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Effect of terminal drought stress on seed yield and its components of some new winter rapeseed lines

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ABSTRACT

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Drought causes significant reductions in crop productivity in many parts of the world, including Iran. Identifying genotypes tolerant to drought stress is therefore one of the foremost goals of crop breeding programs. This study investigated the effect of terminal drought stress on yield and yield components of new winter rapeseed lines, and identified new winter rapeseed lines tolerant to terminal drought stress. A field experiment was conducted to evaluate 17 new winter rapeseed lines and two commercial cultivars (Ahmadi and Opera) under three moisture conditions (optimum irrigation, elimination of irrigation from flowering stage, and elimination of irrigation from silique stage) during two cropping seasons (2012-13 and 2013-14) at the Agricultural Research Station of Islamabad-e-Gharb, Kermanshah, Iran. Drought stress significantly affected all measured traits except days to flowering and 1000-seed weight. Based on the average of three conditions, KS7, KR4, L183, Opera, and HW118 had higher seed yields. These lines (except Opera) also produced higher seed yields when irrigation was eliminated from the flowering and silique development stages, and were identified as winter rapeseed lines tolerant to terminal drought stress with high seed yield potential underoptimum irrigation conditions.

Keywords: flowering, rapeseed, seed yield, silique, terminal drought tolerance.

INTRODUCTION

Water scarcity is a major limitation to plant productivity and is one of the primary factors regulating the distribution of plant species (Boyer, 1982). Over 35% of the world's land surface is considered to be arid or semiarid, experiencing precipitation that is inadequate for production of most crops (Boyer, 1982). Developing crops that are better adapted to water deficits, while maintaining productivity, is therefore a critical requirement for enhancing agricultural production (Jenks and Hasegawa, 2005).

Rapeseed (*Brassica napus* L.) is the third-highest source of vegetable oil and meal for animal feed globally and, in Iran, it has become the most important oilseed crop for producing edible oil. One of the most important goals of rapeseed breeding programs is to identify genotypes tolerant to terminal drought stress. This can be achieved by selecting for genetic variability for yield and its components within and between different Brassica species (Richards, 1978; Richards and Thurling, 1978).

Water supply is critical during flowering and early silique development, when the number of silique and seeds are being determined. These stages of growth usually coincide with increasing temperatures and decreasing soil water supply. Moisture stress causes a dramatic decrease in leaf photosynthesis; leaves wilt and thus branching, silique per plant, silique length, seed size, and seeds per silique are reduced. Seed oil content drops and protein content increases. If moisture stress is severe, recently formed silique may abort.

Moisture stress may also greatly slow or stop root growth, affecting soil water uptake. Some varieties are better adapted and adjust total seed and silique number and harvest indexto reduce the impact of moisture stress on yield (Edwards and Hertel, 2011). Nielsen (1997) showed that canola yield was not significantly reduced by water stress at any particular growth stage, but data indicted lower numbers of siliques and seeds with water stress during reproductive development and lower seed weight with stress during seed filling.

Ghodrati (2012) showed that moisture stress during the flowering stage in some promising genotypes of spring rapeseed significantly affected all measured traits such as plant height, number of siliques per plant, number of seeds per pod, seed yield, days to flowering, days to maturity, and oil content. Namvar *et al*. (2015) reported that drought stress at the flowering stage resulted in a decrease in the number of siliques and number of seeds per plant, leading to reductions in seed yield and oil content.

Rapeseed growers in Iran irrigate rapeseed fields at the flowering and silique development stages, when spring rainfall is unreliable. Some farmers are also choosing to switch to cash crops. Thus it is important to identify rapeseed genotypes that are tolerant to terminal drought stress. This study therefore aimed to assess the response of seed yield and its components of some winter rapeseed lines to terminal drought stress and identify winter rapeseed lines with tolerance to terminal drought stress.

MATERIALS AND METHODS

Seventeen new winter rapeseed lines and two commercial cultivars (Ahmadi and Opera) (Table 1) were compared under three moisture conditions using a randomized complete block design with three replications during two crop seasons (2012-13 and 2013-14) at Agricultural Research Station of Islamabad-e-Gharb, Kermanshah, Iran. Meteorological information for the two growing seasons is presented in Table 2.

