Evaluation of Variation among Durum Wheat F_3 Families for Grain Yield and its Components under Normal and Water-Stress Field Conditions

M. Golabadi, A. Arzani and S. M. M. Maibody

Department of Agronomy and Plant Breeding, College of Agriculture, Isfahan University of Technology, Isfahán, 84156, Iran, e-mail: m_golabadi@ag.iut.ac.ir; a_arzani@cc.iut.ac.ir; maibody@cc.iut.ac.ir

Abstract: Genetic variation in grain yield and morpho-physiological traits were evaluated among 151 F_3 families obtained from a drought tolerant and a drought susceptible hybrid genotype. Most traits, including grain yield, grain yield components, harvest index, excised leaf water retention, and relative water content, were significantly and negatively affected by drought stress. Genetic variance and heritability estimates were highest under drought stress for some traits but for harvest index and relative water content they were highest under irrigation. Selection for higher grain yield, for dry environment should be conducted under stress conditions; for 1000-grain weight, grain weight per spike and harvest index, selection can be accomplished under non-stress environments. Selection criteria for improving grain yield include biological yield and 1000-grain weight in non-stress environment and harvest index, 1000-grain weight and grain/spike in stress environment with the highest direct effect. Relative water content and excise leaf water retention were reduced and increased, respectively, under stress; their genetic variance was reduced under stress. Selection for high tolerance to drought stress in F_3 generation or later should be effective.

Keywords: durum wheat; genetic variation; drought; tolerance; susceptible; morpho-physiological; heritability

Production of wheat is constrained by drought in many regions of the world. Because of the severe limitations imposed by drought, development of cultivars with improved productivity under water stress is important for affected regions (Calhoun *et al*. 1994). The evaluation of drought resistance of different species should be based on the stability of dry matter and grain yield, maintenance of water status and some physiological processes. Improvement of durum wheat (*Triticum turgidum* L. subsp. *durum* Desf.) for drought tolerance may be conducted using either direct selection for tolerance or indirect selection for traits correlated with tolerance. Such correlated traits should be highly heritable and have a high genetic correlation with tolerance. To employ indirect selection, identification of morphophysiological characters conferring drought tolerance is essential.

There are contradictory reports about selection under stress and non-stress environments. Selection for high yield in an optimum environment is effective because genetic variation is usually maximized and genotype-environment interactions are low (Richards 1996), but genotypes selected under optimum environments may not have high yields under drought-stress environments (Calhoun *et al.* 1994). On the other hand, selection for yield under drought-stress conditions is complicated by low heritability and large genotype-environment interactions (Smith *et al*. 1990). Roy and Murfy (1970) suggested that the initial selection of the F_2 generation should be carried out in an optimum environment and subsequent generations should be selected simultaneously under optimum and stress condition. The aim of this study was to evaluate the variation of morphophysiological traits associated with stress tolerance, estimate their heritabilities, assess them as candidates to supplement yield as selection criteria, and to identify the environment in which selection should occur.

MATERIALS AND METHODS

Two durum wheat cultivars, whose responses to drought tolerance had been determined at four locations in central and western regions of Iran during two growing seasons (Arzani 2002), were used. Oste-Gata, the drought tolerant parent, was crossed with Massara-1, the drought susceptible parent, and F_1, F_2 and F_3 progeny produced. One hundred and fifty-one F_2 derived F_3 families were planted in a randomized complete block design with two replications in every environment in November 2003. Water stress was imposed at the 50% flowering stage. Phenotypic traits evaluated were biomass, grain yield and its components, harvest index, height of plant, peduncle length, spike length, length and width of flag leaf, spike weight; the physiological traits evaluated were relative water content (RWC) and excised leaf water retention (ELWR). The physiological traits were measured after drought stress as follows:

$$RWC\% = [(FW- DW)/ (TW- DW)] \times 100$$

and

$$ELWR\% = [1- (\text{weight of new leaves- weight of leaves after 4 hours})/\text{weight of new leaves}] \times 100$$

where: FW – fresh weight
DW – dried weight (in an oven for 72 h at 70°C)
TW – turgor weight (in distilled water for 8 to 10 hours)

Table 1. Means of traits under stress and non-stress environments and percent of variation affected by drought stress in 151 F_3 durum wheat families

