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*Full Length Research Paper*

# Water stress effect on spring rapeseed cultivars yield and yield components in winter planting

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**Since the most widespread limiting factor in agricultural production is water stress, a two year field experiment was carried out in Karaj, Iran during 2008 to 2010 growing seasons to assess the effect of water stress on yield and yield components of spring rapeseed (*Brassica napus* L.) cultivars in winter planting to find the most tolerant cultivars. The experiments was laid out in a four-replicated-randomized complete block, split plot design with two irrigation levels (I: $I_1$= irrigation on the basis of 80 ml evaporation from the class A pan (normal irrigation) and $I_2$= interruption of irrigation from the flowering stage (water stress) as the main plot) and cultivar including $C_1$: RGS 003, $C_2$: Amica, $C_3$: Sarigol, $C_4$: Option 500, $C_5$: Hyola 401, $C_6$: Hyola 42, $C_7$: Hyola 60, $C_8$: Hyola 420, $C_9$: Hyola 330, $C_{10}$: Hyola 308, $C_{11}$: Kimberly, $C_{12}$: RGS 006, $C_{13}$: 19-H, $C_{14}$: Syn-3, $C_{15}$: PR-401/16, $C_{16}$: PP-401/15E, $C_{17}$: PP 308/8, $C_{18}$: PP 308/3, $C_{19}$: ORS 3150-3006, $C_{20}$: ORS 3150-3008, $C_{21}$: RG 4403, $C_{22}$: RG 405/03, $C_{23}$: RGAS 0324 and $C_{24}$: RG 405/02 as subplot. The results of combined analysis of two years revealed that under normal irrigation condition ORS 3150-3008 and under water stress condition RG 405/03 cultivars produced the highest seed yield by average of 2285 and 1544 kg ha$^{-1}$, respectively.**

**Key words:** Rapeseed, *Brassica napus* L., spring cultivars, water stress, yield and yield components, winter planting.

## INTRODUCTION

Rapeseed (*Brassica napus* L.) is a crop which is grown mainly for its high quality oil and protein; although, its yield is often restricted by water deficit and high temperatures during the reproductive growth. Environmental stresses, including drought and temperature, affect nearly every aspect of the physiology and biochemistry of plants and significantly diminish yield (Munns, 2002). The effects of water stress depend on timing, duration and magnitude of water deficiency (Pandey et al., 2001) which the occurrence time is more important than the stress intensity (Sinaki et al., 2007). Flowering is the most sensitive stage to water stress, probably due to susceptibility of pollen development, anthesis and fertilization leading to lower seed yield (Sinaki et al., 2007; Faraji et al., 2009). Many studies reported that water stress significantly has a negative effect on rapeseed yield and yield components. Nasri et al. (2008) reported that water stress decreased the number of siliques per plant, number of seeds per silique, 1000 seeds weight, seed yield, seed oil content and seed oil yield of 5 rapeseed cultivars. Sinaki et al. (2007) reported the reduction of number of siliques per plant, biomass yield and seed yield of rapeseed under water stress. Zakirullah et al. (2000) showed the reduction of the number of secondary branches, number of siliques per primary branch and number of seeds per silique of susceptible rapeseed cultivars under water stress.

Since there is no logical way to increase precipitation in drought periods to modify its undesirable effects, so using the most appropriate agricultural practices to avoid crop sensitive stages meeting dryness and also cultivars which are more tolerant than the others to dryness are the best solutions (Ahmadi and Far, 2000). It is known that in optimal conditions, cultivars may differ much for their yield, but performances might be altered in the case of stressed conditions. Therefore, considering the

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**Table 1.** Analysis of variance for assessed traits (2008-2009).

| Source of variation | DF | NS/P | NS/S | TSW | SY |
|---|---|---|---|---|---|
| Replication | 3 | | | | |
| Irrigation | 1 | ** | ** | ns | ** |
| Error | 3 | - | - | - | - |
| Cultivar | 23 | ** | ** | ** | ** |
| Irrigation × Cultivar | 23 | ** | ** | ** | ** |
| Error | 138 | - | - | - | - |
| Total | 191 | - | - | - | - |
| CV (%) | - | 7.13 | 10.62 | 8.17 | 9.68 |

*, **Significant at 5 and 1%, respectively, ns: not significant.

aforementioned points, the main objective of this study is to assess the effects of water stress at flowering stage on yield and yield components of spring rapeseed cultivars in winter planting to find the most tolerant ones.

## MATERIALS AND METHODS

The experiments were carried out at the experimental farm located in Karaj (50°75′E, 35°9′N; 1313 m a.s.l), Iran during the 2008 to 2009 and 2009 to 2010 crop years. Karaj is a cold temperate and semi arid region. The experimental design was a randomized complete block design arranged in split plot form with four replications. Treatments included two agents: irrigation in two levels including $I_1$: irrigation on the basis of 80 ml evaporation from the class A pan (normal irrigation) and $I_2$: interruption of irrigation from the flowering stage (water stress) as the main plots and cultivar including $C_1$: RGS 003, $C_2$: Amica, $C_3$: Sarigol, $C_4$: Option 500, $C_5$: Hyola 401, $C_6$: Hyola 42, $C_7$: Hyola 60, $C_8$: Hyola 420, $C_9$: Hyola 330, $C_{10}$: Hyola 308, $C_{11}$: Kimberly, $C_{12}$: RGS 006, $C_{13}$: 19-H, $C_{14}$: Syn-3, $C_{15}$: PR-401/16, $C_{16}$: PP-401/15E, $C_{17}$: PP 308/8, $C_{18}$: PP 308/3, $C_{19}$: ORS 3150-3006, $C_{20}$: ORS 3150-3008, $C_{21}$: RG 4403, $C_{22}$: RG 405/03, $C_{23}$: RGAS 0324 and $C_{24}$: RG 405/02 as the subplots. Each experimental plot consisted of 4 rows, 4 m long with 30 cm space between rows and 4 cm distance between plants on the rows. Seeds were planted at 5 October in each year. According to soil analysis, N, P and K fertilizer rates are recommended. P and K fertilizer were applied in pre-plant and N fertilizer was applied in three stages: one-third pre-plant, one-third in stemming stage and one-third in flowering stage. The crop was kept free from weeds by applying 2.5 L/ha Terfelan pre-plant. Cabbage aphid was also controlled during the growing seasons using Metasistox at a rate of 1.5 L/ha.

Number of siliques per plant, number of seeds per silique, 1000 seeds weight and seed yield were determined for each cultivar under both normal irrigation and water stress in both years of the experiment. Number of siliques per plant was determined by harvesting 10 plants at random from the four central rows at physiological maturity stage. Number of seeds per silique was determined by randomizing 30 siliques from all siliques of these 10 plants. Total seed weight (TSW) was determined by measuring the weight of 8 random samples with each of them consisting of 100 seed, from each plot and multiplying it by 10 in order to express it to 1000 seeds. Seed yield in each plot was measured with 12% humidity.

Simple analysis of variance (ANOVA) was performed for assessed traits at the end of each year. Combined analysis of variance was performed for assessed traits after two years of experiment. Also, Duncan's Multiple Range Test (DMRT) (P = 0.05) was used to conduct means comparison.

