditions, whereas its grain yield reduce markedly under stress conditions. Genotypes with b = 1 are considered the most appropriate for farmers, since they respond satisfactorily to environmental conditions, while genotypes with b> 1 are sensible to improvement of the environment and genotypes with b <1 do not respond to improvement of the environment (Okuyama *et al*., 2005).

Heat susceptibility index values (Table 5) ranged from 0.49 to 1.38. The genotypes YR-20 and YR-19 were relatively heat resistant (HSI values < 1), while local cultivar 'Sama' and YR-2 were relatively heat susceptible (HSI > 1). Heat susceptibility index is a measure of yield stability (Ahmad *et al*., 2003). The HSI has sometimes been represented as providing a measure of genotypic yield potential under heat stress conditions (Brukner and Frohberg, 1987). However, HSI does not account for differences in yield potential among genotypes (Clarke *et al*., 1992). HSI actually provides a measure of yield stability based on minimization of yield loss under stressed, compared to non stressed conditions rather than on yield level under dry conditions per se (Clarke *et al*., 1984). Therefore, a stress tolerant genotype as defined by HSI, needs necessarily not to have a high yield potential.

Table 5. Heat susceptibility index (HSI) and stability parameters for grain yield (gm-2) of the 12 bread wheat genotypes over four environments.

Genotype	Mean	b_i	±SE	HSI (Mean of 2-years)
Local	103.8	0.448	±0.224	1.38
YR2	143.8	1.582	±0.252	1.38
YR3	161.2	1.594	±0.465	1.14
YR4	166.6	1.402	±0.105	0.99
YR5	163.4	1.253	±0.375	0.94
YR6	157.1	1.153	±0.199	1.01
YR7	133.0	0.514	±0.131	1.25
YR11	167.9	1.358	±0.387	0.87
YR12	108.3	0.060	±0.158	0.96
YR19	202.1	1.024	±0.718	0.75
YR20	215.8	1.165	±0.527	0.49
Yocora Rojo	163.1	0.446	±0.337	0.93
Mean	157.2			

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السلوك المظهري للمحصول ودرجة الثبات في التراكيب الوراثية للقمح تحت ظروف الإجهاد الحراري للمنطقة الوسطى في المملكة العربية السعودية

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قسم إنتاج النبات ووقايته – كلية الزراعة والطب البيطري – جامعة القصيم
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المستخلص. تهدف الدراسة إلى تقييم التحمل الحراري لـــ ١٢ تركيب وراثي من القمح تحت ظروف أربع بيئات (موعدان زراعيان وسنتان). وزرعت التراكيب الوراثية للقمح في ميعادين: ديسمبر (الملائم) ويناير (الإجهاد الحراري) خلال الموسمين ٢٠٠٥/٢٠٠٦ و٢٠٠٦/٢٠٠٧م. وأظهر تحليل التباين التجميعي أن طول النبات، وطول السنبلة، وعدد الحبوب في السنبلة، ومعامل الحصاد، ومحصول الحبوب كانوا متأثرين معنويا بالسنوات، ومواعيد الزراعة، والتراكيب الوراثية. وأظهرت النتائج أن الميعاد الأول زاد من طول النبات، ومعامل الحصاد، والمحصول. و كانت هناك اختلافات معنوية بين التراكيب الوراثية في كل الصفات المدروسة. وعموما أعطى التركيبان الوراثيان YR-19 & YR-20 أعلى محصول في كلا الموسمين. بينما أعطى الصنف المحلي ’صامة‘ أقل محصول. وبالنسبة للتفاعل بين التراكيب الوراثية ومواعيد الزراعة، أعطى YR-20 أعلى محصول في الميعاد الأول. وبين تحليل الثبات أن التركيبين الوراثيين YR-19 & YR-20 كانا ذوا أعلى محصول ودرجة ثبات. بينما التركيبان الوراثيان YR-3 & YR-2 كانا أقل ثباتاً. و أيضا كان التركيبان الوراثيان YR-19 & YR-20 ذوا مقاومة نسبية للحرارة (HSI values < 1)، بينما كان الصنف المحلي ’صامة’ وYR-2 ذو حساسية نسبية للحرارة (HSI > 1).