Trait	Stress condition (mean ± S.E)	Non-stress condition (mean ± S.E.)	Percent variation
1	96.68 ± 9.60	91.89 ± 9.40	+5.21
2	7.59 ± 0.80	7.29 ± 0.70	+4.10
3	43.85 ± 4.60	40.14 ± 4.30	+9.20
4	12.19 ± 1.02	12.28 ± 0.90	–0.74
5	20 ± 1.70	18.69 ± 1.50	+6.97
6	1.61 ± 0.09	1.67 ± 0.18	–3.59
7	158.63 ± 1.90	157.69 ± 2.50	+0.59
8	168.26 ± 1.60	167.67 ± 1.70	+0.35
9	199.1 ± 1.80	201.4 ± 2.20	–1.16
10	1540.3 ± 31.0	1531.5 ± 31.0	+0.57
11	480.73 ± 11.0	685.7 ± 125	–29.69
12	34.29 ± 3.80	41.89 ± 2.50	–18.40
13	407.2 ± 47.7	419.6 ± 10.3	–2.96
14	2.59 ± 0.39	3.17 ± 0.31	–18.29
15	1.84 ± 0.32	2.35 ± 0.23	–21.61
16	45.06 ± 5.15	46.06 ± 4.40	–2.18
17	490.2 ± 82.9	451.4 ± 70.6	+8.60
18	31.26 ± 4.90	44.77 ± 4.90	–30.19
19	71.11 ± 5.20	74.31 ± 3.10	–4.30
20	72/89 ± 15.4	55.15 ± 11.4	+32.16
21	57.32 ± 8.40	74.86 ± 7.25	–23.43

Negative sign is related to trait reduction due to drought stress: 1– plant length (cm), 2 – spike length (cm), 3 – peduncle length (cm), 4 – awn length (cm), 5 – flag leaf length (cm), 6 – flag leaf width (cm), 7 – days to heading, 8 – days to pollination, 9 – days to maturity, 10 – biomass (g/m^2), 11 – grain yield (g/m^2), 12 – 1000 grain weight (g) 13 – test weight (g), 14 – spike weigh t(g), 15 – grain eight/spike (g), 16 – g rain/spike, 17 – spike (m^2), 18 – harvest index, 19 – spike harvest index, 20 – ELWR, 21 – RWC

The genetic correlation between 21 traits, heritability and K_G^2 for every trait and percent of variation of traits were computed from:

$$h^2x = \frac{\sigma_g^2 x}{\sigma_g^2 x + \frac{\sigma_e^2}{r}}, \quad C = \frac{\bar{x}p \times \bar{x}s}{\bar{x}p} \times 100, \quad K_G^2 = \frac{G_{22}}{G_{11}}$$

where: $\sigma_g^2 x$ – genetic variance of trait x
h^2x – heritability of x
G_{22} – genetic variance of trait x in stress environment
G_{11} – genetic variance of trait x in non-stress environment
C – percent of variation
$\bar{x}p$ – mean trait in non-stress environment
$\bar{x}s$ – mean trait in stress environment

RESULTS AND DISCUSSION

Analysis of variance showed that all traits except spike weight and grain weight per spike in two environments, number of spike per m^2 under stress environment and own length and width of flag leaf under non-stress conditions have varied significantly among the families. Thus these traits can be used as selection criteria. Percent variation due to drought stress varied widely among lines, especially for traits that were related to reproductive stage, such as grain yield, 1000-grain weight, grain number per spike, harvest index, and physiological traits RWC and ELWR (Table 1). Reductions were due to the time of stress and the effect of drought stress on important traits related to grain yield at the reproductive stage. This result is in agreement with that Blum *et al.* (1989), Pandey *et al.* (2001), and Pantuwan *et al.* (2002). Reduction in grain yield under drought stress at late season is due to reduction in grain filling period and reproductive stage, small size of grain, reduction in photosynthesis and lower transfer of photosynthetic material into grains (Westgate 1994). On the other hand, traits related to vegetative stage did not change from stress, since there was no stress at vegetative stage. Kirigwi *et al.* (2004) also suggested that biological yield in wheat did not change from late season drought stress.