## RESULTS AND DISCUSSION

### First year of the experiment

#### *Number of siliques per plant*

The simple effects of treatments and the interaction effect of them on the number of siliques per plant were all significant at P = 0.01 (Table 1). Normal irrigation by average of 99.7 showed a significant preference in comparison to interruption of irrigation from the flowering stage by average of 65.3. Also, assessed cultivars from the number of siliques per plant point of view, placed in different statistical groups as PP 308/8 by average of 122.7 and ORS 3150-3008 by average of 53.3, produced the highest and lowest number of siliques per plant, respectively (Table 2). The study of the interaction effect of irrigation and cultivar on this trait revealed that assessed cultivars from the number of siliques per plant point of view, in different levels of irrigation placed in different statistical groups as RGS 003 by average of 165.3 under normal irrigation condition and Hyola 401 by average of 38.1 under water stress condition produced the highest and lowest number of siliques per plant, respectively. Generally, RGS003 under normal irrigation condition and RG4403 under water stress condition produced the highest number of siliques per plant (Figure 1).

#### *Number of seeds per silique*

The simple effects of irrigation and cultivar and their interaction effect on the number of seeds per silique were all significant at P = 0.01 (Table 1). Normal irrigation by average of 24.9 showed a significant preference in

**Table 2.** Effects and mean comparisons (simple effect) of irrigation and cultivar for assessed traits (2008-2009).

| Treatment | Mean | | | |
|---|---|---|---|---|
| | **NS/P** | **NS/S** | **TSW** | **SY (kg/ha)** |
| **Irrigation** | | | | |
| Normal irrigation | 99.7$^{a}$ | 24.9$^{a}$ | 3$^{a}$ | 1736.8$^{a}$ |
| Water stress | 65.3$^{b}$ | 17.8$^{b}$ | 3.04$^{a}$ | 1005.5$^{b}$ |
| **Cultivar** | | | | |
| RGS 003 | 106.6$^{d}$ | 22.25$^{d-g}$ | 2.97$^{d-h}$ | 1502$^{c-g}$ |
| Amica | 68.3$^{mn}$ | 23.3$^{a-d}$ | 2.85$^{hi}$ | 1277$^{hij}$ |
| Sarigol | 89.65$^{f}$ | 20$^{h}$ | 3.02$^{c-h}$ | 1336$^{hi}$ |
| Option 500 | 80.35$^{h}$ | 22.4$^{c-g}$ | 2.76$^{i}$ | 1245$^{ijk}$ |
| Hyola 401 | 74.05$^{jk}$ | 23.5$^{a-d}$ | 3.19$^{abc}$ | 970.3$^{l}$ |
| Hyola 42 | 77$^{i}$ | 22.8$^{b-f}$ | 2.9$^{f-i}$ | 1240$^{ijk}$ |
| Hyola 60 | 68.55$^{mn}$ | 18.98$^{hi}$ | 3.1$^{a-e}$ | 1167$^{jk}$ |
| Hyola 420 | 61.5$^{op}$ | 21.55$^{fg}$ | 3.14$^{a-d}$ | 1369$^{f-i}$ |
| Hyola 330 | 100.3$^{e}$ | 23.65$^{abc}$ | 3.22$^{ab}$ | 1345$^{hi}$ |
| Hyola 308 | 79.6$^{h}$ | 21.3$^{g}$ | 2.9$^{f-i}$ | 1165$^{jk}$ |
| Kimberly | 84.85$^{g}$ | 24.3$^{a}$ | 3.06$^{b-g}$ | 1383$^{e-i}$ |
| RGS 006 | 59.55$^{p}$ | 18.6$^{i}$ | 3.25$^{a}$ | 1362$^{ghi}$ |
| 19-H | 91.1$^{f}$ | 23.3$^{a-d}$ | 2.89$^{ghi}$ | 1127$^{k}$ |
| SYN-3 | 66.6$^{n}$ | 23.05$^{a-e}$ | 3.12$^{a-e}$ | 1313$^{hij}$ |
| PR-401/16 | 76.2$^{ij}$ | 23.65$^{abc}$ | 3.02$^{c-h}$ | 1298$^{hij}$ |
| PP-401/15E | 63.8$^{o}$ | 20.05$^{h}$ | 2.99$^{d-h}$ | 1371$^{f-i}$ |
| PP-308/8 | 122.7$^{a}$ | 21.8$^{efg}$ | 2.99$^{d-h}$ | 1282$^{hij}$ |
| PP-308/3 | 63.8$^{o}$ | 20.1$^{h}$ | 2.99$^{d-h}$ | 1516$^{c-f}$ |
| ORS 3150-3006 | 122.4$^{a}$ | 21.4$^{g}$ | 3.03$^{c-h}$ | 1538$^{cd}$ |
| ORS 3150-3008 | 53.3$^{q}$ | 17.1$^{j}$ | 2.94$^{e-h}$ | 1798$^{a}$ |
| RG 4403 | 115.8$^{b}$ | 21.6$^{fg}$ | 3.08$^{a-f}$ | 1716$^{ab}$ |
| RG 405/03 | 69.5$^{lm}$ | 16.3$^{j}$ | 2.97$^{d-h}$ | 1641$^{bc}$ |
| RGAS 0324 | 113.1$^{c}$ | 24.15$^{ab}$ | 2.98$^{d-h}$ | 1528$^{cd}$ |
| RG 405/02 | 72$^{kl}$ | 17$^{j}$ | 3.14$^{a-d}$ | 1419$^{d-h}$ |

Any two means sharing a common letter not differ significantly from each other at 5% probability.