Table 1. Code, name, and cross name of winter rapeseed genotypes.

No.	Line code	Cross name	No.	Line code	Cross name
1	HW113	Okapi × Modena	11	SW101	Geronimo × Sunday
2	KS12	GA096 × Zarfam	12	L5	Geronimo × Sunday
3	KARAJ1	Geronimo × SW0756	13	L201	Sunday × Geronimo
4	KR18	Sunday × Modena	14	HW118	Sunday × Modena
5	L73	GA096 × Zarfam	15	KR4	Sunday × Modena
6	L72	Orient × Modena	16	KARAJ2	Geronimo × SW0756
7	HW101	Geronimo × Sunday	17	Ahmadi	Iranian cultivar
8	L146	Geronimo × Sunday	18	KS7	Geronimo × SW0756
9	L210	Sunday × Geronimo	19	Opera	Swedish cultivar
10	L183	GA096 × Zarfam			

Table2. Meteorological information for Islamabad-e-Gharb Agricultural Research Station during the 2012-13 and 2013-14 growing seasons.

	2012-13				2013-14			
	Temperature (°C)			Precipitation (mm)	Temperature (°C)			Precipitation (mm)
Season	Average	Maximum	Minimum		Average	Maximum	Minimum	
Autumn	12.3	32.8	-4.6	145.9	10.9	31.6	-7.2	201.4
Winter	4.8	24.6	-17.2	132.6	3.7	21.2	-12.4	227.7
Spring	15.8	37.8	-5.2	56.2	16.3	37.4	-5.2	70.9
Total				334.7				500

The three moisture conditions were: optimum irrigation, elimination of irrigation fromthe flowering stage, and elimination of irrigation from the silique development stage. Irrigation was applied by sprinklers. Each plot consisted of four rows of five m long with 0.25 m row spacing. In September, seedbeds were prepared using a plow, disc harrow, and leveler, before the experimental plots were seeded in October. Crop nutrition requirements were determined using soil tests and potassium and phosphorus fertilizers were applied during seedbed preparation. Nitrogen fertilizer was also applied at seedbed preparation (one-third) and stem elongation (two-thirds). Super Galant herbicide was used to control narrow leaves weeds.

Some important agronomic traits such as days to beginning of flowering, days to end of flowering, duration of flowering period, plant height, number of branches per plant, number of siliques per plant, number of seeds per silique, and 1000-seed weight were measured and recorded. Seed yield was measured by harvesting 4 m^2 from the central rows of each plot at maturity. Data were analyzed using SAS software (SAS System, 1996) for combined analysis of variance. Mean comparisons were performed using Least Significant Differences (LSD) test.

RESULTS AND DISCUSSION

Combined analysis of variance showed that growing season had a significant effect on agronomic traits such as seed yield, 1000-seed weight, and duration of flowering period (Table 3). Average seed yields under optimum conditions, elimination of irrigation from flowering, and elimination of irrigation from silique developmentin 2011-12 were 4688 kg ha^{-1}, 4292 kg ha^{-1}, and 4084 kg ha^{-1}, respectively (Table 4). Average seed yields were lower during 2012-13 at 3740 kg ha^{-1}, 3387 kg ha^{-1}, and 2779 kgha^{-1}, respectively (Table 4). The higher seed yields in 2011-12 were due to more favorable temperatures during October-November 2011, successful establishment rosette formation, and adequate precipitation during April-May 2012 (Table 2).

Drought stress reduced the duration of the flowering period from 27 days under optimum irrigation to 24 days under irrigation eliminated at the flowering stage. Days to maturity was also reduced from 262 days under optimum conditions to 260 and 258 days when irrigation was eliminated from the silique development and flowering stages, respectively (Table 5). This reduction of days to maturity seems to be a mechanism for escaping terminal drought stress, as also concluded by Rezaizad *et al*. (2011). They reported that days to maturity in 144 rapeseed doubled haploid lines decreased from 273 days under optimum conditions to 270 days when drought stress occurred at the flowering stage. Monajem *et al.* (2011) showed that drought stress at the flowering stage accelerated days to maturity from 234 days under optimum condition to 225 days under drought stress in flowering stage.

