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Comparison of 17 Rapeseed Cultivars under Terminal Water Deficit Conditions Using Drought Tolerance Indices

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ABSTRACT

Drought stress is one of the environmental factors influencing crops growth, development, and production. Two field experiments were performed in Karaj, Iran, to evaluate the drought tolerance indices of 17 winter rapeseed genotypes in 2015-2016 and 2016-2017 growing seasons. The factorial arrangement of treatments was set up as RCBD with three replications. To identify drought tolerant genotypes, several indices were used based on grain yield under normal and deficit irrigation conditions. Yield results showed that cultivars Artist (504.325 g m^{-2}) and L72 (391.525 g m^{-2}) were the superior treatments under normal and deficit irrigation conditions, respectively. According to correlation results, 3-D graphs were drawn based on Geometric Mean Productivity (GMP) and grain yield under normal irrigation and deficit irrigation to categorize the winter rapeseed genotypes in both years. In the first year, Zorica and Lauren were in group A, while in the second year; Mercure, SW102, L72, and HL3721 were in group A. Therefore, they had superior performance and stable grain yield under both irrigation conditions. Biplot diagram showed Lauren (first year) and Mercure (second year) were superior regardless of stress conditions. Altogether, under normal irrigation, Artist genotype, and under stress condition, Mercure, L72 and HL3721 genotypes could be used for cultivation.

Keywords: Biplot, Principal component analysis, Stress susceptibility index.

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INTRODUCTION

Drought or water deficit is one of the environmental stresses that severely influence the crops growth, development, and production (Werteker *et al*., 2010; Ongom *et al*., 2016). The response of crops to water deficit stress is a function of genotypes, intensity and duration of stress, weather conditions and stages of plant growth and development. It should be noted that stress occurrence time is more important than drought stress intensity.

Due to different genetic makeup, genotypes usually vary in their responses to environment, which is called genotype-environment interaction (Mansour *et al*. 2017). The interaction between genotype and environment further complicates breeding work because of difficulties in predicting how genotypes will perform under different environmental conditions (Ceccarelli, 1989; Shakhatreh *et al*., 2001). Drought susceptibility of a genotype is often measured as a function of the reduction in yield under water deficit stress (Blum, 2012). In this context, Rashidi *et al.* (2017) evaluated the response of 36 Brassica genotypes belonging to seven famous species of Brassica. Results of this study showed that moisture, environments, and genotypes have significant influence on grain yield and yield components of *Brassica* species. Mansour *et al.* (2017) reported that grain yield and yield components of barely were affected by genotypes and water deficit stress. Grain yield

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significantly increased by drought-tolerant genotypes followed by moderate tolerant genotypes in comparison with drought-sensitive genotypes. In another research, Samarah *et al.* (2009) reported a 73-87% grain yield reduction as a result of severe drought in various genotypes of barley in a Mediterranean environment. They discussed that drought tolerant cultivars could play a significant role in mitigating the negative impacts of water stress on plants.

There are several indices to evaluate the susceptibility or tolerance of a crop genotype to stress conditions compared to normal condition (Fernandez, 1992). These drought tolerance indices provide a measure of drought based on loss of yield under stress condition in comparison to the non-stress condition that has been used to select drought tolerant genotypes (Bahrami *et al*., 2014). Several indices have been utilized to evaluate the drought tolerance of genotypes based on grain yield under stress and non-stress conditions. Mohammadi (2016) reported that discrimination among the genotypes based on mean values was better under severe stress than mild stress conditions. Rashidi *et al*. (2017) investigated the response of *Brassica* species to water deficit stress. Results of this study based on correlation coefficients showed that Geometric Mean Productivity (GMP), Stress Tolerance Index (STI), and Mean Productivity (MP) were the most appropriate criteria for selecting high-yield genotypes under stress and non-stress conditions.

Brassica napus L. (2n= 38), commonly called rapeseed or colza in many European countries, is an annual crop belonging to Brassicaceae (Cruciferae) family. It is one of the most important oilseed crops worldwide (Zhang *et al*., 2013; Nowosad *et al*., 2016; Eyni-Nargeseh *et al*., 2019) with over 36 million hectares cultivation area in 2014 (FAO 2017). The total area under cultivation of rapeseed in Iran has decreased by 50% compared to the previous years, mainly due to water shortage (Ministry of Agriculture, 2017). Therefore, new researches to increase the area under cultivation of rapeseed are important and essential. Quantitative measurement of drought tolerance criteria has an important role in evaluating different cultivars for drought tolerance (Clarke *et al*., 1992). Also, considering rapeseed as an important oilseed crop and its sensitivity to late season drought, rapeseed genotypes should be evaluated in terms of adaptability and drought tolerance. These findings could be useful to find the appropriate solutions for crop production in semi-arid regions. Therefore, the objective of the current study was to evaluate drought tolerance of 17 new rapeseed genotypes based on drought tolerance indices as well as select and introduce the most drought tolerant genotypes in semi-arid regions.

MATERIALS AND METHODS

Location, Experimental Design and Treatments

Two field experiments were performed at the Research Field of Seed and Plant Improvement Institute (SPII), Karaj, Iran, to evaluate drought tolerance of 17 new winter rapeseed genotypes (cultivar, hybrid, and line) (Table 1) during 2015-2017 growing seasons. The studied genotypes included two Hungarian cultivars (G1- Zorica and G2- Zlanta), seven French hybrids (G3-Artist, G4-Mercure, G5-Kamilo, G6-Lauren, G7-Darko, G8-Alonso and G9-Hydromel), two German hybrids (G10-Rohan and G11-Garou), four Iranian lines (G12-SW102, G13-HL2012, G14-L72 and G15-HL3721), an Iranian cultivar (G16-Ahmadi) and a French cultivar (G17-Okapi). The experimental treatments consisted of two irrigation regimes [normal irrigation during the growing season and withholding irrigation from silique setting stage (69, BBCH-scale) until the end of the growing season] and the aforementioned 17 new winter genotypes of rapeseed. The BBCH-scale is a system for uniform coding of phenologically similar growth stages of all mono- and dicotyledonous plant species. According to this system, "69, BBCH-scale" is considered the end of flowering. More details are given by Lancashire *et al.* (1991). Factorial arrangement of the treatments was set up as a Randomized Complete Block Design (RCBD) with three replications. Each experimental plot consisted of 6 rows, 5 m length with an inter-row distance of 30 cm and inter-plant distance of 4 cm. A two m distance was kept to eliminate all influence of lateral water movement between plots. Irrigation intervals were adjusted based on 80 mm

Table 1. Genetic status, pollination status and maturity group for different genotypes of rapeseed.

