DOI: http://dx.doi.org/10.22092/cbj.2012.100417

Response of grain yield and yield components of promising genotypes of spring rapeseed (*Brassica napus* L.) under non-stress and moisture-stress conditions

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Received: November 2011

ABSTRACT

Ghodrati, G. R. 2012. Response of grain yield and yield components of promising genotypes of spring rapeseed (*Brassica napus* L.) under non-stress and moisture-stressed conditions. **Crop Breeding Journal 2(1):49-56.**

To assess moisture stress tolerance at the reproductive growth stage in 11 promising genotypes of spring rapeseed (*Brassica napus* L.), two field experiments were conducted in two growing seasons (2008-2010) at the Agricultural Research Center of Safiabad, Dezful, Iran. Genotypes were sown under two non-stress (well-irrigated) and moisture stress (irrigation ceased at flowering) conditions using a randomized complete block design with three replications for each moisture regime. Agronomic traits (plant height, number of siliques per plant, number of grains per silique, test grain weight, grain yield, days to flowering, days to maturity and oil content) were measured and recorded. Genotype and moisture regime main effects were highly significant for all the measured traits. Moisture regime × genotype interaction was also highly significant for silique per plant, flowering period and oil content traits, suggesting different responses of genotypes in different moisture conditions. Grain yield reduction (10.9%) in genotype 5 (G5) under moisture stress conditions was significantly lower than in all other genotypes. Genotype 11 (G11) produced the highest oil content, which was significantly higher than that produced by other genotypes in either regime. A significant positive correlation coefficient (r = 0.578*) was observed between grain yield and oil content under non-stress conditions. Grains silique^{-1} had a significant negative correlation with date of maturity under well-watered (r = -0.711**) and moisture stress (r = -0.634*) conditions. Calculated stress tolerance index (STI) varied from 0.47 for G7 to 1.01 for Hyola401. G1 and G4 with high STI values were identified as highly tolerant genotypes. This was in agreement with conclusions reached based on agronomic traits. It is concluded that G1 with 1974 kg ha^{-1} and G4 with 2511 kg ha^{-1} grain yields could be suitable substitutes for cv. Hyola401 under moisture stress and non-stress conditions, respectively.

Key words: agronomic traits, drought tolerance, grain yield, oil content, stress tolerance index

INTRODUCTION

Rapeseed is an important oilseed crop in the agricultural systems of many arid and semiarid areas where its yield is often restricted by water deficits and high temperatures during the reproductive growth stage. Grain yield can be limited even by a relatively short period of soil moisture stress during rapeseed's reproductive development.

The effect of moisture stress on rapeseed crop productivity is a function of genotype, stress intensity and duration, weather conditions and developmental stages (Robertson and Holland, 2004). The timing of moisture stress occurrence is more important than the intensity of the stress (Korte *et al.,* 1983). Grain yield potential of *Brassica* depends on events occurring prior to and during flowering, and the reproductive period is most susceptible to stress (Mendham and Salisbury, 1995). Severe stress decreases the duration of reproductive growth (Hall, 1992), and stress during flowering or ripening results in large yield losses (Stoker and Carter, 1984).

Moisture stress occurring at any time during the reproductive growth period can drastically reduce grain yield. For many grain crops, the worst time to experience moisture stress is during stem elongation and flowering. Gan *et al*. (2004) found that rapeseed recovered if stressed at earlier growth stages, whereas stress during silique development severely reduced most yield components. Masoud Sinaki *et al*. (2007) found that the highest rapeseed yield reduction was observed when moisture stress occurred at flowering and then at silique development. They reported that grain yield reduction caused by short-term moisture stress during stem elongation, flowering and silique development was mostly associated with the reduction in number of siliques plant^{-1}. Rahnema and Bakhshande (2006) reported that the highest grain yield reduction occurred when only one irrigation was applied in spring. Muhammad *et al*. (2007)

found that the highest grain yield was obtained with three irrigations at early vegetative, flowering and grain formation stages. Henry and MacDonald (1978) showed that severe drought decreased oil content and increased protein content of rapeseed.