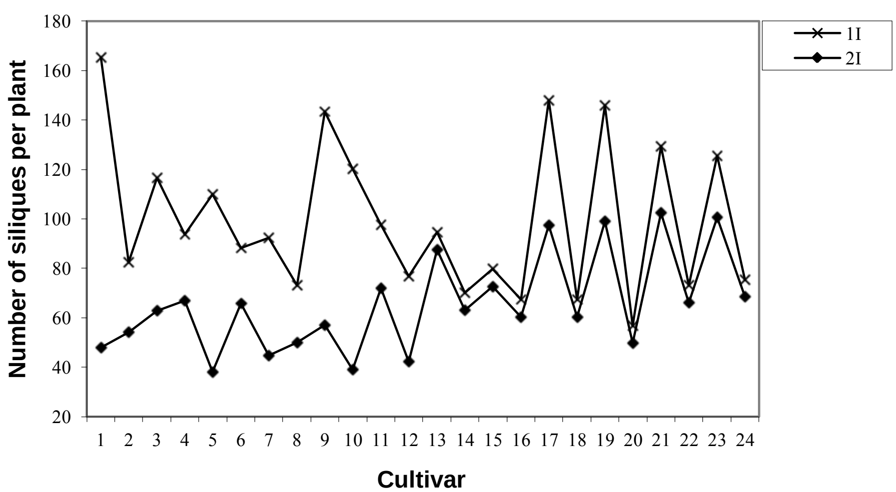


**Figure 1.** Interaction effect of irrigation and cultivar on number of siliques per plant (2008-2009).

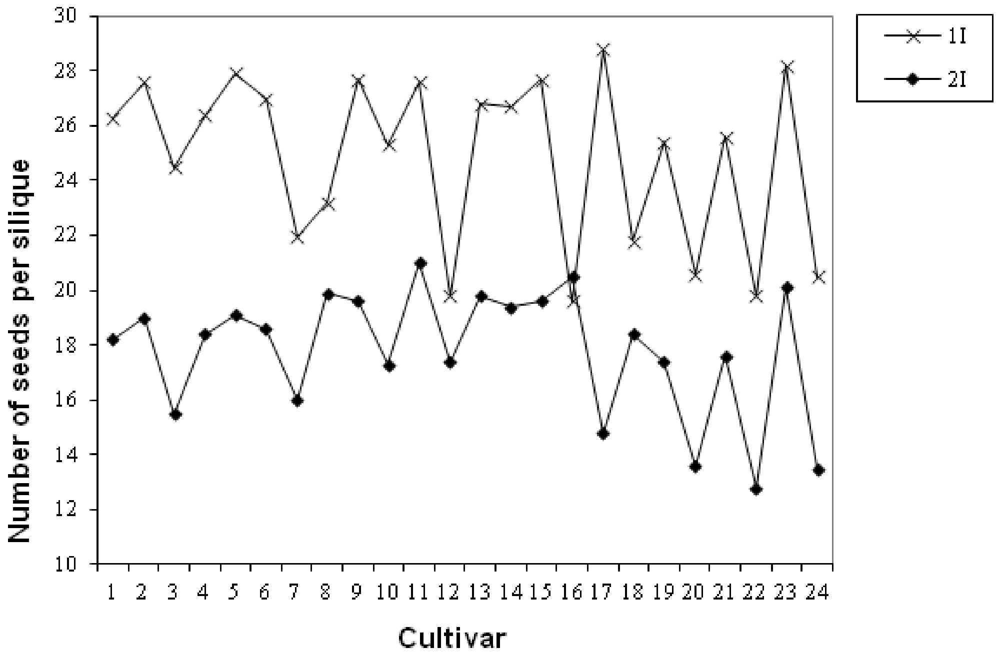


**Figure 2.** Interaction effect of irrigation and cultivar on number of seeds per silique (2008-2009).

comparison to interruption of irrigation from the flowering stage by average of 17.8. Also, assessed cultivars from the number of seeds per silique point of view placed in different statistical groups as Kimberly by average of 24.3 and RG 405/03 by average of 16.3 produced the highest and lowest number of seeds per silique, respectively (Table 2). The study of the interaction effect of irrigation and cultivar on this trait revealed that assessed cultivars from the number of seeds per silique point of view, in different levels of irrigation placed in different statistical groups as PP 308/8 by average of 28.8 under normal irrigation condition and RG 405/03 by average of 12.8 under water stress condition produced the highest and lowest number of seeds per silique, respectively. Generally PP 308/8 under normal irrigation condition and PP 401/15E under water stress condition produced the highest number of seeds per silique (Figure 2).

### *1000 seeds weight*

The simple effect of cultivar and the interaction effect of cultivar and irrigation on 1000 seeds weight were significant at P = 0.01, but the simple effect of irrigation on this trait was not significant (Table 1). Assessed cultivars from the 1000 seeds weight point of view placed in different statistical groups as RGS 006 by average of 3.25 g and Option 500 by average of 2.76 g produced the highest and lowest 1000 seeds weight, respectively (Table 2). The study of the interaction effect of irrigation and cultivar on this trait revealed that assessed cultivars from the 1000 seeds weight point of view, in different levels of irrigation placed in different statistical groups as Hyola 401 by average of 3.46 g under normal irrigation condition and Option 500 by average of 2.69 g under water stress condition produced the highest and lowest 1000 seeds weight, respectively. Generally Hyola 401 under normal irrigation condition and SYN-3 under water stress condition produced the highest 1000 seeds weight (Figure 3).

### *Seed yield*

The simple effects of irrigation and cultivar and their interaction on seed yield were all significant at P = 0.01 (Table 1). Normal irrigation by average of 1736.8 kg $ha^{-1}$ showed a significant preference in comparison to interruption of irrigation from the flowering stage by average of 1005.5 kg/ha. Also assessed cultivars from the seed yield point of view placed in different statistical groups as ORS 3150-3008 by average of 1798 kg/ha and Hyola 401 by average of 970.31 kg/ha produced the highest and lowest seed yield, respectively (Table 2). The study of the interaction effect of irrigation and cultivar on this trait revealed that assessed cultivars from the seed yield point of view, in different levels of irrigation placed in different statistical groups as ORS 3150-3008 by average of 2241 kg/ha under normal irrigation condition and Hyola 401 by average of 487.5 kg/ha under water stress condition produced the highest and lowest seed yield, respectively. Generally, ORS 3150-3008 under normal irrigation condition and RG 405/03 under water stress condition produced the highest seed yield (Figure 4).