Genotype	Genetic Status	Pollination status	Maturity group
G1- Zorica	Cultivar	Open pollinating	Late maturing
G2- Zlanta	Cultivar	Open pollinating	Late maturing
G3- Artist	Hybrid	-	Mid maturing
G4- Mercure	Hybrid	-	Mid maturing
G5-Kamilo	Hybrid	-	Mid maturing
G6- Lauren	Hybrid	-	Mid maturing
G7- Darko	Hybrid	-	Mid maturing
G8-Alonso	Hybrid	-	Mid maturing
G9- Hydromel	Hybrid	-	Mid maturing
G10- Rohan	Hybrid	-	Mid maturing
G11- Garou	Hybrid	-	Mid maturing
G12- SW102	Line	Open pollinating	Mid maturing
G13- HL2012	Line	Open pollinating	Mid maturing
G14- L72	Line	Open pollinating	Mid maturing
G15- HL3721	Line	Open pollinating	Mid maturing
G16- Ahmadi	Cultivar	Open pollinating	Mid maturing
G17- Okapi	Cultivar	Open pollinating	Late maturing

evaporation from Class A evaporation pan (Safavi Fard *et al*., 2018). Water volume entering the field was measured by a water meter. Experimental plots under normal irrigation received 5,760 and 5,120 m^3 water ha^{-1} in 2016 and 2017, respectively, while in deficit irrigation treatments, 1,280 m^3 water ha^{-1} were saved in both years.

The experimental site is located at 50˚ 75′ E longitude, 35˚ 59′ N latitude and 1,321 m in a semi-arid area. Based on the long-term average (from 1985 to 2015), average annual precipitation is 253 mm, which occurs mainly during late autumn to early spring. More details including the mean monthly precipitation, minimum and maximum temperatures are given in Figure 1.

According to the results of soil analysis, soil texture was clay loam. Nitrogen fertilizer was applied in three splits (one-third pre-plant, one-

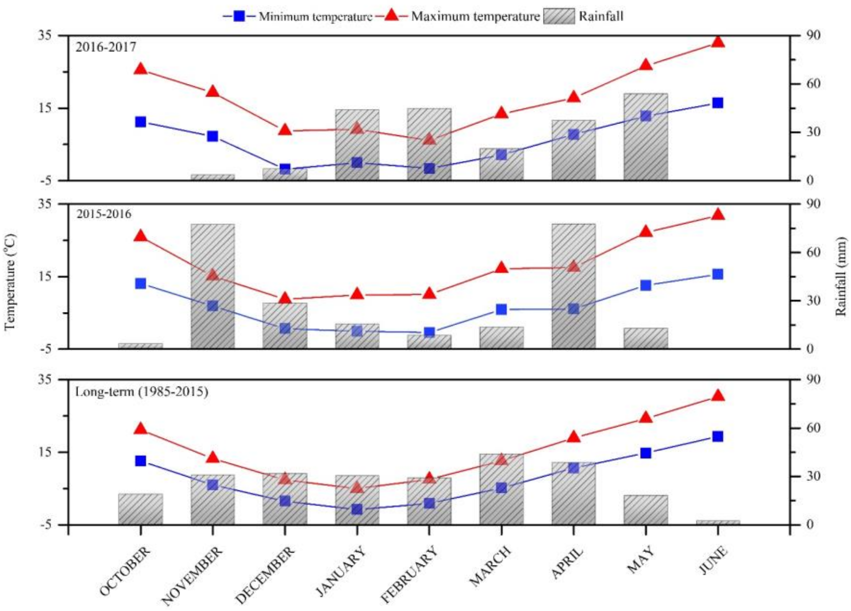

Figure 1. Rainfall (mm), maximum and minimum temperatures (˚C) during growing season of rapeseed in 2015-2016 and 2016-2017.

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third in stemming stage (30-31, BBCH-scale) and one-third in flowering stage (60, BBCH-scale)) but all P and K fertilizers were applied pre-planting. Weeds were controlled with an application of 2.5 L ha^{-1} trifluralin (48% EC) pre-plant and hand weeding in both growing seasons. Finally, rapeseed seeds were planted on 2 October in both years.

Agronomic Traits

To measure the grain yield, the final harvest was conducted by harvesting the four middle rows at physiological maturity (at 14% humidity) when 50% of the grains in the main siliques and primary branches turned brown (Ozer, 2003). Silique number per plant and grain number per silique were counted from 50 randomly selected siliques. The 1,000-grain weight was determined by measuring the weight of eight random samples, each of which consisted of 100 grains, from each plot and multiplying it by 10 to express it to 1,000 grain.

Drought Tolerance Indices

To categorize different genotypes, drought tolerance indices were calculated based on grain yield of genotypes under normal irrigation (non-stress) and withholding irrigation (stress) conditions. In the current study, nine drought tolerance indices including Stress Susceptibility Index (SSI, Fischer and Maurer, 1978), stress Tolerance (TOL, Hossain *et al*., 1990), Geometric Mean Productivity (GMP, Fernandez 1992), Stress Tolerance Index (STI, Fernandez 1992), Drought Susceptibility Index (DSI, Fischer and Maurer 1978), Harmonic Mean (HARM, Fernandez 1992), Mean Productivity (MP, Hossain *et al*. 1990), Yield Stability Index (YSI, Bouslama and Schapaugh, 1984), and Yield Index (YI, Gavuzzi *et al*., 1997) were used.

Statistical Procedures

Combined analysis of variance, mean comparison (Least significant difference, *P< 0.05) and correlation were done using SAS software (version 9.2). Finally, biplot and genotypes distribution graphs were drawn by OriginPro 9.1 software package. In the genotypes distribution graph, x, y, and z are grain yield under deficit irrigation condition (Ys), grain yield under normal irrigation condition (Yp) and stress tolerance indices, respectively. It is also worth noting biplot was obtained from principal component analysis using the grain yield of 17 rapeseed genotypes under normal irrigation (Yp) and deficit irrigation (Ys) conditions, and drought tolerance indices.

RESULTS AND DISCUSSION

Grain Yield and Yield Components

Deficit irrigation had a significant influence on grain yield and yield components of different genotypes (data not shown). According to the results of combined analysis of variance, there were no significant differences between the two years (2015-2016 and 2016-2017) in terms of grain yield and stress tolerance indices (Table 2), but the two-way interaction between genotype and year was statistically significant on grain yield and stress tolerance indices. Therefore, the response of rapeseed genotypes was different in both years, and results are presented for each year separately.

In the first year (Table 3), under normal irrigation condition, Zorica, Lauren and Artist

Table 2. Summary of combined *F* significance from analysis of variance for grain yield under normal irrigation (Yp) and deficit irrigation (Ys) conditions and drought tolerance indices of 17 rapeseed genotypes.[a]

SOV	DF	Yp	Ys	SSI	STI	TOL	DSI	GMP	HAM	YSI	YI	MP
Y	1	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
G	16	**	**	*	**	*	**	**	**	*	**	**
Y×G	16	**	**	*	**	*	**	**	**	*	**	**

[a] Y: Year, G: Genotype, * and **: Significant at the 5 and 1% levels of probability, respectively; ns: Not significant.