In many areas of Iran, the spring rapeseed crop is exposed to drought stress, especially during the reproductive stage. Therefore, the objective of this study was to assess the response of grain yield and yield components in promising spring rapeseed (*Brassica napus* L.) genotypes under normal and moisture-stressed conditions.

MATERIALS AND METHODS

Eleven promising genotypes of spring rapeseed (*Brassica napus* L.); derived from segregating generations, selected in Option 500 and RGS003open-pollinated (OP) cultivars, and Hyola401 as check cultivar, were sown in a randomized complete block design with three replications during two growing seasons (2008-2010) at the Agricultural Research Center of Safiabad, Dezful, Iran (32°16' N, 48°26' E and 82 masl).

Pedigrees of materials, mean monthly temperatures and rainfall for the two growing seasons, long-term regional averages and selected soil properties of the experimental site are shown in Tables 1, 2 and 3. Plant materials were grown in two separate experiments under two irrigation regimes: (1) irrigation after 70 mm evaporation from a class-A pan corresponding to soil water potential of -0.5 MPa (non-stress conditions); and (2) irrigation suspended at the beginning of flowering (moisture stress conditions). Each experiment was sown using a randomized complete block design with three replications. Each plot consisted of six rows, five meters long, with 37.5 cm row spacing. Agronomic traits including plant height, number of siliques plant^{-1}, number of grains silique^{-1}, 1000-grain weight, grain yield, flowering period, days to maturity and seed oil content were measured and recorded. Grain number silique^{-1} was measured on 30 randomly selected siliques in each plot at maturity. A sample of seven plants was harvested from each plot to measure the yield components. Grain yield was estimated by harvesting the four middle rows of each plot. Seed oil content was determined by nuclear magnetic resonance.

Simple and combined analyses of variances were performed on data using MSTAT-$_C$ software. Correlation coefficients among all pairs of variables were calculated by SPSS (version 18.0) statistical software. Each experiment was analyzed based on a randomized complete block design model. Mean comparisons were performed using Fisher's (protected) least significant difference (LSD). Reduction (%) in different traits due to moisture stress was calculated as follows:

$$C = \frac{\overline{X}ns - \overline{X}ds}{\overline{X}ns} * 100 \qquad \text{(Eq. 1)}$$

where $\overline{X}ns$ is the mean of a trait in a given genotype under non-stress conditions and $\overline{X}ds$ is the mean of a trait in the same genotype under moisture stress conditions. Correlation coefficients between grain yield and other characteristics were calculated based on means of the three replications.

The stress tolerance index (STI) was calculated for each genotype following Fernandez (1992):

Table 1. Pedigree of promising spring rapeseed genotypes.

Genotype	Pedigree	Genotype	Pedigree
G1	Sarigol×Bolero	G7	Fusia×Goliat
G2	Fusia×Goliat	G8	Option500 (slec. in OP cultivar)
G3	Hyola420 (slec. in OP cultivar)	G9	RGS003 (slec. in OP cultivar)
G4	Option500 (slec. in OP cultivar)	G10	Sarigol×Bolero
G5	RGS003 (slec. in OP cultivar)	G11	Option500 (slec. in OP cultivar)
G6	RGS003 (slec. in OP cultivar)	H401	Hyola401 (Check)

Table 2. Mean monthly temperature and rainfall during the two growing seasons and long-term averages at Agricultural Research Center of Safiabad, Dezful, Iran.[a]