Terminal drought stress influenced seed yield components, such as siliques per plantand seeds per pod (Table 3). This influence was greater when drought stress was applied from the flowering stage. Siliques per plant and seeds per silique are major components for seed yield (Diepenbrock, 2000); therefore drought stress that reduces siliques per plant and number of seeds per silique also results in lower seed yields (Din *et al*. 2011; Shirani Rad *et al.* 2014). In this study, siliques per plant decreased from 140 under optimum irrigation to 110 and 98 when irrigation was eliminated from the flowering and silique development stages, respectively. Meanwhile seeds per silique reduced from 26 under optimum irrigation to 23 and 21 when irrigation was eliminated fromthe flowering and silique development stages, respectively.

The reduction in siliques per plant and seeds per silique when irrigation was eliminated from the flowering stage were 30% and 19%, respectively, implying that the drought stress had less of an effect on seeds per silique than siliques per plant. This concurs with Sinaki *et al*. (2007) who reported that drought stress caused a 26% reduction in siliques per plant, compared to a 9.9% reduction in seeds per silique.

Terminal drought stress did not significantly affect 1000-seed weight, which was 3.7 g, 3.3 g, and 3.3 g under optimum, deficit irrigation during silique development, and deficit irrigation during flowering treatments, respectively (Table 5). Richards and Thurling (1978) found that late season drought led to the abortion of more than 50% of the siliques in *B. napus* L. and *B. rapa* L., and that the remaining siliques had more and heavier seeds. Champolivier and Merrien (1996) also reported no decrease 1000-seed weight when drought occurred in reproductive development stages, in fact there may have been an increase due to the compensation effect. However other studies have reported reductions in 1000-seed weight caused by drought stress in reproductive stages (Pasban Eslam, 2009; Ghasemyan Ardestani *et al*., 2011; Rezaizad *et al*., 2011; Ghodrati, 2012; Shirani Rad *et al*., 2013; Namvar *et al*., 2015).

Drought stress reduced plant height from 165 cm under optimum irrigation to 153 cm and 120 cm under deficit irrigation during the flowering and silique development stages, respectively (Table 5). Variation in plant height under drought stress is an obvious characteristic that has been observed in most plant species. Namvar *et al*. (2015) reported that deficit irrigation in the primary stages of growth had a large effect on plant height, which was reduced due to fewer nodes and shorter internodes.

As expected due to the reduction in seed yield components, average seed yields also decreased from 4214 kgha^{-1} under optimum conditions to 3808 kgha^{-1}and 3532 kgha^{-1} under deficit irrigation during flowering, and deficit irrigation during the silique development stages, respectively (Table 5). Ghobadi *et al*. (2006) reported that the greatest seed yield reduction (30.3%) was observed when water stress occurred during the flowering stage, followed by when water stress occurred during the silique development stage (20.7%). Water supply is critical during flowering and early silique development, as this is when the numbers of siliques and seed are being determined, though these growth stages usually coincide with increasing temperatures and decreasing soil water supply. Richards and Thurling (1978) found that drought stress at any time during reproductive development reduced seed yield. Shirani Rad *et al.* (2013) reported that seed yield reduced from 4137 kgha^{-1} under optimum condition to 3185 kgha^{-1} in deficit irrigation in stem elongation stage.

There was a significant interaction effect between lines and drought stress conditions, implying that winter rapeseed lines had different reactions to drought stress. Averaged across experimental conditions, KS7, KR4, L183, Opera, and HW118 had higher seed yields of 4367 kg ha^{-1}, 4346 kg ha^{-1}, 4192 kg ha^{-1},4048 kg ha^{-1}, and 4002 kg ha^{-1}, respectively. Despite the significant interaction effect between winter rapeseed lines and drought stress conditions, all these lines (except Opera) also produced higher seed yields under deficit irrigation

Table 3. Combined analysis of variance for seed yield and phonological traits of winter rapeseed lines under optimum and drought-stress conditio