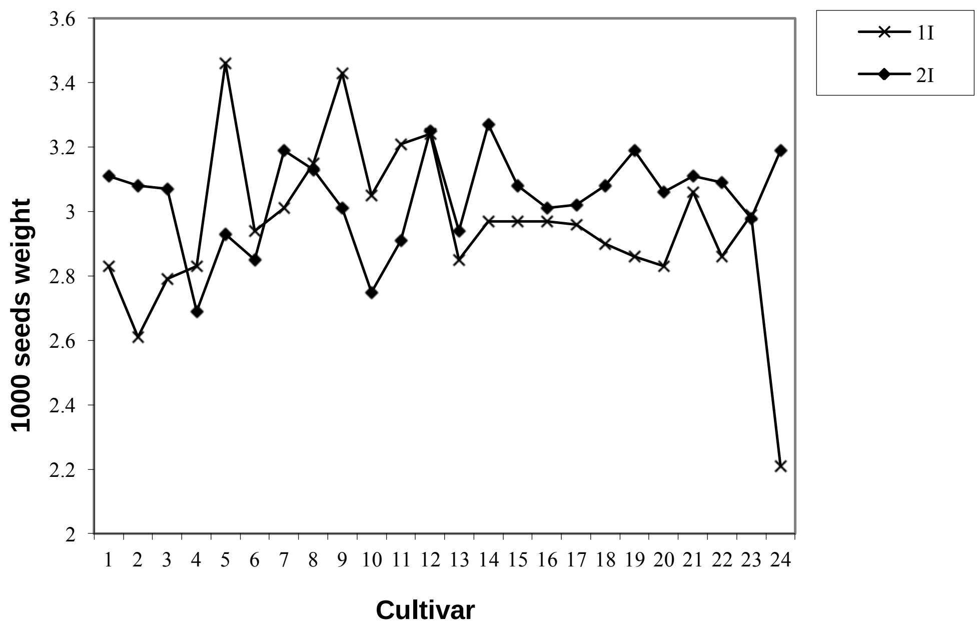


**Figure 3.** Interaction effect of irrigation and cultivar on 1000 seeds weight (g) (2008-2009).

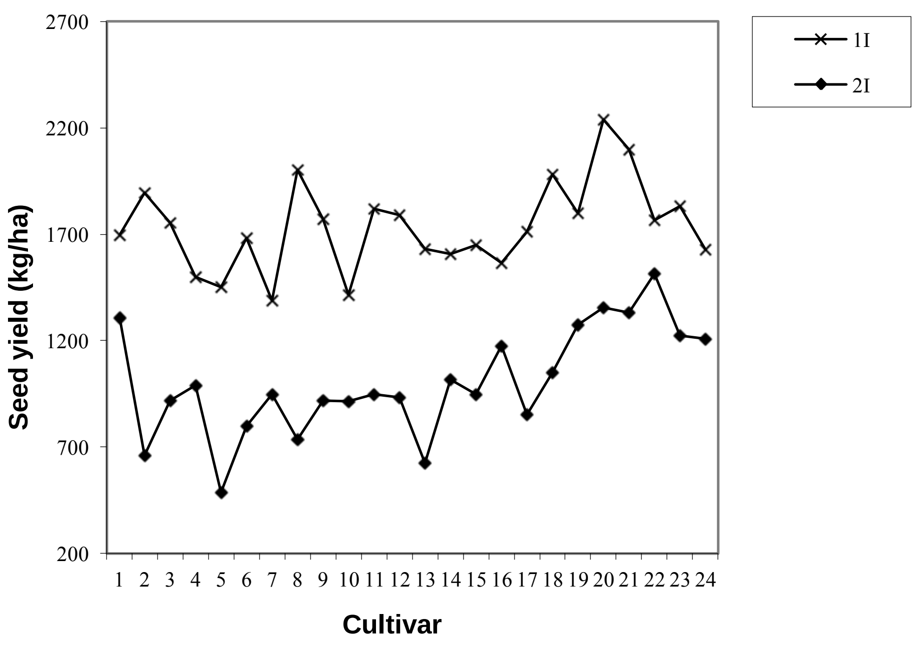


**Figure 4.** Interaction effect of irrigation and cultivar on seed yield (kg/ha) (2008-2009).

## Second year of the experiment

### *Number of siliques per plant*

The simple effects of treatments and the interaction effect of them on the number of siliques per plant were all significant at P = 0.01 (Table 3). Normal irrigation by average of 106.7 showed a significant preference in comparison to interruption of irrigation from the flowering stage by average of 69.9. Also, assessed cultivars from the number of siliques per plant point of view placed in different statistical groups as PP 308/8 yb average of 131.2 and ORS 3150-3008 by average of 57.03 produced the highest and lowest number of siliques per plant,

**Table 3.** Analysis of variance for assessed traits (2009-2010).

| Source of variation | DF | NS/P | NS/S | TSW | SY |
|---|---|---|---|---|---|
| Replication | 3 | | | | |
| Irrigation | 1 | ** | ** | ns | ** |
| Error | 3 | - | - | - | - |
| Cultivar | 23 | ** | ** | ** | ** |
| Irrigation × Cultivar | 23 | ** | ** | ** | ** |
| Error | 138 | - | - | - | - |
| Total | 191 | - | - | - | - |
| CV (%) | - | 8.27 | 9.76 | 7.69 | 9.97 |

*, **Significant at 5 and 1% respectively, ns: not significant.

respectively (Table 4). The study of the interaction effect of irrigation and cultivar on this trait revealed that assessed cultivars from the number of siliques per plant point of view, in different levels of irrigation placed in different statistical groups as RGS 003 by average of 176.9 under normal irrigation condition and Hyola 401 by average of 40.77 under water stress condition produced the highest and lowest number of siliques per plant, respectively. Generally, RGS 003 under normal irrigation condition and RG 4403 under water stress condition produced the highest number of siliques per plant (Figure 5).

### *Number of seeds per silique*

The simple effects of irrigation and cultivar and their interaction effect on the number of seeds per silique were all significant at P = 0.01 (Table 3). Normal irrigation by average of 25.4 showed a significant preference in comparison to interruption of irrigation from the flowering stage by average of 18.2. Also, assessed cultivars from the number of seeds per silique point of view placed in different statistical groups as Kimberly by average of 24.79 and RG 405/03 by average of 16.63 produced the highest and lowest number of seeds per silique, respectively (Table 4). The study of the interaction effect of irrigation and cultivar on this trait revealed that assessed cultivars from the number of seeds per silique point of view, in different levels of irrigation placed in different statistical groups as PP 308/8 by average of 29.38 under normal irrigation condition and RG 405/03 by average of 13.06 under water stress condition produced the highest and lowest number of seeds per silique, respectively. Generally, PP 308/8 under normal irrigation condition and Kimberly under water stress condition produced the highest number of seeds per silique (Figure 6).

### *1000 seeds weight*

The simple effect of cultivar and the interaction effect of cultivar and irrigation on 1000 seeds weight were significant at P = 0.01, but the simple effect of irrigation on this trait was not significant (Table 3). Assessed cultivars from the 1000 seeds weight point of view placed in different statistical groups as RGS 006 yb average of 3.34 g and Option 500 by average of 2.84 g produced the highest and lowest 1000 seeds weight, respectively (Table 4). The study of the interaction effect of irrigation and cultivar on this trait revealed that assessed cultivars from the 1000 seeds weight point of view, in different levels of irrigation placed in different statistical groups as Hyola 401 by average of 3.56 g under normal irrigation condition and Option 500 by average of 2.77 g under water stress condition produced the highest and lowest 1000 seeds weight, respectively. Generally, Hyola 401 under normal irrigation condition and SYN-3 under water stress condition produced the highest 1000 seeds weight (Figure 7).

### *Seed yield*

The simple effects of treatments and the interaction effect of them on seed yield were all significant at P = 0.01 (Table 3). Normal irrigation by average of 1806.3 kg/ha showed a significant preference in comparison to interruption of irrigation from the flowering stage by average of 1045.7 kg/ha. Also, assessed cultivars from the seed yield point of view placed in different statistical groups as ORS 3150-3008 by average of 1870 kg/ha and Hyola 401 by average of 1009 kg/ha produced the highest and lowest seed yield, respectively (Table 4). The study of the interaction effects of irrigation and cultivar on this trait revealed that assessed cultivars from the seed yield point of view, in different levels of irrigation placed in different statistical groups as ORS 3150-3008 by average of 2330 kg/ha under normal irrigation condition and Hyola 401 by average of 507 kg/ha under water stress condition produced the highest and lowest seed yield, respectively. Generally, ORS 3150-3008 under normal irrigation

**Table 4.** Effects and mean comparisons (simple effect) of irrigation and cultivar for assessed traits (2009-2010).

| Treatment | Mean | | | |
|---|---|---|---|---|
| | NS/P | NS/S | TSW | SY (kg/ha) |
| **Irrigation** | | | | |
| Normal irrigation | 106.7[a] | 25.4[a] | 3.09[a] | 1806.3[a] |
| Water stress | 69.9[b] | 18.2[b] | 3.13[a] | 1045.7[b] |
| **Cultivar** | | | | |
| RGS 003 | 114.1[d] | 22.69[d-g] | 3.06[d-g] | 1562[c-g] |
| Amica | 73.08[mn] | 23.77[a-d] | 2.93[gh] | 1328[hij] |
| Sarigol | 95.93f | 20.4[h] | 3.11[c-g] | 1389[hi] |
| Option 500 | 85.97[h] | 22.85[c-g] | 2.84[h] | 1294[ijk] |
| Hyola 401 | 79.23[jk] | 23.97[a-d] | 3.29[abc] | 1009[l] |
| Hyola 42 | 82.39[i] | 23.26[b-f] | 2.98[fgh] | 1289[ijk] |
| Hyola 60 | 73.35[mn] | 19.35[hi] | 3.19[a-e] | 1214[jk] |
| Hyola 420 | 65.81[op] | 21.98[fg] | 3.23[a-d] | 1424[f-i] |
| Hyola 330 | 107.3[e] | 24.12[abc] | 3.31[ab] | 1399[hi] |
| Hyola 308 | 85.17[h] | 21.73[g] | 2.98[fgh] | 1211[jk] |
| Kimberly | 90.79[g] | 24.79[a] | 3.15[b-f] | 1438[e-i] |
| RGS 006 | 63.72[p] | 18.97[i] | 3.34[a] | 1416[ghi] |
| 19-H | 97.48[f] | 23.77[a-d] | 2.98[fgh] | 1172[k] |
| SYN-3 | 71.26[n] | 23.51[a-e] | 3.21[a-e] | 1365[hij] |
| PR-401/16 | 81.53[ij] | 24.12[abc] | 3.11[c-g] | 1350[hij] |
| PP-401/15E | 68.27[o] | 20.45[h] | 3.08[d-g] | 1426[f-i] |
| PP-308/8 | 131.2[a] | 22.24[efg] | 3.08[d-g] | 1333[hij] |
| PP-308/3 | 68.27[o] | 20.5[h] | 3.08[d-g] | 1577[c-f] |
| ORS 3150-3006 | 131[a] | 21.83[g] | 3.12[c-g] | 1599[cd] |
| ORS 3150-3008 | 57.03[g] | 17.44[j] | 3.03[efg] | 1870[a] |
| RG 4403 | 123.9[b] | 22.03[fg] | 3.17[a-f] | 1784[ab] |
| RG 405/03 | 74.37[lm] | 16.63[j] | 3.06[d-g] | 1706[bc] |
| RGAS 0324 | 121[c] | 24.63[ab] | 3.07[d-g] | 1589[cde] |
| RG 405/02 | 77.04[kl] | 17.34[j] | 3.24[a-d] | 1476[d-h] |

Any two means sharing a common letter not differ significantly from each other at 5% probability.