Drought caused reduction in RWC and increase in ELWR. Mean RWC under stress was 57.32% of the irrigated controls (Table 1). These data established that F_3 families differed extensively in their water supply to the leaf and transpiration rate. Some F_3 families had higher RWC values and hence are more resistant. This result is consistent with Siddique *et al.* (2000) who showed that cultivars that were more drought resistant usually maintained higher leaf RWC under stress.

Table 2. Estimates of heritability and K_G^2 (ratio of genetic variances under stress and non-stress environments) in F_3 durum wheat families

Trait	h^2 stress condition	h^2 non-stress condition	K_G^2
1	0.63	0.84	0.78
2	0.80	0.81	1.06
3	0.52	0.72	0.85
4	0.69	0.21	4.85
5	0.51	0.06	10.2
6	0.81	0.23	11.9
7	0.78	0.69	0.71
8	0.76	0.7	0.95
9	0.43	0.39	0.75
10	0.46	0.47	0.95
11	0.45	0.47	0.71
12	0.41	0.39	2.48
13	0.33	0.32	8.19
14	0.12	0.21	0.94
15	0.19	0.09	3.83
16	0.39	0.25	2.23
17	0.69	0.38	0.67
18	0.53	0.62	0.98
19	0.61	0.57	0.97
20	0.74	0.75	1.78
21	0.32	0.46	0.56

1– plant length (cm), 2 – spike length (cm), 3 – peduncle length (cm), 4 – awn length (cm), 5 – flag leaf length (cm), 6 – flag leaf width (cm), 7 – days to heading, 8 – days to pollination, 9 – days to maturity, 10 – biomass (g/m^2), 11 – grain yield (g/m^2), 12 – 1000-grain weight (g), 13 – test weight (g), 14 – spike weight (g), 15 – grain weight/spike (g), 16 – grain/spike, 17 – spike (m^2), 18 – harvest index, 19 – spike harvest index, 20 – ELWR, 21 – RWC

The F_3 lines differed highly for ELWR. The mean of this trait increased from 55.15% to 69.23% under stress environment. Genetic variation for ELWR was already reported by Farshadfar *et al.* (2001) between and within the generation. Winter *et al.* (1988) revealed less water loss in more drought resistant cultivars.

Heritability estimates were moderately high in stress environment for some traits such as grain

Table 3. Path analysis based on genetic correlation for grain yield under drought and irrigated environments on F_3 durum wheat families

Trait	Direct effect	Indirect effect					Total effect
		1	2	3	4	5	
Harvest index	–0.12	–	–0.73	0.51	0.12	0.41	0.18
	(–2.20)	–	(–0.09)	(1.91)	(0.91)	(0.03)	(0.55)
Biomass	1.56	0.05	–	0.103	0.199	–0.991	0.93
	(0.75)	(0.26)	–	(–0.39)	(0.21)	(–0.71)	(0.76)
1000-grain weight	0.86	–0.07	0.18	–	–0.04	–0.62	0.32
	(2.81)	(–1.49)	(–0.11)	–	(–0.93)	(–0.04)	(0.32)
Grain/spike	0.47	–0.03	0.66	0.07	–	–0.56	0.47
	(2.32)	(–0.86)	(0.07)	(–1.12)	–	(–0.026)	(0.38)
Spike (m^2)	–1.22	0.04	1.27	0.44	0.22	–	0.74
	(–0.12)	(0.48)	(0.43)	(–0.95)	(0.48)	–	(0.33)

Data on parenthesis are related to stress condition; residual effect on non-stress condition = –0.101; residual effect on stress condition = –0.027

weight per spike, grain/spike, and spike (m^2) (Table 2). We obtained high h^2 in stress environment for some traits because of the high number of F_3 families with high genetic variance between them under intermediate, but not severe, stress. Heritability for grain yield, HI, RWC and ELWR were higher in non-stress environment, especially for HI and RWC. So traits that have high heritability in every environment may be useful for attention as selection criteria because of high selection efficiency. High heritability for grain yield in non-stress environment has been previously reported (Roy & Murfy 1970).

