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Evaluation of Drought Resistance of Camelina (*Camelina sativa* L.) Doubled Haploid Lines in the Climate Conditions of Kermanshah Province

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ABSTRACT

Water stress is one of the most important limiting abiotic factors for crop plants. The drought resistance was investigated for 35 camelina doubled haploid lines along with a check cultivar (Sohail), under two irrigation conditions (supplementary irrigation and rainfed), during the crop year 2020-2021. The study was conducted in the randomized complete block design by three replications in three regions of Eslamabad-e Gharb, Mahidasht and Mehrgan. The indices of stress sensitivity (SSI), tolerance (Tol), drought resistance (DTI), mean productivity (MP), geometric mean productivity (GMP), harmonic mean (MH), yield stability (YSI) and drought resistance (DI) were calculated using seed yield in two environments of rainfed (Ys) and supplementary irrigation (Yp). There was a significant difference among regions for Y_S, Y_p, MP, GMP, MH, and DTI indices. MP, GMP, MH, DTI and DI indices had significant correlations with two environments. According to MH, MP and GMP, the highest and the lowest drought resistance were observed in the Mehrgan region and Islamabad region, respectively. Mahidasht showed the highest value of drought resistance and Mehrgan showed the lowest value of drought resistance among the lines based on DTI. In addition, the results of the mean comparison, cluster analysis, principal components analysis and the three-dimensional scatter diagram of the lines based on the yield of two environments and the MP index showed that lines 1, 2, 3, 5, 6, 10, 7 and the check cultivar had more drought resistant. These lines had high seed yield in two contrast environments and showed more drought resistance, which is recommendable for breeding programs in the climatic conditions of Kermanshah province.

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1. Introduction

Water scarcity in changing climate scenarios has become a serious threat to sustainable crop production globally, and especially in developing countries of South Asia (Ahmad *et al.*, 2021). Also, in Iran, especially in Kermanshah province, which is one of the dry and semi-arid regions of the country, drought stress, especially at the end of the growing season, is the main reason for the significant decrease in yield. Therefore, studying and investigating various aspects of drought stress is one of the ways to confront the effects of this stress (Seleiman *et al.*, 2021). In fact, drought stress is one of the most complex abiotic stresses worldwide, impacting the growth and development of plants. Furthermore, it is rapidly intensifying and widespread in dry areas, primarily due to climate change. (Nahas *et al.*, 2020). So, drought stress is the main limiting factor for crop yield in most regions of the world, including Iran. (Soltanieh *et al.*, 2023). Therefore, various research methods have been developed to understand the mechanisms used by the plant to tolerate drought, which has caused the cultivars with more tolerant to drought stress (Adel and Carels, 2023).

Camelina sativa L. Crantz is an oilseed belonging to the Brassicaceae family. This plant has been noticed all

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over the world for its remarkable adaptability to various environments, high yield potential, and versatile applications in both edible and non-edible uses (Zanetti *et al*., 2017; Berti *et al*., 2016). Due to the self-pollinating of this plant, pure lines are usually used in breeding programs to produce cultivars. Although camelina is not yet widely cultivated, it can be considered a sister plant to oilseed rape (*Brassica napus* L. var. oleifera) due to its flexibility as a species. Additionally, it requires fewer inputs, more resistance to pests and diseases, and exhibits better resistance to abiotic stresses such as temperature, drought and salinity (Bakhshi *et al*., 2021). This plant grows well in poor soils and it tolerates low soil fertility conditions (Royo-Esnal and Valencia-Gredilla, 2018). Research has shown that camelina is very resistant to environmental stress (Bakhshi *et al*., 2021). Camelina is more resistant to abiotic stresses than Canola and it can compete with other species of the Brassicaceae family in terms of tolerance to environmental stresses (George *et al*., 2018; Pavlista *et al*., 2011). The seed of this plant contains almost 35–45% oil, and the plants complete their life cycle within 60–90 days (Ahmad *et al*., 2021). The development of the cultivation of this plant in the country can be a valuable source for the production of oil for edible, medicinal, and industrial uses.

Due to the difficulty of measuring drought resistance, the most important method is to measure yield under drought stress conditions. The generality of this method comes from the fact that in most cases, other measurement methods could not express the behavior of selected cultivars in field conditions. The resistance that is measured in this way includes a set of many characteristics because it depends not only on the ability of the cultivar to survive against drought stress but also on the characteristics of the plant for growth before, during and after the occurrence of stress (Bao *et al*., 2023). Accordingly, one of the ways to identify drought-resistant genotypes is to select genotypes based on drought resistance indices, based on which resistant genotypes are selected (Bao *et al*., 2023). For this purpose, according to the performance in two stressful and non-stressed environments, the behavior of genotypes has been categorized into four groups (Fernandez, 1992): I. genotypes that have good performance in both stress and non-stress environments, II. genotypes that have high performance (good appearance) only in non-stress environments, III. genotypes that have high performance in stress environments, and IV. genotypes that have a weak expression in both stress and non-stress environments. Indices have been proposed for the selection of genotypes based on yield under stress and non-stress conditions. These indices include SSI, Tol, DTI, MP, GMP, MH, YSI and DI.