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genotypes produced higher grain yield at 532.42, 505.56 and 504.94 g m^{-2}, respectively, while Hydromel genotype produced the lowest grain yield (373.27 g m^{-2}). In deficit irrigation condition, Lauren and Alonso with grain yield at 385.43 and 377.63 g m^{-2}, respectively, were in the top group, while HL2012 genotype had the lowest grain yield (269.63 g m^{-2}) (Table 3). It is worth noting that the average grain yield of genotypes under normal irrigation (440.278 g m^{-2}) was higher compared to deficit irrigation (332.764 g m^{-2}). The response of rapeseed genotypes was different in the second year. Among studied genotypes under normal irrigation condition, HL3721 produced the highest grain yield (532.77 g m^{-2}) followed by Artist, L72, Garu, Mercure, and Hydromel, while Zlanta genotype produced the lowest grain yield (366.58 g m^{-2}) (Table 4). Superior genotypes under deficit irrigation condition were different, such that L72 genotype had the highest grain yield (430.8 g m^{-2}) followed by Mercure, HL3721, HL2012, and Rohan genotypes, while Zorica genotype produced the minimum grain yield (213.57 g m^{-2}) (Table 4).

Averaged over both years, Artist (504.325 g m^{-2}) and (391.525 g m^{-2}) was superior genotype under normal irrigation condition, but L72, HL3721, and Mercure (391.525, 389.245 and 375.445 g m^{-2}, respectively) were most resistant genotypes under deficit condition. High yield in drought-tolerant genotypes could be explained by higher yield components for those genotypes under water stress conditions (Mansour *et al*., 2017). According to Diepenbrock (2000), rapeseed grain yield is a function of different traits, consisting of the number of silique per plant, the number of grains per silique and the individual grain weight. In general, the high grain yield of Artist genotype compared to other genotypes in both years can be attributed to the number of silique per plant (210.8), the number of grains per silique (25.6) and the 1,000-grain weight (4.6 g) (Tables 5 and 6). Results indicated that L72, HL3721, and Mercure genotypes produced more grain yield than other genotypes under deficit irrigation condition due to highest silique per plant (159.8, 165.8 and 139.7, respectively), number of grains per silique (16.8, 17.1 and 13.6, respectively) and 1,000-grain weight (3.22, 3.27 and 2.69 g, respectively) (Tables 5 and 6). According to the results of correlation analysis (Table 7), there was a strong positive and significant correlation between grain yield and yield components (silique $plant^{-1}$, number of grains $silique^{-1}$ and 1,000-grain weight) under normal irrigation and deficit irrigation conditions in both years. The number of silique per plant during the course of development is ultimately determined by reduction in the number of branches, buds, flowers, and young siliques by source capacity, the supply of nutrients, water, and hormonal factors rather than by the potential numbers of flowers and siliques (Diepenbrock, 2000). An increase in the number of grains per silique results in higher source size and, finally, it leads to increased performance (Tayo and Morgan, 1979). The grain weight is the last yield component to be accomplished over development (Diepenbrock, 2000). Overall, the grain weight depends on the rate and duration of the grain filling, and it is the resultant of two sources of current photosynthesis and remobilization. Regarding the decreased grains weight under deficit irrigation treatments, rate and duration of the grain filling would be considered as the main effective factors for grains weight of rapeseed (Sinaki *et al*., 2007).

Drought Tolerance Indices

As seen in Table 3, Lauren and Alonso were the most drought tolerant genotypes in the first year of the experiment. Lauren genotype had the highest values of STI (1.0), GMP (4,397.3), HAM (4,340.7), YI (1.15) and MP (4,455.0). It should be noted that this genotype had no significant difference in terms of other indices (SSI, TOL, and YSI) with superior genotypes (Table 3). Hydromel and Ahmadi genotypes had the lowest values of STI (0.55 and 0.56), GMP (3,268.4 and 3,317.6), DSI (3,739.5 and 3,843.1), HAM (3,232.5 and 3,273.7), YI (0.86) and MP (3,305.0 and 3,362.5), so, they were identified as susceptible genotypes (Table 3). In addition, these genotypes had low grain yield under normal irrigation condition. In the second year of the current study, Mercure, L72, and

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Table 3. Mean of grain yield and drought tolerance indices of rapeseed genotypes under normal irrigation and deficit irrigation conditions in 2015-2016.[a]

Genotypes	Yp (g m^{-2})	Ys (g m^{-2})	SSI	STI	TOL	GMP	DSI	HAM	YSI	YI	MP
Zorica	532.42 (±25.04)a	360.71(±13.52)ab	1.29ab	0.98a	1717.1abc	4374.6ab	5327.6a	4285.9ab	0.68bc	1.08ab	4465.6a
Zlanta	461.51(±11.37)bc	357.45(±26.15)abc	0.91abc	0.84ab	1040.6a-e	4053.6abc	4620.7a-d	4013.0abc	0.77abc	1.07abc	4094.8ab
Artist	504.94(±22.43)ab	302.24(±16.30)b-e	1.62a	0.78bcd	2027.0a	3899.7cde	5052.0abc	3769.0c-f	0.60c	0.90b-e	4035.9abc
Mercure	447.41(±22.59)bcd	336.61(±36.54)a-d	0.99abc	0.77b-e	1107.9a-e	3865.3cde	4483.0b-f	3811.7cde	0.75abc	1.01a-d	3920.1b-e
Kamilo	383.49(±14.32)de	351.90(±29.75)a-d	0.31c	0.69b-f	315.2e	3661.4c-g	3793.1f	3646.4c-g	0.92a	1.05a-d	3676.7b-f
Lauren	505.56(±11.20)ab	385.43(±40.27)a	0.95abc	1.00a	1201.3a-e	4397.3a	5066.5ab	4340.7a	0.77abc	1.15a	4455.0a
Darko	404.98(±10.01)cde	293.22(±29.98)de	1.11abc	0.61ef	1117.7a-e	3434.2fg	4054.9def	3378.8efg	0.72abc	0.88cde	3491.0ef
Alonso	437.57(±18.05)b-e	377.63(±5.36)a	0.55bc	0.85ab	599.4de	4063.3abc	4384.1b-f	4050.7abc	0.86ab	1.13a	4076.0ab
Hydromel	373.27(±12.93)e	287.73(±29.52)de	0.93abc	0.55f	855.4b-e	3268.4g	3739.5f	3232.5g	0.77abc	0.86de	3305.0f
Rohan	455.62(±41.65)bc	304.53(±5.20)b-e	1.31ab	0.71b-f	1510.9a-d	3718.5c-f	4559.5b-e	3638.5c-g	0.67bc	0.91b-e	3800.7b-e
Garou	380.73(±3.72)de	332.60(±27.81)a-e	0.52bc	0.65c-f	481.3de	3553.8d-g	4269.5def	3541.0d-g	0.87ab	0.99a-e	3566.7def
SW102	459.88(±39.30)bc	340.15(±27.96)a-d	1.01abc	0.80bc	1197.2a-e	3940.6cd	4605.8a-d	3882.4bcd	0.75abc	1.02a-d	4000.2bc
HL2012	455.37(±45.93)bc	269.59(±19.65)e	1.60a	0.63def	1857.8ab	3487.5efg	4556.6b-e	3357.0fg	0.60c	0.81e	3624.8c-f
L72	429.11(±29.67)cde	352.25(±7.80)a-d	0.70bc	0.77b-e	768.6cde	3882.3cde	4298.7c-f	3858.1bcd	0.82ab	1.05a-d	3906.8b-e
HL3721	431.15(±21.83)cde	367.04(±27.33)ab	0.56bc	0.81bc	641.1de	3963.3bcd	4308.4c-f	3936.1a-d	0.86ab	1.10ab	3990.9bcd
Ahmadi	383.49(±30.63)de	289.02(±14.33)de	0.95abc	0.56f	944.7b-e	3317.6fg	3843.1ef	3273.7g	0.76abc	0.86de	3362.5f
Okapi	438.23(±33.48)b-e	348.90(±13.04)a-d	0.81abc	0.79bcd	893.3b-e	3908.1cde	4387.9b-f	3880.8bcd	0.80abc	1.04a-d	3935.6bcd