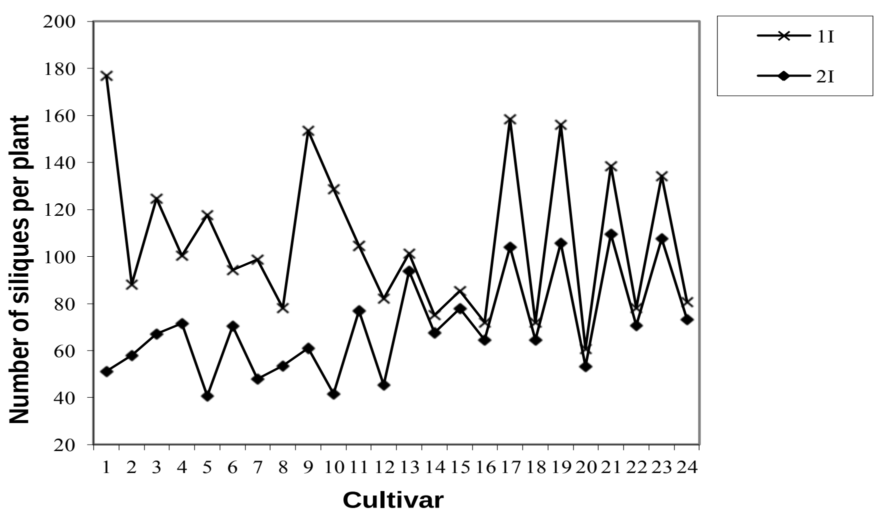


**Figure 5.** Interaction effect of irrigation and cultivar on number of siliques per plant (2009-2010).

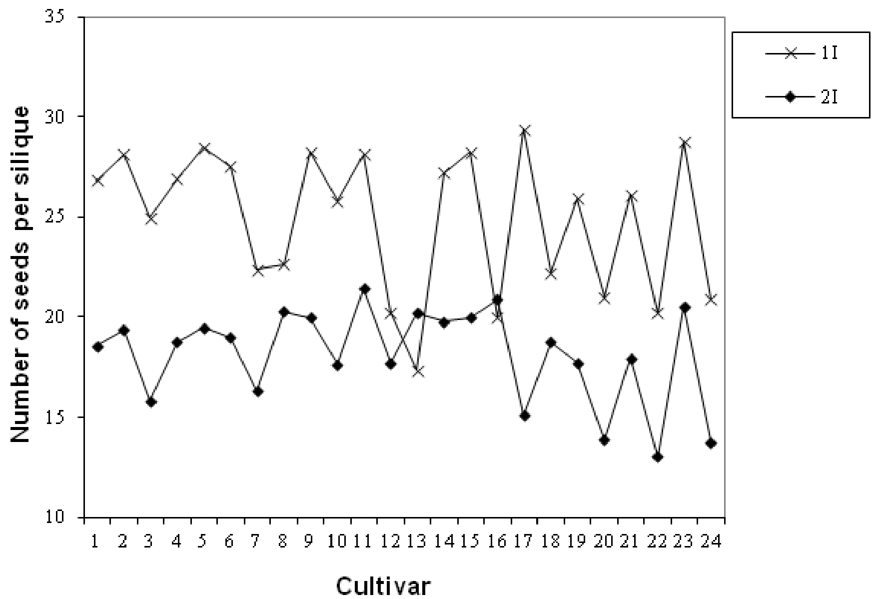


**Figure 6.** Interaction effect of irrigation and cultivar on number of seeds per silique (2009-2010).

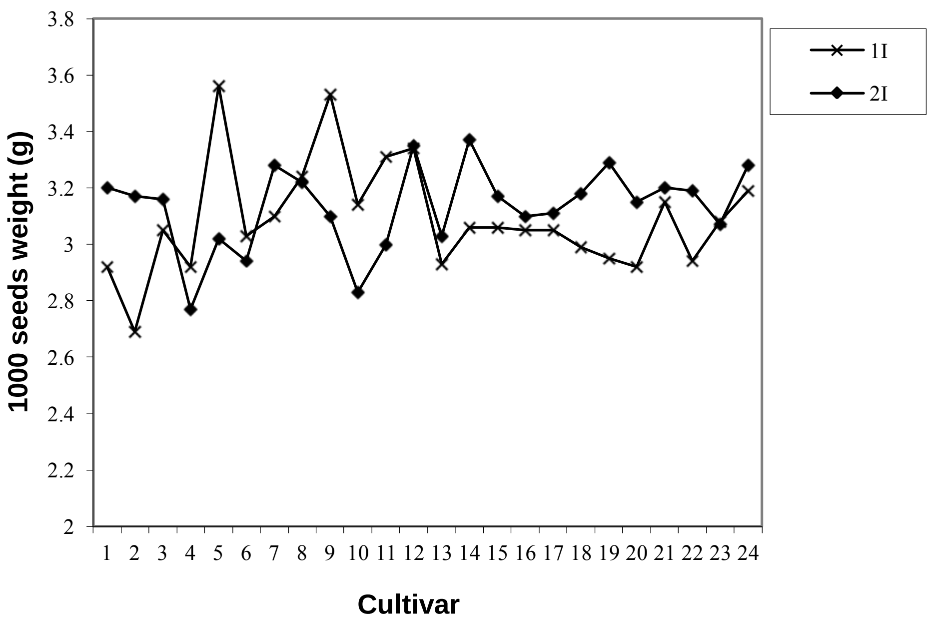


**Figure 7**. Interaction effect of irrigation and cultivar on 1000 seeds weight (g) (2009-2010).

condition and RG 405/03 under water stress condition produced the highest seed yield (Figure 8).