	Rainfall (mm)			Temperature (°C)		
	2008-2009	2009-2010	Long term	2008-2009	2009-2010	Long term
September	3.0	12.5	0.8	33.1	30.9	31.1
October	8.0	66.9	11.1	26.2	26.5	26.0
November	84.1	38.0	35.2	18.9	19.3	18.9
December	0.0	46.0	72.0	13.2	14.7	13.9
January	22.5	36.7	69.8	11.2	14.3	12.7
February	16.0	25.1	46.5	15.6	16.1	13.6
March	10.9	1.8	49.8	18.0	20.3	17.3
April	18.7	69.3	28.3	22.3	24.3	22.9
May	7.7	33.0	6.1	30.7	29.5	29.2
June	0.0	0.0	0.1	34.7	35.5	33.8
July	0.0	0.0	0.1	36.1	37.6	36.0
August	0.0	0.0	0.0	35.9	30.8	35.4
Total	170.9	329.3	319.8	---	---	---

[a]Unpublished report, agro-meteorological office at Safiabad, Dezful, Iran.

$$STI = (Y_P)(Y_S)/(\bar{Y}_P)^2 \quad \text{(Eq.2)}$$

where Y_S is grain yield under stress, Y_P is grain yield under non-stress conditions, and $\bar{Y}_P$ is the average grain yield of all genotypes under non-stress conditions.

Table 3. Some physico-chemical properties of the silty loam soil at the test site.

Soil property	Amount
Organic matter (%)	0.7
Total N (mg kg^{-1})	880.0
Phosphorus (mg kg^{-1})	11.6
Potassium (mg kg^{-1})	184.0
EC (dS m^{-1})	0.8
pH	7.0

RESULTS

The analysis of variance showed that main effects of genotype and moisture regime were highly significant for all traits (Table 4). Moisture regime × genotype interaction was also highly significant for number of siliques $plant^{-1}$, flowering period and oil content (Table 4), suggesting genotypes had a different response to each moisture regime. Means of agronomic traits under non-stress and moisture stress conditions, as well as the reduction (%) in the tested traits due to moisture stress are presented in Table 5.

Grain yield ranged from 1826 kg ha^{-1} for G7 to 2537 kg ha^{-1} for H401 under non-stress conditions and varied from 1318 kg ha^{-1} for G7 to 2025 kg ha^{-1} and for H401 under moisture stress conditions. In G5, the reduction (10.9%) in grain yield due to moisture stress was significantly lower than in all of the other genotypes (Table 5).

Genotype G9 produced the highest number of siliques $plant^{-1}$, which was significantly higher than the number produced by all other genotypes under both conditions. On the other hand, G7 had the lowest number of siliques $plant^{-1}$ under moisture stress conditions.

Number of siliques $plant^{-1}$ ranged from 100 for G11 and G2 to 130 for G9 in non-stress conditions, and from 84 for G7 to 112 for G9 in moisture stress conditions (Table 5). Thousand-grain weight varied from 3.24 g to 3.91 g for G5 and G7, respectively, in non-stress conditions (Table 5). Under moisture stress conditions, 1000-grain weight ranged from 2.87 g for G3 to 3.41 g for G10 (Table 5). Calculated correlation coefficients among the traits for both non-stress and moisture stress conditions are presented in Table 6. A significant positive correlation coefficient ($r = 0.578^{*}$) was found between grain yield and oil content under non-stress conditions (Table 6). Grain number $silique^{-1}$ also had a significant negative correlation with days to maturity under non-stress ($r = -0.711^{**}$) and moisture stress ($r = -0.634^{*}$) conditions, because the flowering period of later-maturing genotypes coincided with high temperatures. Days to maturity under moisture stress conditions had a significant positive correlation with plant height ($r = 0.616^{*}$) and oil content ($r = 0.655^{*}$) (Table 6).

Results showed that G1 and G4 were highly tolerant to moisture stress conditions, while G7 was the most sensitive genotype (Table 6).