[a] Means within a columns followed by similar letters are not significantly different at 5% probability level. Note: The value after the (±) is standard error.

Table 4. Mean of grain yield and drought tolerance indices of rapeseed genotypes under normal irrigation and deficit irrigation conditions in 2016-2017.[a]

Genotypes	Yp (g m^{-2})	Ys (g m^{-2})	SSI	STI	TOL	GMP	DSI	HAM	YSI	YI	MP
Zorica	423.04(±19.90)c-g	213.59(±8.01)h	1.93a	0.45h	2094.5a	3000.6h	4232.5c-f	2829.6h	0.50e	0.64h	3183.1h
Zlanta	366.58(±9.03)g	306.57(±22.43)efg	0.63cde	0.57e-h	600.0de	3345.7fgh	3678.0ef	3325.9fg	0.83abc	0.92efg	3365.7fgh
Artist	503.71(±22.37)ab	305.79(±16.49)efg	1.53ab	0.78cd	1979.3ab	3917.7de	5039.8abc	3792.9de	0.61de	0.92efg	4047.5cde
Mercure	476.17(±24.04)a-d	414.28(±44.97)ab	0.48e	1.00ab	619.0de	4423.7abc	4761.3bcd	4395.5abc	0.87a	1.25ab	4452.2abc
Kamilo	417.68(±15.60)c-f	254.04(±21.48)gh	1.52ab	0.53fgh	1636.4a-d	3246.9gh	4179.5c-f	3140.4gh	0.61de	0.76gh	3358.6fgh
Lauren	408.23(±9.05)d-g	338.78(±35.40)def	0.65b-e	0.70c-f	694.5cde	3704.6def	4077.8def	3674.4def	0.83a-d	1.02def	3735.1def
Darko	424.67(±10.50)c-g	230.59(±23.58)h	1.78a	0.49gh	1940.8ab	3118.6h	4249.0c-f	2970.1gh	0.54e	0.69h	3276.3gh
Alonso	398.76(±16.44)efg	280.96(±3.99)fgh	1.15a-e	0.57e-h	1178.0a-e	3345.8fgh	3991.0def	3293.9fg	0.70a-e	0.85fgh	3398.6fgh
Hydromel	473.53(±16.41)a-d	301.04(±30.89)efg	1.42abc	0.72cde	1724.9abc	3765.9def	4738.3bcd	3661.9def	0.63cde	0.91efg	3872.8de
Rohan	432.47(±39.53)c-g	368.20(±6.29)a-d	0.53de	0.81cd	642.7de	3983.6cde	4336.1c-f	3964.0cde	0.86ab	1.11a-e	4003.4de
Garou	476.46(±4.66)a-d	309.83(±25.91)efg	1.37a-d	0.75cd	1666.3a-d	3837.0de	4767.6bcd	3745.3def	0.64b-e	0.93efg	3931.5de
SW102	456.20(±38.98)b-e	359.54(±29.55)b-e	0.78b-e	0.83bcd	966.5b-e	4035.1cde	4625.5bcd	3992.2cde	0.80a-d	1.08b-e	4078.7cd
HL2012	449.28(±45.31)b-f	380.66(±27.74)a-d	0.51de	0.87bc	686.2cde	4116.4bcd	4492.7b-e	4083.3bcd	0.86ab	1.15a-d	4149.7bcd
L72	482.70(±33.37)abc	430.80(±9.54)a	0.38e	1.06a	519.0e	4553.6ab	5904.9a	4539.9ab	0.90a	1.30a	4567.5ab
HL3721	532.78(±26.97)a	411.45(±30.64)abc	0.85b-e	1.11a	1213.3a-e	4664.7a	5337.5ab	4609.5a	0.78a-d	1.24abc	4721.1a
Ahmadi	419.72(±19.33)c-g	359.70(±22.24)b-e	0.54de	0.76cd	600.2de	3877.3de	4209.2c-f	3857.7de	0.86ab	1.09b-e	3897.1de
Okapi	379.98(±29.03)fg	344.36(±12.87)c-f	0.34e	0.67d-g	356.0e	3615.4efg	3606.0f	3609.0ef	0.91a	1.04c-f	3621.7efg

[a] Means within a columns followed by similar letters are not significantly different at 5% probability level. Note: The value after the (±) is standard error.