Not much research has been done on drought resistance in camelina, but the results have shown that drought resistance of spring biotypes performed better than winter types under stress conditions (Čanak *et al*., 2020). Also, research has shown that the use of selenium can increase drought resistance in camelina (Ahmad *et al*., 2021). The drought resistance of camelina doubled haploid lines was investigated in one location in Kermanshah province and the superior lines were identified using drought resistance indices (Esmaeili *et al*., 2023), but in the present study, the drought resistance of the lines was investigated in several locations, so that the results can be generalized to the major areas of camellia cultivation in Kermanshah province. On the other hand, the composition of the lines was different from the previous research and new lines were investigated so that if possible newer resistant lines could be identified and introduced.

2. Materials and methods

2.1. The plant material

In order to evaluate the resistance to drought in the climatic conditions of Kermanshah Province, a number of 35 doubled haploid lines were examined along with Soheil cultivar as a check. This cultivar was introduced in 2017 and is the only inner-improved cultivar that tolerates drought and cold and is resistant to pests and diseases. It is also suitable for autumn cultivation in many climates conditions (Rostami Ahmadvandi *et al*., 2021a). The list of investigated lines along with their origin is presented in Table 1.

2.2. Experimental sites

The investigated lines were evaluated in three research stations of Eslamabad-e Gharb, Mahidasht and Mehrgan in the crop year of 2020-2021. These research stations belong to the Center for Education, Research of Agriculture and Natural Resources of Kermanshah province. The choice of these locations was due to the fact that the largest area under camelina cultivation in Kermanshah province is done in the intended areas. The geographical and soil characteristics of the stations and the meteorological statistics are presented in Tables 2 and 3, respectively.

Table 1. The list of studied doubled haploid lines.

Line code	Doubled haploid number	Paternal parent		Maternal parent	
		Origin	Cultivar	Origin	Cultivar
DH1	10	Poland	Czestochowska	Former Soviet Union	Chulymskij
DH2	11	Russia	Omskij Mestnyj	Russia	Przybrodzka
DH3	14	Denmark	Hoga	Poland	Calena
DH4	15	Greece	Blaine Greek	Germany	Voronezh349
DH5	16	Poland	Czestochowska	Former Soviet Union	Boha
DH6	18	Poland	Volynskaja	Denmark	Przybrodzka
DH7	20	Denmark	Hoga	Poland	Svalöf
DH8	28	Former Soviet Union	Ukrajinskij	Sweden	Przybrodzka
DH9	31	Denmark	Hoga	Poland	Lindo
DH10	33	Former Soviet Union	Ukrajinskaja	Germany	Calena
DH11	36	Greece	Blaine Greek	Germany	Omskij Mestnyj
DH12	38	Irkutsk Region	Irkutskij Mestnyj	Russia	Saratouskij
DH13	40	Poland	Bronowska	Russia	Chulymskij
DH14	41	Russia	Omskij Mestnyj	Russia	Omskij Mestnyj
DH15	60	Irkutsk Region	Irkutskij Mestnyj	Russia	Voronezh349
DH16	61	Poland	Czestochowska	Former Soviet Union	Voronezskij 349
DH17	66	Kyrgyzstan	Kirgizskij 1	Russia	Came
DH18	69	Former Soviet Union	Volynskaja	Germany	Lindo
DH19	72	Former Soviet Union	Ukrajinskaja	Germany	VNIIMK17
DH20	75	Poland	Borowska	Former Soviet Union	Came
DH21	76	Former Soviet Union	Volynskaja	Germany	Voronezskij 349
DH22	77	Kyrgyzstan	Kirgizskij 1	Russia	Came
DH23	82	Former Soviet Union	Omskij	Germany	Calena
DH24	84	Greece	Blaine Greek	Germany	VNIIMK17
DH25	85	Poland	Borowska	Former Soviet Union	Came
DH26	94	Former Soviet Union	Omskij	Germany	Boha
DH27	97	Poland	Volynskaja	Denmark	Came
DH28	100	Former Soviet Union	Omskij	Germany	Zavolzskij
DH29	102	Former Soviet Union	Sortandinskij	Former Soviet Union	Svalöf
DH30	105	Former Soviet Union	Ukrajinskij	Sweden	Lindo
DH31	107	Former Soviet Union	Ukrajinskaja	Germany	Calena
DH32	114	Greece	Blaine Greek	Germany	Lindo
DH33	122	Former Soviet Union	Ukrajinskaja	Germany	Lindo
DH34	128	Former Soviet Union	Ukrajinskaja	Germany	Calena
DH35	200	North America	Suneson	France	CCE11
Chek	Sohail	Greece	Blaine Greek	Germany	Chulymskij

Table 2. The geographical and soil characteristics of the studied stations.