DISCUSSION

Moisture stress had profound negative effects on agronomic traits. All physiological processes (such as photosynthesis, cell turgidity and cell and tissue growth in plants) are directly affected by water (Reddi and Reddi, 1995). Yield losses of 60-100% due to long spells of water shortage (drought) have been reported in different crop species including canola-type Brassica (Singh *et al*., 2002). In this experiment, Hayola401 produced the highest grain yield under both conditions, followed by G4, G11 and G1. The average number of siliques $plant^{-1}$ decreased under moisture stress conditions, and G9 had the highest number of siliques plant-^{1} under both conditions (Table 5). These results are consistent with those reported by Nielson (1997) and Leilah *et al*. (2002). Significant differences were found in 1000-grain weight between irrigation regimes and among genotypes (Tables 3 and 5). Irrigation influenced grain number $silique^{-1}$ more than other yield components. The water deficit shortened the duration of flowering to maturity more than other growth stages (Masoud Sinaki *et al.,* 2007).

Daneshmand *et al*. (2007) reported that under moisture stressed conditions, rapeseed cultivars that were able to maintain high relative water content had higher grain yield. Moisture stress conditions significantly decreased number of siliques $plant^{-1}$, number of grains $silique^{-1}$ and 1000-grain weight, which led to lower grain yield (Table 5). Number of siliques $plant^{-1}$ and 1000-grain weight were the most sensitive yield components to moisture stress during the reproductive growth stage in both growing seasons, as was also shown by Diepenbrock (2000). It is inferred that moisture stress reduced yield probably by inducing silique abortion as a result of limited photosynthesis. Clarke and Simpson (1978) suggested that silique number $plant^{-1}$ increased under non-stress conditions primarily due to lengthening of the flowering period. Flowering was the most sensitive stage to moisture stress, probably due to the susceptibility of pollen grain development, anthesis and fertilization, which resulted in lower grain yield (Champolivier and Merrin, 1996;

Table 4. Combined analysis of variance for agronomic traits of rapeseed genotypes grown in two moisture regin

Sources of variation	d.f	Mean square					
		Grain yield	Silique plant^{-1}	1000-grain weight	Grain silique^{-1}	Flowering period	Days to maturi
Year (Y)	1	39610.0**	19911**	19.500**	65.00**	132.000**	51.36**
Replication/Y	4	53.7	45	0.109	8.17	0.306	3.67
Moisture regime (M)	1	11725.0**	9102**	8.390**	201.00**	201.000**	125.00**
Y × M	1	4095.0**	383*	7.640**	3.64 ns	245.000**	12.25*
Genotype (G)	11	513.0**	864**	0.280**	68.89**	17.8.00**	20.78**
Y × G	11	236.0**	1358**	0.086 ns	10.14 ns	14.050**	7.03**
M × G	11	744.0 ns	228**	0.134 ns	1.44 ns	10.800**	1.48 ns
Y × M × G	11	704.0 ns	89 ns	0.078 ns	1.33 ns	9.580**	2.06 ns
Error	92	395.0	90	0.087	5.52	3.320	2.09
CV (%)	-	10.06	9.21	8.950	9.44	2.440	0.98

*** and **: Significant at the 0.05 and 0.01 probability levels, respectively.**

Table 5. Means of agronomic traits of rapeseed genotypes (G) under non-stress (NS) and moisture stress (MS) conditions and %