Table 5. Mean of silique plant^{-1}, number of grain plant^{-1} and 1000-grain weight (g) of rapeseed genotypes under normal irrigation condition in 2015-2016 and 2016-2017.[a]

Genotypes	Silique plant^{-1}		Number of grain plant^{-1}		1000-Grain weight (g)	
	2016	2017	2016	2017	2016	2017
Zorica	215.09a	170.90gh	26.87a	21.35c-g	4.82a	3.83de
Zlanta	180.86f-i	143.65j	21.94c-g	17.43h	3.86d-g	3.07f
Artist	211.12ab	210.60b	25.66ab	25.60ab	4.6ab	4.59ab
Mercure	195.47cde	208.04bcd	23.42a-e	24.93abc	4.16b-e	4.43b
Kamilo	173.45hij	188.95ef	20.39e-h	22.21b-f	3.81d-h	4.15bcd
Lauren	200.07bcd	161.55hi	24.34a-d	19.65fgh	4.4abc	3.55ef
Darko	164.73j	172.74gh	19.95e-h	20.93d-h	3.63fgh	3.80de
Alonso	189.02d-g	172.26gh	21.86c-g	19.92e-h	4.11cde	3.75de
Hydromel	164.61j	208.82bc	19.02gh	24.13bcd	3.47gh	4.41b
Rohan	205.56abc	195.12def	24.79abc	23.53b-e	4.61ab	4.38bc
Garou	175.46g-i	219.58b	19.74fgh	24.71abc	3.69e-h	4.62ab
SW102	197.63b-d	196.05cde	24.28a-d	24.08bcd	4.28bcd	4.24bcd
HL2012	184.57e-h	182.10fg	21.27d-h	20.98d-h	3.96c-f	3.90cde
L72	170.30ij	191.57fe	19.11gh	21.49d-g	3.41gh	3.84de
HL3721	194.06c-f	239.81a	22.65b-f	27.99a	4.08c-f	5.04a
Ahmadi	169.54ij	166.63hi	18.08h	17.33h	3.37h	3.23f
Okapi	180.83f-i	156.80ij	20.66e-h	17.91gh	3.74e-h	3.24f

[a] Means within a columns followed by similar letters are not significantly different at 5% probability level.

Table 6. Mean of silique plant^{-1}, number of grain plant^{-1} and 1000-grain weight (g) of rapeseed genotypes under deficit irrigation condition in 2015-2016 and 2016-2017.[a]

Genotypes	Silique plant^{-1}		Number of grain plant^{-1}		1000-Grain weight (g)	
	2016	2017	2016	2017	2016	2017
Zorica	136.6bcd	80.87j	14.5c-f	8.61h	2.86b-e	
Zlanta	141.6bc	121.44fg	15.2bcd	13.06ef	2.98a-d	2.55def
Artist	132.1cd	133.71def	13.9c-g	14.05cde	2.8b-e	2.83cde
Mercure	125.3def	154.27bc	12.2fgh	15.01cde	2.41ef	2.97bcd
Kamilo	146.3ab	105.64hi	15.9bc	11.52fg	3.2abc	2.31f
Lauren	158.6a	139.49de	18.6a	16.37abc	3.44a	3.02bcd
Darko	119.7ef	94.15i	11.5gh	9.04gh	2.2f	1.73g
Alonso	156.7a	116.58gh	17.3ab	12.88ef	3.28ab	2.43ef
Hydromel	128.3de	134.29de	13d-h	13.65def	2.5def	2.61def
Rohan	132.8cd	160.58b	13.2d-h	15.99bcd	2.7c-f	3.27abc
Garou	136.6bcd	127.30efg	14.1c-f	13.19ef	2.81b-e	2.62def
SW102	127.3def	134.57de	12.6e-h	13.30ef	2.48def	2.62def
HL2012	117.6ef	166.09ab	11.5gh	16.24abc	2.26f	3.19abc
L72	143.8bc	175.87a	15.1b-e	18.56a	2.9b-e	3.54a
HL3721	156.3a	175.29a	16.2abc	18.14ab	3.08abc	3.46ab
Ahmadi	115.9f	161.04b	10.7h	15.37cde	2.26f	3.21abc
Okapi	147ab	145.12cd	15.5bcd	15.27cde	2.97a-d	2.93cde

[a] Means within a columns followed by similar letters are not significantly different at 5% probability level.

Table 7. Correlation coefficient between grain yield of rapeseed genotypes and yield attributes under normal irrigation and deficit irrigation conditions in 2015-2016 and 2016-2017.[a]

Yield component	2015-2016			2016-2017		
	Y1	Y2	Y3	Y1	Y2	Y3
Normal irrigation						
Y2	0.86**			0.92**		
Y3	0.88**	0.96**		0.88**	0.95**	
Y4	0.84**	0.96**	0.98**	0.86**	0.96**	0.98**
Deficit irrigation						
Y2	0.87**			0.95**		
Y3	0.85**	0.98**		0.91**	0.96**	
Y4	0.84**	0.96**	0.98**	0.92**	0.97**	0.98**

[a] Y1: Grain yield; Y2: Silique plant^{-1}; Y3: Number of grain plant^{-1}, Y4: 1000-grain weight.** Significant 1% levels of probability.

HL3721 were considered as the most suitable genotypes because of high grain yield under both normal and deficit irrigation conditions (Table 4). In contrast, Zorica, Kamilo, and Darko were considered as the most susceptible genotypes under both normal and deficit irrigation conditions (Table 4). L72 genotype had high values of STI (1.06), TOL (519.0), GMP (4,553.6), DSI (5,904.9), HAM (4,439.9), YSI (0.90), YI (1.30) and MP (4,567.5) (Table 4). Also, this genotype had a low value of SSI (0.38). It should be noted that L72 genotype was not superior in terms of some indices (SSI, STI, TOL, GMP, HAM, YSI, MP), but there was no significant difference between L72 and other superior genotypes (Mercure and HL3721) (Table 4). Zorica had the lowest values of STI (0.45), GMP (3,000.6), HAM (2,829.6), YSI (0.64) and MP (3,183.1). On the other hand, this genotype had the highest values of SSI (1.93) and TOL (2,094.5) (Table 4); therefore, it was identified as the most susceptible genotype under deficit irrigation and normal irrigation conditions.

Stress Susceptibility Index (SSI) is used to measure the yield stability, i.e. the changes in both stress and non-stress conditions (Fischer and Maurer, 1978). The high value of SSI represents relatively more sensitivity to stress, while the low value is favoured. Tolerance (TOL) index is the difference in grain yield between non-stress (Yp) and stress (Ys) conditions, and the low value of TOL shows higher tolerance to stress. Thus, selection based on this criterion resulted in the selection of low-yielding genotypes under the non-stress condition and high-yielding genotypes under stress condition (Fernandez, 1992). Mean Productivity (MP) is defined as the average of Yp and Ys, but it has an upward bias when there are larger differences between Yp and Ys. The Stress Tolerance Index (STI) and Geometric Mean Productivity (GMP) proposed by Fernandez (1992) to identify genotypes with higher yield potential and stress tolerance under stress and non-stress conditions. The GMP index is less sensitive to extreme values, and it is a better index relative to MP index to separate superior genotypes under stress and non-stress conditions (Rosielle and Hamblin, 1981). Breeders interested in relative performance have used the GMP to evaluate the drought tolerant genotypes (Ramirez and Kelly, 1998). The STI was defined as a useful criterion to determine the high yield and stress tolerance potential of genotypes. The genotypes with high values of STI and GMP are superior in terms of grain yield under both stress and non-stress conditions (Fernandez, 1992). The Yield Index (YI) (Gavuzzi *et al*., 1997) and Yield Stability Index (YSI) (Bouslama and Schapaugh, 1984) were defined as tools to evaluate the stability of genotypes under stress and non-stress conditions. Higher values of YI and YSI indicate more performance stability under stress condition. AS expected, selection based