According to Rosielle and Hamblin (1981), if there is a larger genetic variance in a stress environment than in a non-stress one, combined with a high genotypic correlation between the two environment ($rg_{12}K^2_G > 1$), then selection in the stress environment will raise performance in both environments and will be more effective for this purpose than selection in the non-stress environments. For grain yield, the amount of K^2_G was 0.71 and the genetic correlation between grain yield in stress and non-stress environment was 0.85. Because $K^2_G < 1$, we need to select for high yield for every environment separately. Other traits such as RWC, ELWR and height of plant showed similar results. On the other hand, for some traits such as 1000 grain weight, grain weight per spike, biological yield and HI the selection of genotypes can be carried out under non-stress or stress environment because they have $K^2_G > 1$.

Path analysis revealed that biological yield and spike number per m^2 had the greatest positive and negative direct effect on yield, under non-stress environment (Table 3). Although the direct effect of spike number per m^2 was negative, because of positive indirect effects, its genetic correlation with grain yield was positive. One thousand grain weight also had a high direct effect on yield. It may used as a selection criterion if high spike number per m^2 does not reduce it.

Path analysis in the stress environment revealed that 1000-grain weight and grain number per spike had the greatest positive direct effect on yield (2.81 and 2.32, respectively), but there were high indirect effects. In order for these traits to be used in the selection procedure, some other trait should be examined because increasing grain number per spike reduces 1000-grain weight and we need a compromise between them so that increasing grainyield and high positive indirect effect by 1000 grain weight and grain number per spike does not reduce 1000-grain weight. Harvest index had the highest negative direct effect on grain number per spike on grain yield; thus, we can use high HI as the high yield if these two traits increase.

References

Arzani A. (2002): Grain yield performance of durum wheat germplasm under Iranian dry land and irrigated field conditions. Sabaro Journal of Breeding and Genetics, **34**: 9–18.

Blum A., Golan G., Mayer J., Sinmena B., Shpiler L., Burra J. (1989): The drought response of landraces of what from the northern Negev desert in Israel. Euphytica, **43**: 87–96.

Calhoun D.S., Gebehu G., Miranda A., Rajaram S., Van Ginkel M. (1994): Choosing evaluation environments to increase wheat grain yield under drought condition. Crop Science, **34**: 673–678

Farshadfar E., Ghanadha M., Zahravi M., Sutka J. (2001): Generation mean analysis of drought tolerance in wheat (*Triticum aestivum* L.) Acta Agronomica Hungarica, **46**: 59–66.

Kirigwi F.M., Van Ginkel M., Trethowan R., Sears R.G., Rajaram S., Paulsen G.M. (2004): Evaluation of selection strategies for wheat adaptation across water regimes. Euphytica, **135**: 361–371.

Pandey R.K., Maronville J.W., Admou A. (2001): Tropical wheat response to irrigation and nitrogen in a sahelian environment. I. Grain yield, yield components and water use efficiency. European Journal of Agronomy, **15**: 93–105.

Pantuwan G., Fakai S., Cooper M., Rajataserrku S., Tool J.C. (2002): Yield response of rice (*Oryza sativa* L.) genotypes to different types of drought under rainfed low lands. Part 1. Grain yield and yield components. Field Crops Research, **73**: 153–168.

Richards R.A. (1996): Defining selection criteria to improve yield under drought. Plant Growth Regulation, **20**: 157–166.

Rosielle A.A., Hamblin J. (1981): Theoretical aspects of selection for yield in stress and non-stress environments. Crop Science, **21**: 943–946.

Roy N.N., Murfy B.R. (1970): A selection procedure in wheat for stress environment. Euphytica, **19**: 509–521.

Siddique M.R.B., Hamid A., Islam M.S. (2000): Drought stress effects on water relations of wheat. Botanical Bulletin of Academia Sinica, **41**: 35–39.

Smith M.E., Coffman W.R., Baker T.C. (1990): Environmental effects on selection under high and low-input conditions. In: Kang M.S. (ed.): Genotype-by-Environment Interaction and Plant Breeding. Louisiana State University, Baton, LA.: 261–272.

Westgate M.E. (1994): Water status and development of maize endosperm and embryo daring drought. Crop Science, **34**: 76–83.

Winter S.R., Musick J., Tporter K.B. (1988): Evaluation of screening techniques for breeding drought- resistant winter wheat. Crop Science, **28**: 512–516.