Region	Geographic longitude	Geographic latitude	Altitude (m)	Clay (%)	Silt (%)	Sand (%)	Soil texture	Zn (p.p.m)	Fe (p.p.m)
Eslamabad-e Gharb	46º 59'	34º 08'	1260	51.6	37.7	10.7	C	0.58	5.6
Mahidasht	46º 49'	34º 16'	1360	47.1	45.6	7.4	Si-C	0.65	6.8
Mehrgan	47º 09'	34º 09'	1270	33.3	45.7	21.0	C-L	0.84	7.4
Region	**Depth (cm)**	**Mn (p.p.m)**	**Cu (p.p.m)**	**av.K (p.p.m)**	**av. P (p.p.m)**	**O.C (%)**	**pH**	**Ec×10^3**	**TNV (%)**
Eslamabad-e Gharb	0-30	14.0	3.6	565.0	20.2	1.0	8.0	0.75	11.0
Mahidasht	0-30	19.0	3.6	462.0	23.6	1.2	7.8	0.92	33.5
Mehrgan	0-30	5.9	2.6	360.0	7.9	1.4	7.6	0.58	12.3

Table 3. The meteorological statistics of the studied stations based on information of meteorological administration of Kermanshah Province from 1995 to 2021.

Region	Average annual rainfall (mm)	Number of rainy days	Average humidity (%)	Average maximum temperature (ºC)	Average minimum temperature (ºC)	Number of frosty days
Eslamabad-e Gharb	445.85	66.19	49.62	22.68	5.53	10.7
Mahidasht	379.40	50.15	52.48	22.57	4.48	7.4
Mehrgan	398.57	70.95	43.13	24.01	7.23	21.0

2.3. Experimental design and agricultural operations

This research was carried out in the form of a randomized complete block design with three replications, in two rainfed and supplementary irrigation conditions, in three research stations. Each plot consisted of two lines by length of 1.5 m with 20 cm line distance and an approximate density of 400 seeds per m^2. Also, the distance between each plot was considered 50 cm. In rainfed and supplementary irrigation conditions, the first irrigation after planting was done at the end of October 2020 in all three stations simultaneously. For supplementary irrigation conditions, irrigation was done by flood irrigation method in two stages of flowering and seed filling. In rainfed conditions, irrigation was not done throughout the growth period. No chemical fertilizers were used during the experiment and weeding was done manually.

Harvesting was done in early July 2020, and when the plants reached complete maturity by removing the edge effect for each plot, the plants were harvested with a length of one meter. After separating the straw and stubble, the cleaned seeds were weighed with an accuracy of 0.01 grams, and the weight was recorded as the seed yield of each plot. According to the harvested area, the yield was calculated in Kg/ha for each plot. In order to evaluate the drought resistance of the studied lines according to the seed yield of two rainfed environments (Ys) and supplementary irrigation environments (Yp) in terms of kg/ha in three locations, drought resistance indices were calculated with three repetitions in each region according to the calculation formulas (Table 4).

Table 4. Drought resistance indices along with their calculation formula.

Index	Calculation formula	Reference
MP	$MP = (Ys+Yp)/2$	Rosielle and Hamblin (1981)
Tol	$TOL = Yp - Ys$	Rosielle and Hamblin (1981)
GMP	$GMP = \sqrt{Yp \times Ys}$	Fernandez (1992)
MH	$HARM = \frac{2}{(\frac{1}{Yp} + \frac{1}{Ys})}$	Fernandez (1992)
SSI	$SSI = \frac{[1-(Ys/Yp)]}{SI}$	Fischer and Maurer (1978)
DTI	$DTI = (Yp \times Ys)/(\overline{Y}p)^2$	Fernandez (1992)
YSI	$YSI = Ys/Yp$	Bouslama and Schapaugh (1984)
DI	$DI = Ys \times (Ys/Yp)/\overline{Y}p$	Lan (1998)

Based on the data obtained from the drought resistance indices of the three tested locations, compound variance analysis, mean comparison with the LSD method at the 5% level, and correlation analysis with Pearson's method for indices with the yield of two environments were performed with SPSS 18. In the next step, cluster analysis was performed with WARD's method based on Euclidean distance square, and principal components analysis was conducted using Minitab 16 software.

3. Results

3.1. The compound variance analysis of drought resistance indices

Variance analysis of drought resistance indices in the three studied locations are presented in Table 5. The results showed that there was a significant difference between the locations for the YS, MP, GMP and MH indices at the 1% level, and for the YP and DTI indices at the 5% level.

But for Tol, SSI, YSI and DI indices, no significant differences were observed among the regions. On the other hand, there was a significant difference at the 1% level for all the indices among the studied lines, and the interaction effect of genotype×location was also significant at the 1% level for all the indices.

Table 5. Compound variance analysis of drought resistance indices of camelina doubled haploid lines in the three investigated regions.