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on high values of YI and YSI leads to the selection of high-yielding genotypes under both stress and non-stress conditions (Mohammadi, 2016). The genotypes have higher performance under both stress and non-stress conditions if Harmonic Mean (HAM) (Fernandez, 1992) and Drought Sensitivity Index (DSI) (Fischer and Maurer, 1978) have high values. It is worth noting that in DSI, the contribution of performance under non-stress condition is more than that of stress condition. In the same way, Dorostkar *et al*. (2015) concluded that superior genotypes could be selected based on high values of STI, MP and GMP and low value of SSI. El-Rawy and Hassa (2014) reported that there was a positive correlation among wheat grain yield under stress condition and STI, YSI, and HAM.

3-D Graph Based on Stress Tolerance Criterion

The correlation coefficients were calculated between grain yield under normal irrigation (Yp) and deficit irrigation (Ys) conditions with drought tolerance indices to determine the most desirable stress tolerance criterion (Tables 8 and 9). Grain yields (Yp and Ys) were found to have a highly significant positive correlation with GMP and STI in both years (Tables 8 and 9).

Considering that the aim of the current study was selection of the high yield genotypes under deficit irrigation, thus, three dimensional graphs were drawn based on GMP and grain yield under normal irrigation (Yp) and deficit irrigation (Ys) conditions to categorize the 17 rapeseed genotypes in both

Table 8. Correlation coefficient between grain yield of rapeseed genotypes and drought tolerance indices under normal irrigation (Yp) and deficit irrigation (Ys) conditions in 2015-2016.

Genotype	Yp	Ys	SSI	STI	TOL	GMP	DSI	HAM	YSI	YI
Ys	0.32^{ns}									
SSI	0.57*	-0.57*								
STI	0.80**	0.81**	-0.006^{ns}							
TOL	0.72**	-0.41^{ns}	0.97**	0.18^{ns}						
GMP	0.80**	0.82**	-0.01^{ns}	0.99**	0.17^{ns}					
DSI	0.97**	0.33^{ns}	0.53*	0.79**	0.68**	0.79**				
HAM	0.73**	0.87**	-0.12^{ns}	0.99**	0.06^{ns}	0.99**	0.73**			
YSI	-0.56*	0.58*	-0.99**	0.02^{ns}	-0.97**	0.02^{ns}	-0.52*	0.13^{ns}		
YI	0.33^{ns}	0.99**	-0.57*	0.82**	-0.40^{ns}	0.82**	0.34^{ns}	0.88**	0.58*	
MP	0.86**	0.75**	0.09^{ns}	0.99**	0.28^{ns}	0.99**	0.85**	0.97**	-0.08^{ns}	0.75**

* and **: Significant at 5 and 1% levels of probability, respectively; ns: Not significant.

Table 9. Correlation coefficient between grain yield of rapeseed genotypes under normal irrigation (Yp) and deficit irrigation (Ys) conditions and drought tolerance indices in 2016-2017.

Index	Yp	Ys	SSI	STI	TOL	GMP	DSI	HAM	YSI	YI
Ys	0.43^{ns}									
SSI	0.11^{ns}	-0.84**								
STI	0.76**	0.93**	-0.59*							
TOL	0.28^{ns}	-0.73**	0.98**	-0.44^{ns}						
GMP	0.71**	0.93**	-0.60**	0.99**	-0.45^{ns}					
DSI	0.89**	0.51*	-0.02^{ns}	0.75**	0.12^{ns}	0.74**				
HAM	0.66**	0.96**	-0.66**	0.99**	-0.52*	0.99**	0.69**			
YSI	-0.10^{ns}	0.84**	-0.99**	0.59*	-0.97**	0.61**	0.03^{ns}	0.67**		
YI	0.42^{ns}	0.99**	-0.84**	0.92**	-0.74**	0.93**	0.51*	0.96**	0.85**	
MP	0.78**	0.89**	-0.52*	0.99**	-0.36^{ns}	0.99**	0.79**	0.98**	0.53*	0.89**

* and **: Significant at the 5% and 1% levels of probability, respectively; ns: Not significant.

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years Figure 2 (a -b). Sio-Se Mardeh *et al*. (2006) stated that MP, GMP, and STI were more suitable indices for identifying high yielding cultivars under moderate stress. Results of Naderi and Emam (2014) showed that there were significant positive correlations between rapeseed yield with several drought indices such as STI, GMP, MP, and HAM under both deficit irrigation and normal irrigation conditions. They suggested these indices were suitable to identify the drought tolerance of rapeseed cultivars.

Three dimensional graphs divide the genotypes into four groups and each division represents one combination of the genotypes: high yields under both environments (Group A); high yield in a normal environment (Group B); high yield in a stressful environment (Group C); and low yield under both environmental conditions (Group D) (Fernandez, 1992; Bahrami *et al*., 2014). In the first year, Zorica and Lauren genotypes were in Group A, all of which had superior performance and stable grain yield under both normal irrigation and deficit irrigation conditions. Darko, Hydromel and Ahmadi genotypes were in Group D and performed poorly in both conditions. As previously explained, the response of rapeseed genotypes was different in both years of the experiment. In the second year, Mercure, SW102, L72, and HL3721 genotypes were in Group A and Zorica, Zlanta, Kamilo, Darko, and Alonso genotypes were in Group D. Likewise, in different studies, the same method was used to categorize the genotypes into four groups based on their performance under stress and non-stress conditions (Fernandez, 1992; Rashidi *et al*., 2017; Kamrani *et al*., 2018).

Principal Component Analysis Using Drought Tolerance Indices and Grain Yield

Considering that 3-D graph categorizes all genotypes based on three variables (Yp, Ys, and GMP), the biplot diagrams were drawn to investigate and compare the genotypes as well as the interrelationship among all drought tolerance indices Figure 3 (a-b). As previously explained, biplot diagram was obtained from principal component analysis using the grain yield under normal irrigation (Yp) and deficit irrigation (Ys) conditions, and drought tolerance indices in 17 rapeseed genotypes (Table 10). Given that Eigenvalues were greater than or equal to 1.0, the first and second components, in total, explained more than 98.7% of the variation of the drought tolerance indices in both years (Table 10).