		Mean squares						
Source of variation	D.F.	Seed yield	Days to beginning of flowering	Days to end of flowering	Duration of flowering period	Days to maturity	Plant height	Silique per plant
Year (Y)	1	84108706**	3485.6**	26.2*	4193.4**	175.0^{ns}	32280.3^{ns}	14457^{ns}
Drought (D)	2	15517092*	4.1^{ns}	161.7**	227.1*	514.2**	62161.2*	52361*
Y×Drought	2	666784^{ns}	3.3^{ns}	0.5^{ns}	7.0^{ns}	18.5^{ns}	6461.0*	4748^{ns}
Error a	12	1226253	7.8	2.7	3.6	14.5	982.2	2411
Genotype (G)	18	1238874*	86.7**	35.9**	23.8**	72.4^{ns}	1253.7*	1092^{ns}
G×Drought	36	650131^{ns}	2.2^{ns}	1.7^{ns}	2.0^{ns}	8.4^{ns}	263.9^{ns}	909^{ns}
G×Y	18	893352**	4.2^{ns}	3.7^{ns}	6.7**	56.8**	404.5^{ns}	1164^{ns}
Y× D ×G	36	1038077**	3.3^{ns}	2.7^{ns}	2.0^{ns}	5.3^{ns}	304.8^{ns}	847^{ns}
Error b	216	277838	4.3	3.3	3.4	4.1	224.0	678
C.V. (%)		13.6	1.1	0.8	7.1	0.8	10.3	22.4

* and **: Significant at the 5% and 1% probability levels, respectively.
ns = not significant

Table 4. Average seed yield of winter rapeseed lines under optimum and terminal drought stress conditions during 201

	2012-13			2013-14		
Genotype	Optimum irrigation	Elimination of irrigation from silique stage	Elimination of irrigation from flowering stage	Optimum irrigation	Elimination of irrigation from silique stage	Elimi irriga flowe
HW113	4367	4365	4638	3693	3199	
KS12	3818	4489	4678	3899	3679	
KARAJ1	3704	4012	3905	4133	2990	
KR18	4741	4217	3081	4040	3119	
L73	4591	4898	3818	4489	3336	
L72	4275	4549	4237	3895	3045	
HW101	4283	3478	3519	4637	2568	
L146	5475	4412	4838	3694	2973	
L210	4411	3667	3832	3683	3041	
L183	5489	4119	4468	3788	3893	
SW101	4078	3775	3895	3970	3153	
L5	3809	4383	4021	3334	3211	
L201	4826	4870	4273	3542	2752	
HW118	5544	4187	4094	3274	3631	
KR4	6328	4792	4229	3130	4062	
KARAJ2	4592	3655	3594	3668	4143	
Ahmadi	3731	3804	3852	3157	3965	
KS7	5989	4445	4544	3303	4214	
Opera	6869	3830	3834	3393	3464	
Mean	4785	4208	4071	3722	3391	

Table 5. Agronomic and phonological traits for winter rapeseed lines under optimum irrigation and terminal drought s

	Days to beginning of flowering			Days to end of flowering			
Genotype	Optimum irrigation	Elimination of irrigation from silique stage	Elimination of Irrigation from flowering stage	Optimum irrigation	Elimination of irrigation From silique stage	Elimination of irrigation from flowering stage	Optimum irrigatio
HW113	194	194	193	221	220	217	27
KS12	190	192	191	219	219	217	29
KARAJ1	189	191	191	218	217	214	29
KR18	189	188	189	219	218	217	30
L73	195	194	195	221	220	220	27
L72	195	195	196	222	221	220	28
HW101	196	195	196	222	222	220	27
L146	195	194	195	222	222	219	27
L210	195	195	195	221	221	218	26
L183	192	192	193	220	219	218	27
SW101	194	195	195	221	220	219	27
L5	193	193	194	221	220	219	27
L201	195	195	197	221	221	220	26
HW118	196	196	195	223	221	220	27
KR4	192	192	192	220	219	218	28
KARAJ2	192	192	191	219	219	217	28
Ahmadi	195	194	196	220	219	217	25
KS7	191	192	191	219	220	217	28
Opera	197	197	198	223	222	221	26
Mean	193	193	194	221	220	218	27
LSD ($P \le 0.05$)	2.1	2.0	3.9	2.4	1.7	3.3	1.8

Table 5 (cont.)