Sources of variation	df	Y_p	Y_s	MP	Tol	GMP
Location	2	558418*	397160**	445949**	127342^{ns}	448683**
Error1	6	52281	10342	10146	84658	7531
Line	35	1330184**	878252**	967475**	546974**	959863**
Line × Location	70	34267**	49651**	28973**	51942**	30565**
Error2	210	16913	5645	7003	17104	6205

Sources of variation	df	MH	SSI	DTI	YSI	DI
Location	2	450930**	0.092^{ns}	0.069*	0.058^{ns}	0.033^{ns}
Error1	6	6194	0.359	0.013	0.022	0.042
Line	35	963434**	2.054**	1.577**	0.144**	0.732**
Line × Location	70	33031**	0.262**	0.060**	0.018**	0.086**
Error2	210	5815	0.064	0.01	0.004	0.010

** Significant at 1% level, * Significant at 5% level and ^{ns} Non-significant difference.

3.2. Investigation of drought resistance indices in three regions

The mean comparison of drought resistance indices in three locations with the LSD method at the 5% level is presented in Table 6. According to the results, it was observed that Mehrgan had the highest Y_p with an average of 1570 kg/ha, which was not significantly different from the Mahidasht location (average of 1501 Kg//ha), and Eslamabad-e Gharb had the lowest Y_p with an average of 1426 Kg/ha, which with Mahidasht location did not show any significant difference.

For rainfed yield, it was also observed that the highest yield was allocated to Mehrgan with 1138 kg/ha, which was not significantly different from Mahidasht with an average of 1137 kg/ha, and the lowest yield belonged to Eslamabad-e Gharb with an average of 1033 kg/ha, which was not significantly different at 5% level with two other places, according to the LSD test.

The highest MP was in the Mehrgan region with an average of 1354 Kg/ha, which was significantly different from other locations, and the lowest average productivity was assigned to Eslamabad-e Gharb with an average of 1230 Kg/ha, which was significantly different from other locations. Mahidasht had an average MP compared to the other two locations with an average of 1319 Kg/ha, which showed a significant difference with both locations.

For Tol, no significant differences were observed among the locations. However, lines in Mahidasht showed more tolerance to drought with an average of 363.3, and in the Mehrgan region with an average of 431.8, less drought tolerance was observed and Eslamabad-e Gharb was between these two locations with an average of 493.6.

For the geometric mean of productivity, it was also observed that Mehrgan had the highest value with an average of 1329 and had a significant difference with the other two locations at the level of 5%, and the lowest GMP was assigned to Eslamabad-e Gharb with an average of 1206 and showed a significant difference with other locations. Finally, Mahidasht was placed in the middle between the two locations for GMP with an average of 1299 and had a significant difference with both locations.

For the harmonic mean index, it was observed that the two locations of Mehrgan and Mahidasht had the highest values with an average of 1305 and 1281 respectively and were in the same group, and Eslamabad-e Gharb had the lowest harmonic value with an average of 1183 and showed a significant difference with the other two locations. Regarding the stress sensitivity index, no significant difference was observed between the three locations. But Eslamabad-e Gharb had the highest SSI with an average of 0.984, and Mahidasht and Mehrgan were in the next ranks for SSI with 0.934 and 0.933, respectively.

According to the mean comparison, the Mahidasht region had the highest DTI with an average of 0.804, which was not significantly different from Eslamabad-e Gharb with an average of 0.778. The lowest DTI was observed in the Mehrgan region with an average of 0.754, which was not significantly different from Eslamabad-e Gharb.

For YSI, no significant difference was observed among the three locations, although Mahidasht had the highest value with an average of 0.774, followed by Mehrgan and Eslamabad-e Gharb with an average of 0.743 and 0.729, respectively. Regarding DI, no significant difference was observed between the locations and the values of this index were 0.788, 0.759 and 0.757 for the three regions of Mahidasht, Eslamabad-e Gharb and Mehrgan, respectively.

Table 6. Mean Comparison of drought resistance indices in three locations with the LSD method at the 5% level.

Locations	Yp (Kg/ha)	Ys (Kg/ha)	MP	Tol	GMP
Eslamabad-e Gharb	1426^{b}	1033^{b}	1230^{c}	393.6^{a}	1206^{c}
Mahidasht	1501^{ab}	1137^{a}	1319^{b}	363.3^{a}	1299^{b}
Mehrgan	1570^{a}	1138^{a}	1354^{a}	431.8^{a}	1329^{a}
LSD (5%)	76.14	33.86	33.54	96.88	28.9

Locations	MH	SSI	DTI	YSI	DI
Eslamabad-e Gharb	1183^{b}	0.984^{a}	0.778^{ab}	0.729^{a}	0.759^{a}
Mahidasht	1281^{a}	0.934^{a}	0.804^{a}	0.774^{a}	0.788^{a}
Mehrgan	1305^{a}	0.933^{a}	0.754^{b}	0.743^{a}	0.757^{a}
LSD (5%)	26.17	0.199	0.038	0.049	0.068

The Means with the same letters are not significantly different from each other.