Genotype		Grain yield (kg ha^{-1})	No. of siliques plant^{-1}	1000-grain weight (g)	No. of grains silique^{-1}	Flowering period (days)	Days to r
	NS	2361.0ab	114.0abc	3.83ab	25.0ab	31.0abc	149.
G1	MS	1974.0ab	88.0bc	3.00ab	21.0bcd	30.0ab	146.
	%R	16.4	22.8	21.70	16.0	3.2	2.
	NS	2276.0abc	100.0c	3.55ab	29.0a	34.0a	148.
G2	MS	1644.0bcd	98.0abc	2.90b	26.0ab	28.0ab	146.
	%R	27.8	2.0	18.30	10.3	17.6	1.
	NS	1919.0bc	102.0bc	3.47ab	29.0a	33.0abc	146.
G3	MS	1420.0cd	86.0c	2.87b	27.0a	28.0ab	144.
	%R	26.0	15.7	17.30	6.9	15.2	1.
	NS	2511.0a	112.0abc	3.53ab	27.0ab	30.0bc	147.
G4	MS	1790.0ab	88.0bc	2.97ab	24.0abcd	29.0ab	146.
	%R	28.7	21.4	15.90	11.1	3.3	0.
	NS	2142.0abc	101.0bc	3.24b	26.0ab	29.0c	148.
G5	MS	1909.0ab	86.0c	2.91b	24.0abcd	28.0ab	146.
	%R	10.9	14.9	10.20	7.7	3.4	1.
	NS	2208.0abc	120.0ab	3.32ab	28.0ab	30.0bc	148.
G6	MS	1671.0bc	99.0abc	3.03ab	25.0abc	29.0ab	146.
	%R	24.3	17.5	8.70	10.7	3.3	1.
	NS	1826.0c	110.0bc	3.91a	26.0ab	33.0ab	145.
G7	MS	1318.0d	84.0c	3.18ab	25.0abc	31.0a	144.
	%R	27.8	23.6	18.70	3.8	6.1	0.
	NS	2282.0abc	108.0bc	3.35ab	24.0b	32.0abc	150.
G8	MS	1648.0bcd	105.0abc	3.23ab	21.0bcd	28.0ab	148.
	%R	27.8	2.8	3.60	12.5	12.5	1.
	NS	2414.0ab	130.0a	3.34ab	23.0b	34.0a	149.
G9	MS	1746.0abc	112.0a	2.96ab	20.0d	29.0ab	146.
	%R	27.7	13.8	11.40	13.0	14.7	2.
	NS	2207.0abc	115.0abc	3.66ab	23.0b	31.0abc	149.
G10	MS	1419.0cd	94.0abc	3.41a	21.0cd	28.0ab	148.
	%R	35.7	18.3	6.90	8.7	9.7	0.
	NS	2446.0ab	100.0c	3.65ab	23.0b	29.0c	150.
G11	MS	1718.0abc	90.0abc	3.08ab	22.0bcd	28.0ab	148.
	%R	29.8	10.0	15.60	4.3	3.4	1.
	NS	2537.0a	120.0ab	3.63ab	29.0a	29.0c	147.
Hyola401 (check)	MS	2025.0a	108.0ab	3.16ab	27.0a	28.0ab	146.
	%R	20.2	10.0	13.00	6.9	3.4	0.

Means, in each column and for each moisture regime, followed by at least one letter in common are not significantly different at the 5% probability level usin (LSD).

Table 6. Correlation coefficients between grain yield and its components under non-stress (above diagonal) and moisture stress

	Grain yield	No. of silique plant^{-1}	1000-grain weight	No. of grain silique^{-1}	Flowering period	Days to matur
Grain yield	1	0.316 ^{ns}	-0.107 ^{ns}	-0.192 ^{ns}	-0.361 ^{ns}	0.545
Silique plant^{-1}	0.268 ^{ns}	1	-0.055 ^{ns}	-0.185 ^{ns}	0.109 ^{ns}	0.075
1000 grain weight	-0.294 ^{ns}	0.160 ^{ns}	1	0.005 ^{ns}	0.112 ^{ns}	-0.355
Grain silique^{-1}	-0.036 ^{ns}	-0.120 ^{ns}	-0.375 ^{ns}	1	0.049 ^{ns}	-0.711
Flowering period	-0.132 ^{ns}	-0.301 ^{ns}	0.056 ^{ns}	-0.178 ^{ns}	1	-0.196
Days to maturity	0.200 ^{ns}	0.296 ^{ns}	0.495 ^{ns}	-0.634*	-0.367 ^{ns}	1
Plant height	0.293 ^{ns}	0.131 ^{ns}	0.066 ^{ns}	-0.467 ^{ns}	-0.573 ^{ns}	0.616
Oil content	0.771**	0.266 ^{ns}	0.027 ^{ns}	-0.318 ^{ns}	-0.384 ^{ns}	0.655

*** and ** Significant at the 0.05 and 0.01 probability levels, respectively.**
ns= Not significant.

Table 7. Grain yield under non-stress (GY_{non}) and moisture stress (GY_{ms}) conditions, and stress tolerance index (STI) of rapeseed genotypes.