The principal component analysis indicated

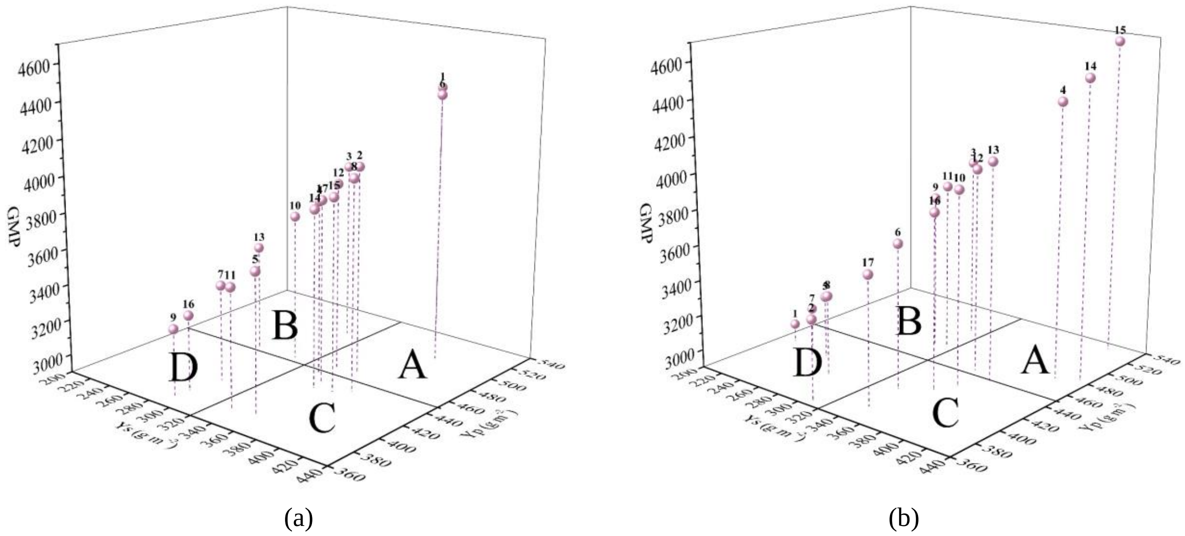
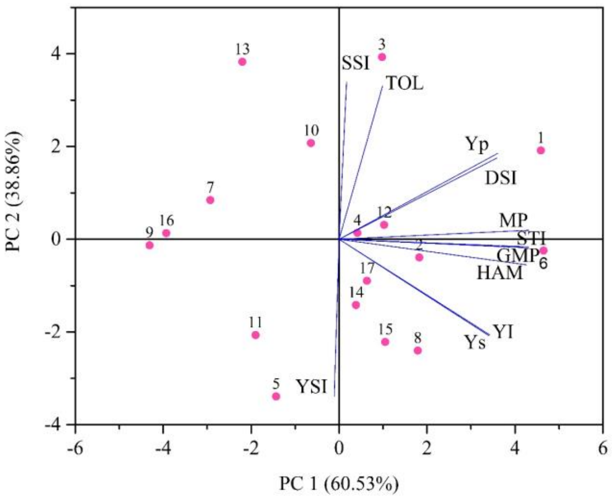


Figure 2. Three-dimensional diagram for identifying drought tolerance genotypes based on grain yield under normal irrigation (Yp) and deficit irrigation (Ys) conditions as well as the GMP in (a) 2015-2016 (b) 2016-2017.Numbers inside the chart are according to the codes of Table 1 (i.e. G1 to G17).



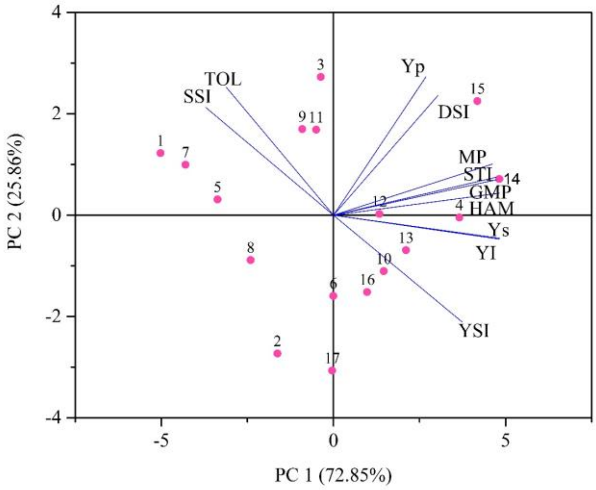


Figure 3. Biplot diagram based on the first and second components obtained from PCA using the grain yield under normal irrigation (Yp) and deficit irrigation (Ys) conditions, and drought tolerance indices in 17 rapeseed genotypes in (a) 2015-2016, (b) 2016-2017. Numbers inside the chart are according to the codes of Table 1 (G1 to G17).

that the first Component (PC1) explained 60.53% of the total yield variation in the first year and it was positively correlated with STI, GMP, HAM, and MP (Table 10). Hence, the first component (PC1) could be named as the yield potential component (Figure 3-a). The second Component (PC2) explained 38.86% of the total variation in the first year, and it showed a high and positive correlation with SSI and TOL as well as a negative correlation with Ys, YSI, and YI. Thus, PC2 could be named as the stress susceptibility component, which can identify the drought tolerant genotypes from drought-sensitive ones (Figure 3-a).

According to biplot diagram, genotypes that had high PC1 (high productivity) and low PC2 (low susceptibility) are suitable under normal irrigation and deficit irrigation conditions. Accordingly, the results of the current study showed that Lauren (G6) was superior genotype under both deficit irrigation and normal irrigation conditions. In contrast, genotypes with low PC1 (low productivity) and high PC2 (high susceptibility) are susceptible under normal irrigation and deficit irrigation conditions. Therefore, their cultivation is not recommended. These genotypes included Darko (G7), Rohan (G10) and HL2012 (G13). As a result, Kamilo (G5) and Garou (G11) with both low PC1 and PC2 had low sensitivity to deficit irrigation and can be used in breeding programs for drought tolerance (Dorostkar *et al*., 2015). Based on the biplot diagram, indices are positively correlated if the angle between their vectors is < 90˚, negatively correlated if the angle is > 90˚, and independent if the angle is 90˚ (Yan and Kang, 2003). According to Figure 3-a, Yp positively correlated with the TOL, DSI, MP, GMP, STI, SSI and HAM indices, as shown by the acute angle between their vectors, while Ys positively correlated with the MP, GMP, STI, HAM, YSI and YI indices. Ys had a high negative correlation with SSI and TOL indices as shown by the obtuse angle between their vectors.