3.3. Investigation of lines based on drought resistance indices

The mean comparison of drought resistance indices among the examined lines with the LSD method at the 5% level is presented in Table 7. Line 5 had the highest seed yield with an average of 2221 Kg/ha in supplementary irrigation conditions, which was not significantly different from the check variety and line 3. Line 20 had the lowest seed yield with an average of 979.6 Kg/ha under supplementary irrigation conditions, which was not significantly different from lines 26, 33, 19, 34 and 31. In rainfed conditions, line 5 showed the highest seed yield with an average of 1804 Kg/ha, which was significantly different from other lines. On the other hand, line 6 was ranked second in yield with 1688 Kg/ha, which did not show a significant difference with lines 3 and 10, and it was observed that the check variety after these four lines had an average yield of 1603 Kg/ha. But the lowest yields were assigned to lines 16, 20, 14, 15, 25, 8, 30 and 27, respectively, with an average between 786.5 and 1.835 Kg/ha and there were no significant differences with lines 17 and 23.

For the MP index, it was observed that line 5 had the highest value with an average of 2013 and had a significant difference with other lines, followed by line 3 with an average of 1883, which did not have a significant difference with lines 6 and the Check variety. On the other hand, line 20 had the lowest MP with an average of 888.8, which was significantly different from other lines, and in the next stage, three lines 30, 27 and 26 had low MP, respectively, with an average of 970.7, 971.2 and 1.975, which had no significant difference with lines 25, 33, 17, 34, 14, 19, 29 and 31.

For the tolerance index, it was observed that line 35 had the lowest value of this index with an average of 5.28, and in other words, it showed the highest tolerance to stress and there was no significant difference with lines 26, 31, 19, 32, 34, 33 and 29.

On the other hand, line 15 had the highest value of this index with an average of 144.3, indicating the lowest tolerance to stress compared to other lines. Moreover, in the next stage, line 24 had the highest tolerance index with an average of 95.70, which showed no significant difference when compared to line 13.

The highest GMP was assigned to line 5 with an average of 2000, which had a significant difference compared to other lines. In the next stage, line 3 had the highest amount with an average of 1869, which was not significantly different from line 6 and the check variety. The lowest GMP was assigned to line 20 with an average of 883.3, which was significantly different from other lines, and then lines 30 and 27 had low geometric mean with an average of 0.960 and 3.960, respectively, and with lines 26, 25, 17, 33, 14 and 34 had no significant difference.

The highest MH with an average of 1988 was assigned to line 5 and had a significant difference with other lines at the 5% level. In the next stage, lines 3 and 6 had a high harmonic mean with an average of 1856 and 1855, respectively, which did not have a significant difference with the check variety and line 10.

The lowest level of this index was observed for line 20 with an average of 877.8 and had a significant difference with other lines, and in the next stage lines 30, 27, 25, 26, 17, 14 and 33 had low MH that were placed in the same group. The lowest SSI was assigned to line 35 with an average of 0.141, which was not significantly different from line 26. In the second step, line 26 had the lowest SSI with an average of 0.340, which was not significantly different from lines 19, 31, 32, 34, 33 and 22.

The highest SSI was allocated to line 15 with an average of 2.206, which was significantly different from other lines, and in the next step, lines 24, 13 and 16 had high SSI with averages of 1.871, 1.870 and 1.839, respectively, these three lines did not differ significantly, but they had significant differences with other lines. The highest level of DTI was assigned to line 5 with an average of 1.786 and showed a significant difference with other lines. In the following, lines 6 and 3 had the highest DTI with an average of 1.576 and 1.565, respectively, which were not significantly different from the check variety. The lowest DTI was observed for line 20 with an average of 0.350 and there was no significant difference with lines 27, 30, 26, 17 and 25. The highest YSI was obtained for line 35 with an average of 0.962, which was not significantly different from line 26. In the second step, line 26 had YSI with an average of 0.909 and showed no significant difference with lines 19, 31, 32, 34 and 29.

The lowest level of YSI was observed in line 15 with an average of 0.417, which was significantly different from other lines, and in the next order, lines 24, 13 and 16 had the lowest level of YSI, respectively, with an average of 0.506, 0.507 and 0.512, which had a significant difference with other lines. For the drought tolerance index, it was observed that line 5 had the highest average with an average of 1.343 and there was no significant difference with lines 6 and 10. In the second stage, line 6 had an average of 1.264 and showed no significant difference with lines 10, 3 and 35. The lowest amount of DI was allocated to line 15 with an average of 0.307, which was not significantly different from line 16, and next was line 16 with an average of 0.369, which was not significantly different from lines 13, 8 and 24.

Table 7. Mean comparison of camelina lines based on drought resistance indices.