Genotypes	GY_{non}(kg ha^{-1})	GY_{ms}(kg ha^{-1})	STI
G1	2362 ab	1974 ab	0.91
G2	2276 abc	1644 bcd	0.73
G3	1919 bc	1420 cd	0.53
G4	2511 a	1790 ab	0.88
G5	2142 abc	1909 ab	0.80
G6	2208 abc	1671 bc	0.72
G7	1826 c	1318 d	0.47
G8	2282 abc	1649 bcd	0.74
G9	2414 ab	1746 abc	0.82
G10	2207 abc	1419 cd	0.61
G11	2446 ab	1718 abc	0.82
Hyola401 (check)	2537 a	2025 a	1.01

Means, in each column, followed by at least one letter in common are not significantly different at the 5% probability level using Fisher`s (protected) least significant difference (LSD).

Faraji *et al.,* 2009; Masoud Sinaki *et al.,* 2007). In general, rapeseed crops are susceptible to moisture stress during flowering, but cultivars differ in their sensitivity to this stress (Richards and Thurling, 1978).

Grain yield reduction under soil moisture stress condition at silique formation was also associated with the reduction in number of siliques plant^{-1}. Krogman and Hobbs (1975) indicated that both leaves and siliques are important in photosynthesis, and grain yield increases with adequate soil moisture. Stresses imposed at a later stage of development reduce sink size (Mendham and Salisbury, 1995), shorten the duration of grain-filling (Hall, 1992) and limit the crop's opportunity to recover (Morrison, 1993). Irrigation had more influence on grains per silique than other yield components, and water deficit influenced flowering to maturity duration more than other growth stages (Masoud Sinaki *et al.,* 2007). Daneshmand *et al.* (2007) suggested that under moisture stressed conditions, rapeseed cultivars that were able to maintain high relative water content produced higher grain yield.

Reduction in plant height in an environment with water deficit has been confirmed by many researchers (Francois, 1994; Ashraf and Sarwar, 2002). Plant growth depends on cell expansion and enlargement, which is probably a plant's most sensitive physiological aspect when there is a water deficit; this leads to reduced plant productivity (Larson, 1992) and ultimately affects plant height. Phenolic compounds produced in plants during moisture stress conditions also contribute to reducing plant growth (Einhelling and Souza, 1992; Blum *et al*., 1991).

Oil content is of the greatest importance for production profitability (Robertson and Holland, 2004). Since oil yield is obtained by multiplying oil content by grain yield, and the magnitude of variation in oil content of improved rapeseed cultivars is low, therefore, grain yield has the greatest effect on oil yield. By breeding and selecting cultivars for high grain yield, high oil yield can also be achieved. Sharghi *et al.* (2011) reported that interrupting irrigation at flowering significantly decreased oil content and oil yield of rapeseed cultivars. In the present study, it was concluded that G11, with the highest oil content and the lowest reduction in this trait under moisture stress conditions, performed better than the other genotypes (Table 5). Considering its high oil yield potential, G4 may be a suitable substitute for Hyola401 under moisture stress conditions. Hyola401 and G7 had the highest (0.91) and lowest (0.47) STI and were thus the most tolerant and susceptible genotypes, respectively (Table 7). Genotypes with high STI values are drought tolerant because they show a smaller reduction in grain yield under stress compared with non-stress conditions.