	Days to maturity			Plant height			
Genotype	Optimum irrigation	Elimination of irrigation from silique stage	Elimination of irrigation from flowering stage	Optimum irrigation	Elimination of Irrigation From silique stage	Elimination of irrigation from flowering stage	Optimum irrigation
HW113	263	260	259	164	144	119	139
KS12	262	260	258	159	152	126	144
KARAJ1	259	259	257	134	115	111	143
KR18	262	260	257	162	150	115	142
L73	263	260	257	166	154	112	148
L72	264	261	259	172	165	116	125
HW101	263	261	260	178	166	114	137
L146	263	262	260	170	160	122	140
L210	262	262	260	163	157	114	121
L183	262	261	259	168	158	125	151
SW101	264	262	260	180	160	140	140
L5	263	261	259	160	152	112	134
L201	263	262	259	171	166	122	139
HW118	265	262	260	170	159	118	140
KR4	262	261	259	168	151	112	132
KARAJ2	263	261	258	163	149	132	173
Ahmadi	261	260	258	164	149	125	135
KS7	262	261	258	166	149	128	146
Opera	260	251	248	151	149	112	136
Mean	262	260	258	165	153	120	140
LSD ($P \leq 0.05$)	2.9	6.8	9.3	11.9	14.3	48.9	19.7

Table 5 (cont.)

	Seeds per silique			1000-seed weight			
Genotype	Optimum irrigation	Elimination of irrigation from silique stage	Elimination of irrigation from flowering stage	Optimum irrigation	Elimination of irrigation From silique stage	Elimination of irrigation from flowering stage	Optim irrigat
HW113	27	21	20	3.5	3.3	3.1	403
KS12	26	22	21	3.7	3.6	3.7	385
KARAJ1	28	22	23	3.8	3.3	3.2	391
KR18	26	22	22	3.8	3.4	3.5	439
L73	27	22	21	3.7	3.1	3.2	454
L72	28	24	22	3.6	3.2	3.2	408
HW101	27	24	21	3.7	3	3.2	446
L146	27	25	22	3.8	3.1	3.5	458
L210	26	23	20	3.8	3.3	3.4	404
L183	26	23	20	3.7	3.3	3.4	463
SW101	27	22	22	3.7	3.3	3.2	402
L5	26	22	21	3.7	3.4	3.5	357
L201	27	24	22	3.6	3.3	3.3	418
HW118	26	24	21	3.7	3.2	3.5	440
KR4	27	24	22	3.6	3.5	3.5	472
KARAJ2	26	22	21	3.9	3.6	3.7	413
Ahmadi	25	22	21	4	3.7	3.9	344
KS7	25	21	20	3.8	3.8	3.8	464
Opera	28	23	22	4.1	3.7	3.7	513
Mean	27	23	21	3.7	3.4	3.4	425
LSD ($P \leq 0.05$)	2.8	3.8	0.45	0.29	0.4	0.5	738

during the flowering and silique development stages (Table 5).

Opera produced the highest seed yield (5131 kgha^{-1}) under optimum condition, but its seed yield was reduced under deficit irrigation during the flowering and silique development stages (Table 5). Hence, this cultivar is only suitable for water limited regions. Ahmadi had lower seed yield under optimum conditions than under drought stress, largely due to excess waterlogging under the sprinkler irrigation system (Table 5). Four of the lines were identified as high potential yield lines with reasonable levels of tolerance to drought stress during there productive development stages.

CONCLUSIONS

Drought stress during the reproductive growth stages of rapeseed lines, especially the flowering stage, decreased seed yield and its components (e.g. siliques per plant and seeds per pod). Winter rapeseed lines responded differently to drought stress, however, the top yielding winter rapeseed lines under optimum irrigation performed successfully indeficit irrigation conditions.

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