Line	Yp (Kg/ha)	Ys (Kg/ha)	MP	Tol	GMP
DH1	2008^{bcd}	1452^{e}	1730de	55.65^{de}	1707^{e}
DH2	1997^{b-e}	1562^{d}	1780de	43.59^{e-j}	1765de
DH3	2106^{ab}	1661^{bc}	1883^{b}	44.50^{e-j}	1869^{b}
DH4	1687^{g}	1358^{f}	1523^{f}	32.89^{j-m}	1511^{f}
DH5	2221^{a}	1804^{a}	2013^{a}	41.67^{g-l}	2000^{a}
DH6	2067^{bc}	1688^{b}	1877^{bc}	37.93^{h-m}	1866^{bc}
DH7	1883^{ef}	1535^{d}	1709^{e}	34.78^{i-m}	1696^{e}
DH8	1442^{hij}	818.9^{p}	1131^{lmn}	62.35^{d}	1082^{lm}
DH9	1727^{g}	1180^{g}	1453^{fg}	54.65^{def}	1426^{g}
DH10	1968^{cde}	1642^{bc}	1805^{cd}	32.65^{j-m}	1796^{cd}
DH11	1353^{jk}	1009^{ij}	1181^{klm}	34.33^{i-m}	1167^{jk}
DH12	1431^{ij}	979.4^{jkl}	1205^{jkl}	45.16^{e-i}	1182^{ij}
DH13	1784^{fg}	906.0^{mno}	1345^{hi}	87.82^{bc}	1269^{h}
DH14	1274^{kl}	799.8^{p}	1037^{opq}	47.41^{e-h}	1006^{n-r}
DH15	1951^{cde}	808.5^{p}	1380^{gh}	114.3^{a}	1254^{hi}
DH16	1561^{h}	786.5^{p}	1174^{klm}	77.42^{c}	1104^{kl}
DH17	1180^{lmn}	837.9^{op}	1009^{pq}	34.22^{i-m}	992.3^{pqr}
DH18	1365^{jk}	1014^{ij}	1190^{kl}	35.17^{i-m}	1172^{jk}
DH19	1095^{nop}	986.3^{jk}	1041^{opq}	10.92^{pq}	1039^{l-q}
DH20	979.4^{p}	797.9^{p}	888.8^{r}	18.17^{nop}	883.3^{s}
DH21	1225^{lm}	915.8^{lmn}	1071^{nop}	30.94^{klm}	1057^{l-p}
DH22	1488^{hi}	1062^{hi}	1275^{ij}	42.58^{f-k}	1256^{h}
DH23	1377^{ijk}	846.3^{nop}	1112^{mno}	53.07^{d-g}	1077^{lmn}
DH24	1927de	970.2^{j-m}	1449^{fg}	95.70^{b}	1364^{g}
DH25	1185^{lmn}	814.9^{p}	999.9^{pq}	36.98^{h-m}	981.0^{qr}
DH26	1021^{op}	929.5^{klm}	975.1^{q}	9.128^{pq}	973.5^{qr}
DH27	1107^{mno}	835.1^{p}	971.2^{q}	27.21^{mno}	960.3^{r}
DH28	1398^{ij}	1096^{h}	1247^{jk}	30.16^{lmn}	1225^{hij}
DH29	1126^{mno}	960.1^{j-m}	1043^{opq}	16.61^{opq}	1038^{l-q}
DH30	1108^{mno}	833.5^{p}	970.7^{q}	27.43^{mno}	960.0^{r}
DH31	1098^{nop}	989.0^{jk}	1043^{opq}	10.90^{pq}	1041^{l-q}
DH32	1130^{mno}	1011^{ij}	1070^{nop}	11.99^{pq}	1068^{l-o}
DH33	1088^{nop}	923.3^{klm}	1006^{pq}	16.42^{opq}	1001^{o-r}
DH34	1097^{nop}	947.8^{j-m}	1022^{pq}	14.89^{pq}	1018^{m-r}
DH35	1396^{ij}	1343^{f}	1370^{h}	5.283^{q}	1369^{g}
Check	2117^{ab}	1603^{cd}	1860^{bc}	51.41^{d-g}	1836^{bcd}
LSD 5%	120.9	69.82	77.77	12.15	73.2

The means with the same letters are not significantly different from each other using LSD test.

Continued Table 7. Mean comparison of camelina lines based on drought resistance indices.