Nevertheless, this index *per se* appears to have serious limitations when it comes to quantifying genotype response to moisture conditions, because it is based on maximizing yield production under stress conditions as compared with non-stress conditions. Sadeghzade-Ahari (2006) and Behmaram *et al.* (2006) reported that STI is a highly efficient index for identifying rapeseed genotypes with high grain yield under normal and water stress conditions. However, Hyola401 and G1, identified as stress tolerant by STI, may have some tolerance mechanisms and could be used as sources of drought stress tolerance in rapeseed breeding programs aimed at developing new improved germplasm with high grain yield potential.

It is concluded that cv. Hyola401 and genotypes G1 and G4 performed better than the other genotypes in both moisture regimes (Table 5). Considering their high grain yield potential, G1 and G4 could be suitable substitutes for Hyola401 under moisture stress and non-stress conditions, respectively.

REFERENCES

Ashraf, M. Y., and G. Sarwar. 2002. Salt tolerance potential in members of Brassicaceae. Physiological studies on water relations and mineral content. Pp. 237-245. In: R. Ahmad and K. A. Malik (eds.). Prospects for Saline Agriculture. Kluwer Academic Publishers, The Netherlands.

Behmaram, R. A., A. Faraji, and H. Amiari-Oghan. 2006. Evaluation of drought tolerance in spring rapeseed cultivars (*Brassica napus* L.). Pp. 496. In: Proceedings of the 9th Iranian Crop Sciences Congress. University of Tehran, Aboureyhan Campus.

Blum, A., J. W. E. Janson, L. Ramseur, and E. W.

Tollner. 1991. The effect of drying top soil and a possible non-hydraulic root signals on wheat growth and yield. J. Exp. Botany. 42: 1225-1231.

Champolivier, L., and A. Merrin. 1996. Effects of water stress applied at different growth stages to *Brassica napus* L. var. *oleifera* on yield, yield components and grain quality. Europ. J. Agron. 5: 153-160.

Clark, J. M., and G. M. Simpson. 1978. Influence of irrigation and graining rate on yield and yield components of *Brassica napus* cv. Tower. Can. J. Plant Sci. 58: 731-737.

Daneshmand, A., A. H. Shirani-Rad, and J. Daneshian, 2007. Ecophysiological and agronomical aspects of rapeseed (*Brassica napus* L.) genotypes as affected by soil water availability. Pp. 244. In: Proceedings of the 12th International Rapeseed Congress, Agronomy Section, Sustainable Development in Cruciferous Oilseed Crops Production. Science Press, USA.

Diepenbrock, W. 2000. Yield analysis of winter oilseed rape (*Brassica napus* L.): a review. Field Crops Res. 67: 35-49.

Einhelling, F. A., and I. F. Souza. 1992. Phytotoxicity of sorgoleone found in grain sorghum root exudates. J. Chem. Ecol. 18: 1-11.

Faraji, A., N. Lattifi, A. Soltani, and A. H. Shirani-Rad. 2009. Grain yield and water use efficiency of canola (*Brassica napus* L.) as affected by high temperature stress and supplemental irrigation. Agric. Water Manage. 96: 132-140.

Fernandez, G. C. J. 1992. Effective selection criteria for assessing plant stress tolerance. Pp. 257-270. In: C. G. Kuo (ed.). Proceedings of the International Symposium on Adaptation of Vegetables and other Food Crops in Temperature and Water Stress Environments. Shanhua, Taiwan.

Francois, L. E. 1994. Growth, grain yield and oil content of canola grown under saline conditions. Agron. J. 86: 233-237.

Gan, Y., S. V. Angadi, H. Cutforth, V. V. Angadi, and C. L. Mc Donald. 2004. Canola and mustard response to short periods of temperature and water stress at different developmental stages. Can. J. Plant Sci. 84: 697-704.

Hall, A. E. 1992. Breeding for heat tolerance. Plant Breed. Rev. 10: 129-168.