## Both years of the experiment

### *Number of siliques per plant*

The simple effects of treatments and the interaction effect of them on the number of siliques per plant were all significant at P = 0.01 (Table 5). Normal irrigation by average of 103.2 showed a significant preference in comparison to interruption of irrigation from the flowering stage by average of 67.6. Also, assessed cultivars from the number of siliques per plant point of view placed in different statistical groups as PP 308/8 by average of 126.9 and ORS 3150-3008 by average of 55.17 produced

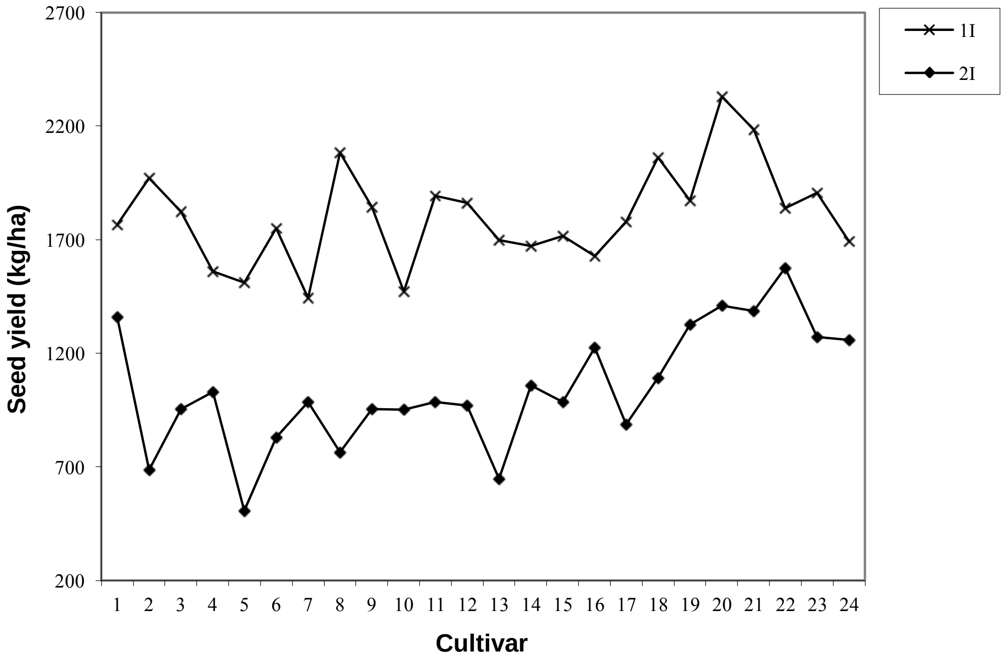


**Figure 8.** Interaction effect of irrigation and cultivar on seed yield (kg/ha) (2009-2010).

**Table 5.** Combined analysis of variance for assessed traits (2008-2010).

| Source of variation | DF | NS/P | NS/S | TSW | SY |
|---|---|---|---|---|---|
| Year | 1 | * | ** | ** | * |
| Error | 6 | | | | |
| Irrigation | 1 | ** | ** | ns | ** |
| Year × Irrigation | 1 | * | ns | ns | ns |
| Error | 6 | | | | |
| Cultivar | 23 | ** | ** | ** | ** |
| Year× Cultivar | 23 | ns | ns | ns | ns |
| Irrigation × Cultivar | 23 | ** | ** | ** | ** |
| Year × Irrigation × Cultivar | 23 | ns | ns | ns | ns |
| Error | 276 | | | | |
| Total | 383 | - | - | - | - |
| CV (%) | - | 3.1 | 5.62 | 5.17 | 9.67 |

*, **Significant at 5 and 1% respectively, ns: not significant.

the highest and lowest number of siliques per plant, respectively (Table 6). The study of the interaction effect of irrigation and cultivar on this trait revealed that assessed cultivars from the number of siliques per plant point of view, in different levels of irrigation placed in different statistical groups as RGS 003 by average of 171.1 under normal irrigation condition and Hyola 401 by average of 39.43 under water stress condition produced the highest and lowest number of siliques per plant, respectively. Generally, RGS 003 under normal irrigation condition and RG 4403 under water stress condition produced the highest number of siliques per plant (Figure 9). Totally, among rapeseed yield components, the number of siliques per plant has the most susceptibility to water stress as water stress during flowering and silique formation stages prominently decrease the number of siliques per plant due to higher falling of flowers and siliques (Sinaki et al., 2007). It seems imposed water stress from the flowering stage in this experiment reduces the number of siliques per plant through the reduction of flowering period and reproductive growth, and also, no fertilization of some flowers lead to fall of the flowers (Wright et al., 1996). Daneshmand et al. (2008) reported a 59% reduction of the number of siliques per

**Table 6.** Effects and mean comparisons (simple effect) of irrigation and cultivar for assessed traits (2008-2010).

| Treatment | Mean | | | |
|---|---|---|---|---|
| | NS/P | NS/S | TSW | SY(kg/ha) |
| **Irrigation** | | | | |
| Normal irrigation | 103.2$^{a}$ | 25.1$^{a}$ | 3.05$^{a}$ | 1771.6$^{a}$ |
| Water stress | 67.6$^{b}$ | 18$^{b}$ | 3.09$^{a}$ | 1025.6$^{b}$ |
| **Cultivar** | | | | |
| RGS 003 | 110.3$^{d}$ | 22.47$^{efg}$ | 3.02$^{fgh}$ | 1532$^{cd}$ |
| Amica | 70.69$^{lm}$ | 23.53$^{bcd}$ | 2.89$^{ij}$ | 1303$^{fg}$ |
| Sarigol | 92.79$^{f}$ | 20.2$^{i}$ | 3.06$^{d-h}$ | 1363$^{efg}$ |
| Option 500 | 83.16$^{h}$ | 22.62$^{def}$ | 2.8$^{j}$ | 1269$^{gh}$ |
| Hyola 401 | 76.64$^{j}$ | 23.73$^{abc}$ | 3.24$^{abc}$ | 989.7$^{j}$ |
| Hyola 42 | 79.69$^{i}$ | 23.03$^{cde}$ | 2.94$^{hi}$ | 1265$^{gh}$ |
| Hyola 60 | 70.95$^{l}$ | 19.16$^{j}$ | 3.14$^{b-f}$ | 1191$^{hi}$ |
| Hyola 420 | 63.65$^{o}$ | 21.77$^{fgh}$ | 3.18$^{a-d}$ | 1396$^{ef}$ |
| Hyola 330 | 103.8$^{e}$ | 23.89$^{abc}$ | 3.27$^{ab}$ | 1372$^{efg}$ |
| Hyola 308 | 82.39$^{h}$ | 21.51$^{h}$ | 2.94$^{hi}$ | 1188$^{hi}$ |
| Kimberly | 87.82$^{g}$ | 24.54$^{a}$ | 3.11$^{d-g}$ | 1410$^{ef}$ |
| RGS 006 | 61.63$^{p}$ | 18.79$^{j}$ | 3.3$^{a}$ | 1389$^{ef}$ |
| 19-H | 94.29$^{f}$ | 23.53$^{bcd}$ | 2.94$^{hi}$ | 1150$^{i}$ |
| SYN-3 | 68.93$^{m}$ | 23.28$^{cde}$ | 3.16$^{b-e}$ | 1339$^{efg}$ |
| PR-401/16 | 78.87$^{i}$ | 23.89$^{abc}$ | 3.07$^{d-h}$ | 1324$^{fg}$ |
| PP-401/15E | 66.03$^{n}$ | 20.25$^{i}$ | 3.03$^{fgh}$ | 1399$^{ef}$ |
| PP-308/8 | 126.9$^{a}$ | 22.02$^{fgh}$ | 3.03$^{fgh}$ | 1308$^{fg}$ |
| PP-308/3 | 66.03$^{n}$ | 20.3$^{i}$ | 3.04$^{e-h}$ | 1547$^{c}$ |
| ORS 3150-3006 | 126.7$^{a}$ | 21.61$^{gh}$ | 3.07$^{d-g}$ | 1568$^{c}$ |
| ORS 3150-3008 | 55.17$^{q}$ | 17.27$^{k}$ | 2.99$^{ghi}$ | 1834$^{a}$ |
| RG 4403 | 119.9$^{b}$ | 21.82$^{fgh}$ | 3.13$^{c-f}$ | 1750$^{ab}$ |
| RG 405/03 | 71.93$^{l}$ | 16.46$^{k}$ | 3.02$^{fgh}$ | 1673$^{b}$ |
| RGAS 0324 | 117.1$^{c}$ | 24.39$^{ab}$ | 3.03$^{fgh}$ | 1559$^{c}$ |
| RG 405/02 | 74.52$^{k}$ | 17.17$^{k}$ | 3.19$^{a-d}$ | 1447$^{de}$ |

Any two means sharing a common letter not differ significantly from each other at 5% probability.

plant in rapeseed cultivars under water stress condition. Zakirullah et al. (2000) reported that susceptible rapeseed varieties would experience a high reduction in their number of siliques under water stress, while reduction in tolerant rapeseed varieties would be lower.