Line	MH	SSI	DTI	YSI	DI
DH1	1685^{d}	1.053^{f-j}	1.303^{e}	0.723^{k-n}	0.952^{e}
DH2	1750^{cd}	0.821^{j-o}	1.407^{d}	0.782^{f-k}	1.115^{d}
DH3	1856^{b}	0.799^{k-p}	1.565^{b}	0.790^{e-j}	1.197^{bcd}
DH4	1500^{e}	0.687^{n-q}	1.019^{f}	0.813^{d-i}	1.002^{e}
DH5	1988^{a}	0.700^{l-q}	1.786^{a}	0.816^{d-h}	1.343^{a}
DH6	1855^{b}	0.693^{m-q}	1.576^{b}	0.816^{d-h}	1.264^{ab}
DH7	1683^{d}	0.684^{n-q}	1.292^{e}	0.822^{d-g}	1.167^{cd}
DH8	1037^{jkl}	1.575^{c}	0.522^{lmn}	0.581^{q}	0.435^{pqr}
DH9	1398^{f}	1.187^{d-g}	0.909^{g}	0.684^{nop}	0.736^{ghi}
DH10	1787^{bc}	0.627^{o-r}	1.464^{cd}	0.834^{def}	1.260^{abc}
DH11	1153^{i}	0.955^{g-k}	0.615^{jkl}	0.746^{j-m}	0.686^{ijk}
DH12	1159^{i}	1.203^{def}	0.624^{ijk}	0.686^{nop}	0.614^{kl}
DH13	1198^{hi}	1.870^{b}	0.719^{h}	0.507^{r}	0.421^{qr}
DH14	976.8^{klm}	1.360^{cde}	0.45^{nop}	0.637^{opq}	0.467^{opq}
DH15	1140^{i}	2.206^{a}	0.705^{hij}	0.417^{s}	0.307^{s}
DH16	1040^{jkl}	1.839^{b}	0.545^{klm}	0.512^{r}	0.369^{rs}
DH17	976.1^{klm}	1.066^{f-i}	0.439^{n-q}	0.717^{lmn}	0.547^{l-o}
DH18	1156^{i}	0.953^{g-k}	0.619^{jk}	0.741^{j-n}	0.697^{ijk}
DH19	1036^{jkl}	0.386^{s}	0.483^{m-p}	0.902^{bc}	0.814^{fg}
DH20	877.8^{n}	0.687^{n-q}	0.35^{q}	0.815^{d-h}	0.593^{lm}
DH21	1044^{jk}	0.926^{h-m}	0.497^{m-p}	0.754^{jkl}	0.628^{jkl}
DH22	1237^{gh}	1.081^{f-i}	0.713^{hi}	0.715^{lmn}	0.693^{ijk}
DH23	1043^{jk}	1.407^{cd}	0.519^{mno}	0.628^{pq}	0.481^{n-q}
DH24	1285^{g}	1.871^{b}	0.83^{g}	0.506^{r}	0.448^{pqr}
DH25	962.4^{m}	1.154^{e-h}	0.43^{n-q}	0.695^{mno}	0.514^{m-p}
DH26	972.0^{lm}	0.340st	0.427^{opq}	0.909^{ab}	0.767^{f-i}
DH27	949.7^{m}	0.909^{i-n}	0.41^{1pq}	0.760^{h-l}	0.576^{lm}
DH28	1205^{hi}	0.748^{k-q}	0.669^{hij}	0.814^{d-h}	0.837^{f}
DH29	1034^{jkl}	0.571^{p-s}	0.48^{m-p}	0.851^{bcd}	0.746^{f-i}
DH30	949.6^{m}	0.932^{h-l}	0.41^{pq}	0.755^{i-l}	0.571^{lmn}
DH31	1039^{jkl}	0.391^{s}	0.484^{m-p}	0.896^{bc}	0.807^{fgh}
DH32	1065^{j}	0.411^{rs}	0.509^{mno}	0.893^{bc}	0.824^{fg}
DH33	995.6^{j-m}	0.561^{qrs}	0.447^{nop}	0.848^{cde}	0.714^{hij}
DH34	1014^{j-m}	0.521^{qrs}	0.461^{m-p}	0.862^{bcd}	0.745^{f-i}
DH35	1369^{f}	0.141^{t}	0.837^{g}	0.962^{a}	1.174^{bcd}
Check	1813^{bc}	0.893^{i-n}	1.513^{bc}	0.767^{g-l}	1.135^{d}
LSD (5%)	70.87	0.235	0.093	0.059	0.093

The means with the same letters are not significantly different from each other using LSD test.

3.4. Correlation of drought resistance indices

Table 8 presents the correlation of drought resistance indices with Pearson's method. It was observed that the indices of MP, GMP, MH, DTI and DI have a positive and significant correlation at the 1% level with the yield of two environments (Ys and Yp). Therefore, these indices were more suitable for evaluating drought resistance than others. Tol had a positive correlation only with Yp, and the YSI had a positive and significant correlation with the Ys. On the other hand, SSI had a negative and significant correlation with the rainfed environment at the level of 5%.

3.5. Grouping of lines based on drought resistance indicators

Fig. 1 shows the cluster diagram of the grouping of lines using cluster analysis. According to the diagram, the lines were placed in three distinct groups. The first group included lines 1, 2, 10, 7, 3, 6, 5 and the check cultivar. The lines of this group had the highest yield in both rainfed and supplementary irrigation environments and had the highest MP, GMP, MH, DTI and DI, and were placed between the other two groups for three indices of Tol, SSI and YSI. The second group included lines 4, 9, 35, 8, 23, 16, 11, 18, 28, 12, 22, 13, 24, and 15, and the lines of this group have the highest Tol (lowest drought tolerance according to this index), SSI and the least YSI, and for other indices were showed an average level of drought resistance. The third group consisted of lines 21, 25, 17, 14, 20, 27, 30, 19, 31, 32, 26, 29, 33 and 34, which had the lowest yield in two environments. These lines showed weak performance based on MP, GMP, MH, DTI and DI and had the highest tolerance to drought according to Tol, SSI and YSI.

Table 8. Correlation of drought resistance indices (n=36).