Henry, J. L., and K. B. McDonald. 1978. The effects of soil and fertilizer nitrogen and moisture stress on yield, oil and protein content of rape. Can. J. Plant Sci. 58: 303-310.

Korte, L. L., J. H. Williams, J. E. Specht, and R. C. Sorenson. 1983. Irrigation of soybean genotypes during reproductive ontogeny: II. Yield component responses. Crop Sci. 23: 528-533.

Krogman, K. K., and E. H. Hobbs. 1975. Yield and morphological response of rape (*Brassica campestris* L., cv. Span) to irrigation and fertilizer treatments. Can. J. Plant Sci. 55: 903-909.

Larson, K. L. 1992. Drought injury and resistance of crop plants. Pp. 147-162. In: S. U. Gupta (ed.). Physiological aspects of dryland farming. Oxford & IBH Publishing Co. Pvt. Ltd., New Delhi.

Leilah, A. A., S. A. Al-Khateeb, A. Al-Naiem, and S. Al-Thabet. 2002. Response of some canola (*Brassica napus* L.) cultivars to drought. Agricultural and Water Resources Development Symposium in the Reign of the Two Holy Mosques King Fahad Bin Abdulaziz-God's Mercy Be Upon Him.

Masoud Sinaki, M. J., E. Majidi Heravan, H. Shirani Rad, G. Noormohammadi, and G. Zarei. 2007. The effects of water deficit during growth stages of canola (*Brassica napus* L.). Am-Eurasia J. Agric. Environ. Sci. 2: 417-422.

Mendham, N. J., and P. A. Salisbury. 1995. Physiology, crop development, growth and yield. Pp. 11-64. In: D. S. Kimber and D. I. McGregor (eds.). Brassica Oilseeds: Production and utilization. CAB International, London.

Morrison, M. J. 1993. Heat stress during reproduction in summer rape. Can. J. Botany. 71: 303-308.

Muhammad, T., A. Ali, M. A. Nadeem, A. Tanveer, and Q. M. Sabir. 2007. Performance of canola (*Brassica napus* L.) under different irrigation levels. Pak. J. Botany. 39: 739-746.

Nielson, D. C. 1997. Water use and yield of canola under dryland conditions in the central Great Plains. J. Prod. Agric. 10: 307-313.

Rahnema, M., and A. M. Bakhshande. 2006. Determination of optimum irrigation level and compatible canola varieties in the Mediterranean environment. Asian J. Plant Sci. 5: 543-546.

Reddi, G. H. S., and T. Y. Reddi. 1995. Irrigation of principal crops. Pp. 229-259. In: Efficient use of irrigation water. 2nd edition. Kalyani Publishers. New Delhi, India.

Richards, R. A., and N. Thurling. 1978. Variation between and within species of rapeseed (*Brassica napus* and *B. campestris*) in response to drought stress. I. Sensitivity at different stages of development. Aust. J. Agric. Res. 29: 469-477.

Robertson, M. J., and J. F. Holland. 2004. Production risk of canola in semiarid subtropics of Australia. Aust. J. Agric. Res. 55: 525-538.

Sadeghzade-Ahari, D. 2006. Evaluation for tolerance to drought stress in dryland promising durum wheat genotypes. Iranian J. Crop. Sci. 8 (1): 30-45.

Sharghi, Y., A. H. Shirani-Rad, A. Ayenehband, G. Noormohammadi, and H. Zahedi. 2011. Yield and yield components of six canola (*Brassica napus* L.) cultivars affected by planting date and water deficit stress. Afric. J. of Biotech. 10(46): 9309-9313.

Singh, M. P., U. N. Pandey, R. K. Lal, and G. S. Chaturvedi. 2002. Response of *Brassica* species to different irrigation regimes. Indian J. Plant Physiol. 1(7): 66-69.

Stoker, R., and K. E. Carter. 1984. Effect of irrigation and nitrogen on yield and quality of oilseed rape. N. Z. J. Exp. Agric. 12: 219-224.