***Number of seeds per silique***

The simple effects of irrigation and cultivar and their interaction effect on the number of seeds per silique were all significant at P = 0.01 (Table 5). Normal irrigation by average of 25.1 showed a significant preference in comparison to interruption of irrigation from the flowering stage by average of 18. Also, assessed cultivars from the number of seeds per silique point of view placed in different statistical groups as Kimberly by average of 24.54 and RG 405/03 by average of 16.46 produced the highest and lowest number of seeds per silique, respectively (Table 6). The study of the interaction effect of irrigation and cultivar on this trait revealed that assessed cultivars from the number of seeds per silique point of view, in different levels of irrigation placed in different statistical groups as PP 308/8 by average of29.09 under normal irrigation condition and RG 405/03 by average of 12.93 under water stress condition produced the highest and lowest number of seeds per silique, respectively. Generally, PP 308/8 under normal irrigation condition and Kimberly under water stress condition produced the highest number of seeds per silique (Figure 10). Our results are in line with the findings of Daneshmand et al. (2008).

***1000 seeds weight***

The simple effect of cultivar and the interaction effect of cultivar and irrigation on 1000 seeds weight were

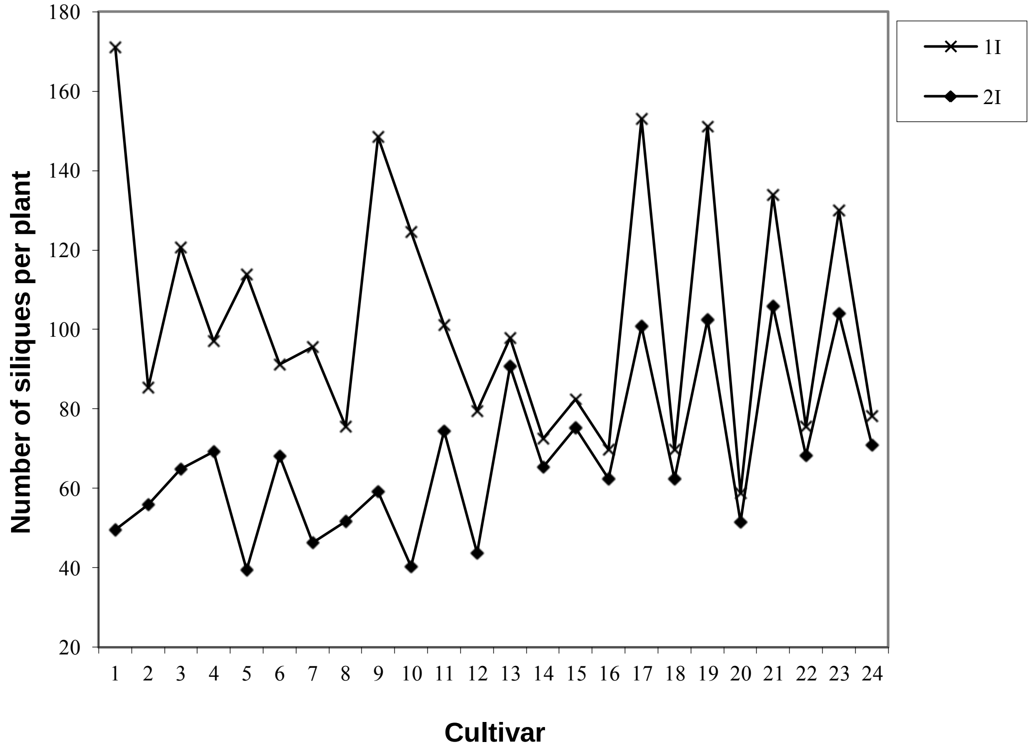


**Figure 9.** Interaction effect of irrigation and cultivar on number of siliques per plant (2008-2010).

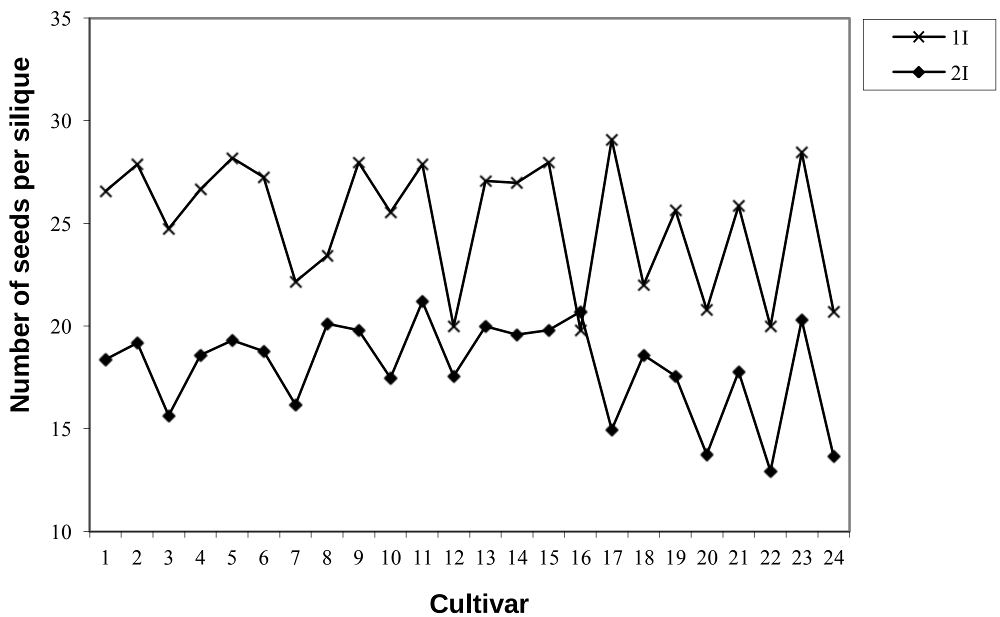


**Figure 10.** Interaction effect of irrigation and cultivar on number of seeds per silique (2008-2010).

significant at P = 0.01, but the simple effect of irrigation on this trait was not significant (Table 5). Assessed cultivars from the 1000 seeds weight point of view placed in different statistical groups as RGS 006 by average of 3.3 g and Option 500 by average of 2.8 g produced the highest and lowest 1000 seeds weight, respectively