In the second year, the first Component (PC1) explained 72.85% of the total variation and exhibited a strong and positive correlation with Ys, STI, GMP, HAM, YI, and MP; while the second Component (PC2) explained 25.86% of the total variation and exhibited a high positive correlation with Yp, SSI, TOL, and DSI (Table 10; Figure 3-b). Therefore, PC1 and PC2 were named drought tolerance and stress susceptibility components, respectively. Rohan (G10), HL2012 (G13) and Ahmadi (G16) had high PC1 and low PC2; therefore, these genotypes are suitable under

Table 10. Results of PCA for grain yield of rapeseed genotypes under normal irrigation (Yp) and withholding irrigation (Ys) conditions and drought tolerance indices in 2015-2016 and 2016-2017 growing seasons.

Component	Eigenvalue	Variance (%)	Yp	Ys	SSI	STI	MP
First year							
PC1	6.65	60.53	0.32	0.30	0.01	0.38	0.38
PC2	4.27	38.86	0.26	-0.29	0.48	-0.02	0.02
Second year							
PC1	8.01	72.85	0.19	0.34	-0.26	0.34	0.33
PC2	2.84	25.86	0.48	-0.08	0.38	0.13	0.18

Component	Eigenvalue	Variance (%)	TOL	GMP	DSI	HAM	YSI	YI
First year								
PC1	6.65	60.53	0.08	0.38	0.32	0.38	-0.009	0.30
PC2	4.27	38.86	0.47	-0.02	0.24	-0.07	-0.48	-0.29
Second year								
PC1	8.01	72.85	-0.22	0.34	0.22	0.34	0.27	0.34
PC2	2.84	25.86	0.45	0.12	0.42	0.07	-0.37	-0.08

normal irrigation and deficit irrigation conditions, but Mercure (G4) was the best genotypes due to values of PC1 and PC2. In contrast, Zorica (G1), Artist (G3), Darko (G7), Hydromel (G9) and Garou (G11) had low PC1 and high PC2, so, these genotypes are susceptible under normal irrigation and deficit irrigation conditions, and their cultivation is not recommended. The genotypes that had high PC1 were superior under normal irrigation condition such as L72 (G14) and HL3721 (G15). Finally, Zlanta (G2) and Alonso (G8) with both low PC1 and PC2 had low sensitivity to deficit irrigation and can be used in breeding programs for drought tolerance. Based on the angle between vectors, Yp positively correlated with the DSI, MP, STI, GMP, HAM, TOL and YI indices, as shown by the acute angle between their vectors, while Ys positively correlated with the YI, HAM, GMP, STI, MP, YSI and DSI indices. It should be noted that Ys had a high negative correlation with TOL and SSI, as shown by the obtuse angle between their vectors, while Yp had near zero correlation with SSI and YSI indices, as shown by their nearly perpendicular vectors. Several researchers (PCA) have used the same method to investigate and select the superior genotypes under stress and non-stress conditions (Bennani *et al*., 2017; Khalili *et al*., 2016). Kaya *et al*. (2002) and Kamrani *et al.* (2018) reported that stable genotypes had greater PC1 but lower PC2 values. Results of Rashidi *et al.* (2017) using PCA showed that *B. napus* and *B. carinata* were known as superior species for both normal and mild drought-stress conditions. In this research, Species of *B. oleracea* and *B. rapa* showed very low susceptibility and productivity under mild and intense stress conditions. *B. fruticulosa* was also recognized as a specie with high susceptibility and low productivity in both mild and intense stress. Bahrami *et al.* (2014) reported that Kermanshah47, IL, Hamedan38, Syrian, and Kordestan5 were known as superior safflower genotypes with high PC1 but low PC2 values.

CONCLUSIONS

Generally, the results illustrated that cultivar Artist (on average 504.325 g m^{-2}) was a superior genotype under normal irrigation condition, but L72 (on average 391.525 g m^{-2}), HL3721 (on average 389.245 g m^{-2}), and Mercure (on average 375.445 g m^{-2}) were the most tolerant genotypes under deficit irrigation condition. Based on the 3-D graphs, in the first year, Zorica and Lauren genotypes were in group A, but in the second year, Mercure, SW102, L72, and HL3721 genotypes were in group A, all of which had superior performance and stable grain yield under both normal irrigation and deficit irrigation conditions. According to biplot diagram, Lauren (first year) and Mercure (second year)

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were superior genotypes under both deficit irrigation and normal irrigation conditions. In conclusion, the results of the present study using different approaches indicated that, under normal irrigation condition, Artist genotype, and under deficit irrigation condition, Mercure, L72, and HL3721 genotypes had high grain yield, and their cultivation is recommended in areas with similar climates.

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مقایسه هفده رقم کلزا تحت شرایط کم‌آبی انتهای فصل با استفاده از شاخص‌های تحمل به خشکی

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چکیده

تنش خشکی یکی از عوامل زیست محیطی است که رشد، نمو و تولید محصولات زراعی را تحت تأثیر قرار می‌دهد. به‌منظور ارزیابی شاخص‌های تحمل به خشکی در ۱۷ ژنوتیپ زمستانه کلزا دو آزمایش مزرعه‌ای در سال‌های ۱۳۹۵-۱۳۹۴ و ۱۳۹۶-۱۳۹۵، در کرج، ایران انجام شد. آزمایش به صورت فاکتوریل و در قالب طرح بلوک‌های کامل تصادفی با سه تکرار اجرا شد. برای شناسایی ژنوتیپ‌های متحمل به خشکی، چندین شاخص مبتنی بر عملکرد دانه تحت شرایط قطع آبیاری و آبیاری معمولی استفاده شد. نتایج عملکرد نشان داد که ژنوتیپ‌های Artist (۵۰۴۳/۲۵ کیلوگرم در هکتار) و L72 (۳۹۱۵/۲۵ کیلوگرم در هکتار) به ترتیب تیمارهای برتر تحت شرایط آبیاری معمولی و قطع آبیاری بودند. با توجه به نتایج همبستگی برای طبقه‌بندی ژنوتیپ‌های زمستانه کلزا، نمودارهای سه بعدی بر اساس متوسط بهره‌وری هندسی (GMP) و عملکرد دانه تحت شرایط آبیاری معمولی و قطع آبیاری در هر دو سال رسم شدند. در سال اول، ژنوتیپ‌های Zorica و Lauren در گروه A قرار گرفتند، در حالی که در سال دوم، این جایگاه به ژنوتیپ‌های Mercure، SW102، L72 و HL3721 اختصاص یافت. بر این اساس می‌توان اذعان داشت که این ژنوتیپ‌ها تحت هر دو تیمار آبیاری برتری و عملکرد دانه پایدار داشتند. نمودار بای‌پلات نشان داد Lauren (سال اول) و Mercure (سال دوم) در شرایط بدون تنش برتر بودند. در مجموع، ژنوتیپ Artist تحت شرایط آبیاری معمولی و ژنوتیپ‌های Mercure، L72 و HL3721 تحت شرایط تنش برای کشت قابل توصیه می‌باشند.

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