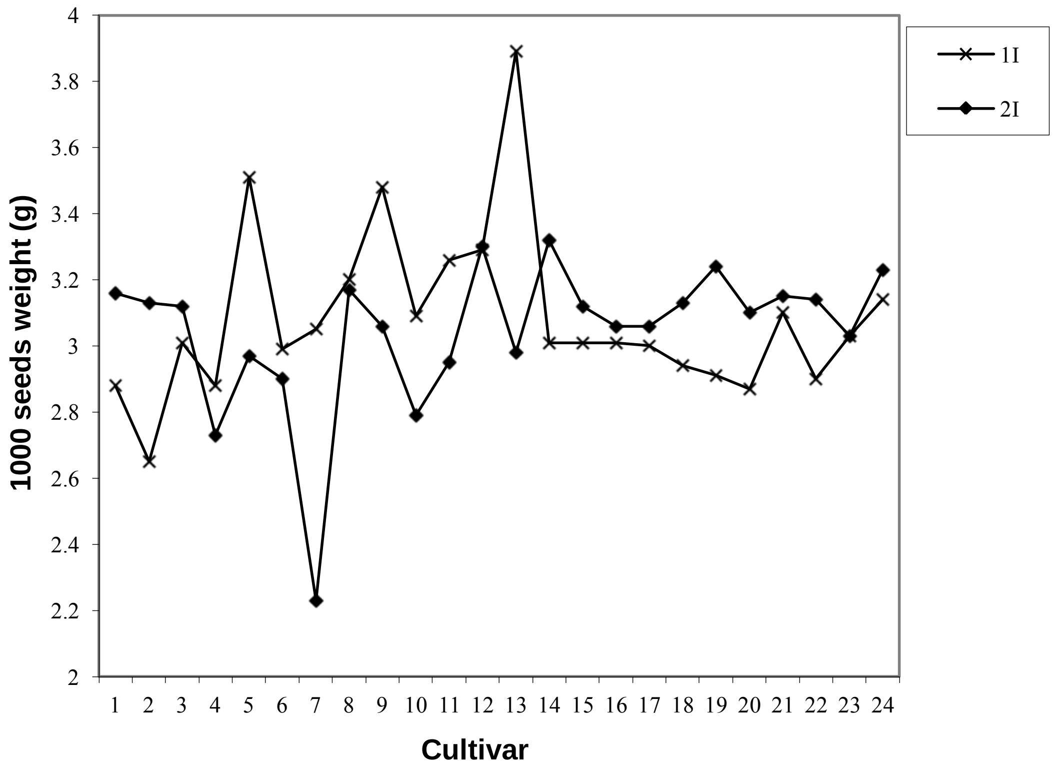


**Figure 11.** Interaction effect of irrigation and cultivar on 1000 seeds weight (g) (2008-2010).

(Table 6). The study of the interaction effect of irrigation and cultivar on this trait revealed that assessed cultivars from the 1000 seeds weight point of view, in different levels of irrigation placed in different statistical groups as Hyola 401 by average of 3.51 g under normal irrigation condition and Option 500 by average of 2.73 g under water stress condition produced the highest and lowest 1000 seeds weight, respectively. Generally, Hyola 401 under normal irrigation condition and SYN-3 under water stress condition produced the highest 1000 seeds weight (Figure 11). Nasri et al. (2008), Sinaki et al. (2007) and Sadaqat et al. (2003) reported the same results.

### *Seed yield*

The simple effects of treatments and the interaction effect of them on seed yield were all significant at P = 0.01 (Table 5). Normal irrigation by average of 1771.6 kg/ha showed a significant preference in comparison to interruption of irrigation from the flowering stage by average of 1025.6 kg/ha. Also, assessed cultivars from the seed yield point of view placed in different statistical groups as ORS 3150-3008 by average of 1834 kg/ha and Hyola 401 by average of 989.7 kg/ha produced the highest and lowest seed yield, respectively (Table 6). The study of the interaction effects of irrigation and cultivar on this trait revealed that assessed cultivars from the seed yield point of view, in different levels of irrigation placed in different statistical groups as ORS 3150-3008 by average of 2285 kg/ha under normal irrigation condition and Hyola 401 by average of 497.3 kg/ha under water stress condition produced the highest and lowest seed yield, respectively. Generally, ORS 3150-3008 under normal irrigation condition and RG 405/03 under water stress condition produced the highest seed yield (Figure 12).

Plants respond to drought by closing their stomata, which reduces leaf transpiration and prevents the development of excessive water deficits in their tissues. The drawback of the stomatal closure for plants is that their carbon gain is lowered and their growth is impaired. It seems that water stress caused yield reduction probably by inducing pod abortion via this limiting photosynthesis. It appears that water stress hampered flowering and reduced the probability of developing flower to pod and its occurrence during flowering and pod formation resulted in pod abortion (Kimber and McGregor, 1995). Gammelvind et al. (1996) also reported that water deficient in late vegetative and early reproductive growth stages reduces photosynthetic rate in leaves and therefore yield. Sinaki et al. (2007), Zakirullah et al. (2000), Nasri et al. (2008) and Faraji et al. (2009) reported the same results. Morrison and Stewart (2002) reported the genetic difference among rapeseed cultivars from the seed yield point of view. Naeemi et al. (2007) also reported a difference among spring and autumn rapeseed cultivar in response to irrigation.

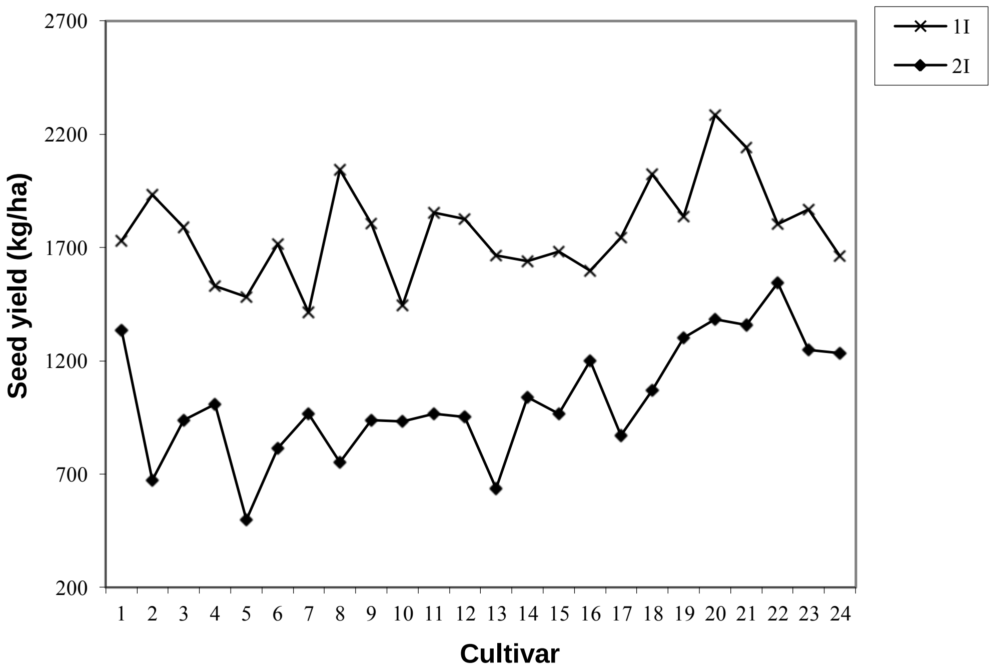


**Figure 12.** Interaction effect of irrigation and cultivar on seed yield (kg/ha) (2008-2010).

## Conclusions

Using tolerant cultivars to water stress helps to modify the water stress effects not only in flowering stage which is the most sensitive stage to drought but also in whole plant growth stages. This study provides new information about the effect of water stress from the flowering stage on yield and yield components of spring rapeseed cultivars in winter planting which helps us to choose the most appropriate and tolerant cultivars for cultivation in a region with cold temperate and semi arid region like Karaj. Generally, our results showed that under normal irrigation condition ORS 3150-3008 and under water stress condition RG 405/03 cultivars produced the highest seed yield. Therefore, ORS 3150-3008 is recommended as the best cultivar if there is no water deficit in winter planting for a cold temperate region and RG 405/03 is recommended as the best cultivar under late season drought condition in the same condition.

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