Indices	Yp	Ys	MP	Tol	GMP	MH	SSI	DTI	YSI
Ys	0.77**								
MP	0.95**	0.93**							
Tol	0.59**	-0.07	0.31						
GMP	0.93**	0.95**	1.00**	0.23					
MH	0.89**	0.97**	0.99**	0.16	1.00**				
SSI	0.30	-0.37*	0.00	0.94**	-0.07	-0.14			
DTI	0.91**	0.96**	0.99**	0.20	1.00**	1.00**	-0.10		
YSI	-0.30	0.37*	0.00	-0.94**	0.08	0.15	-1.00**	0.11	
DI	0.50**	0.94**	0.74**	-0.40*	0.79**	0.83**	-0.67**	0.81**	0.67**

* and *:Significant at the 1 and 5 % level, respectively.

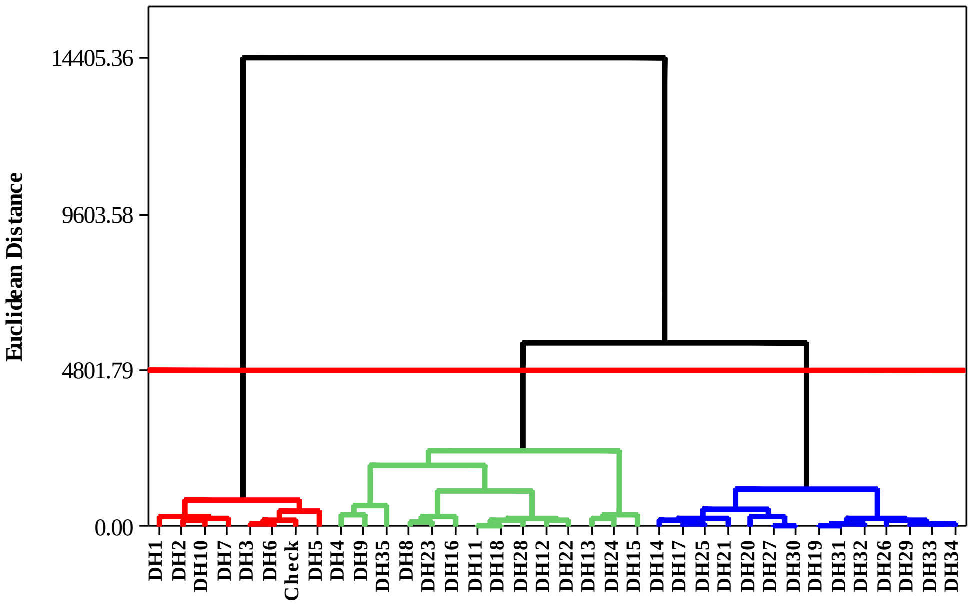

Figure 1. Cluster analysis of lines based on drought resistance indices by Ward's method

3.6. Principal component analysis of the lines based on drought resistance indices

Based on the results of the principal component analysis of the lines, according to the yield of two environments and drought resistance indices, the number of two components were extracted that had an eigenvalue above one. The two first component were explained 64.8 and 34.8 percent of the variance, respectively and in total, 99.6 percent of the variance were explained based on the two components. According to the first component Y_s, Y_p, MP, GMP, MH, DTI and DI had the most positive contribution, and based on the second component, the indices of Tol and SSI had the most positive contribution and YSI had the largest negative contribution (Table 9).

Table 9. Eigenvalue, percentage of variance, cumulative variance and the values of the first and second components resulting from the principal components analysis of the lines based on the yield of two environments and drought resistance indices.

Indices	First component	Second component
Y_s	<u>0.342</u>	0.261
Yp	<u>0.386</u>	-0.096
MP	<u>0.385</u>	0.107
Tol	0.045	<u>0.529</u>
GMP	<u>0.390</u>	0.067
MH	<u>0.392</u>	0.029
SSI	-0.077	<u>0.524</u>
DTI	<u>0.390</u>	0.049
YSI	0.078	<u>-0.524</u>
DI	<u>0.337</u>	-0.272
Eigenvalue	6.48	3.48
Percentage of variance	64.8	34.8
Cumulative variance	64.8	99.6

In Fig. 2, the biplot diagram of the first two components is presented, and according to the diagram, it was observed that the distribution of the lines corresponded to the grouping obtained from the cluster analysis of the lines, that the results of cluster analysis are shown in different colors in the diagram. Based on this, it was observed that the lines 1, 2, 10, 7, 3, 6, 5 and the check cultivar with the highest resistance to drought based on the indices correlated with the two environments were located in the same region and on the other hand, the lines of 4, 9, 35, 8, 23, 16, 11, 18, 28, 12, 22, 13, 24, and 15, which had moderate drought resistance based on cluster analysis, were more concentrated in the middle of the graph and finally, the lines of 21, 25, 17, 14, 20, 27, 30, 19, 31, 32, 26, 29, 33 and 34, which were the most sensitive lines for rainfed conditions, were also located in the same area of the graph.

On the other hand, it was observed that the convergence of the indices in the graph was consistent with the results obtained from the correlation of the indices and the three indices of Tol, SSI and YSI had a greater angle with the yield of two environments. In other words, the trend of these three indices was different from the yield of two environments, which was consistent with the correlation results.

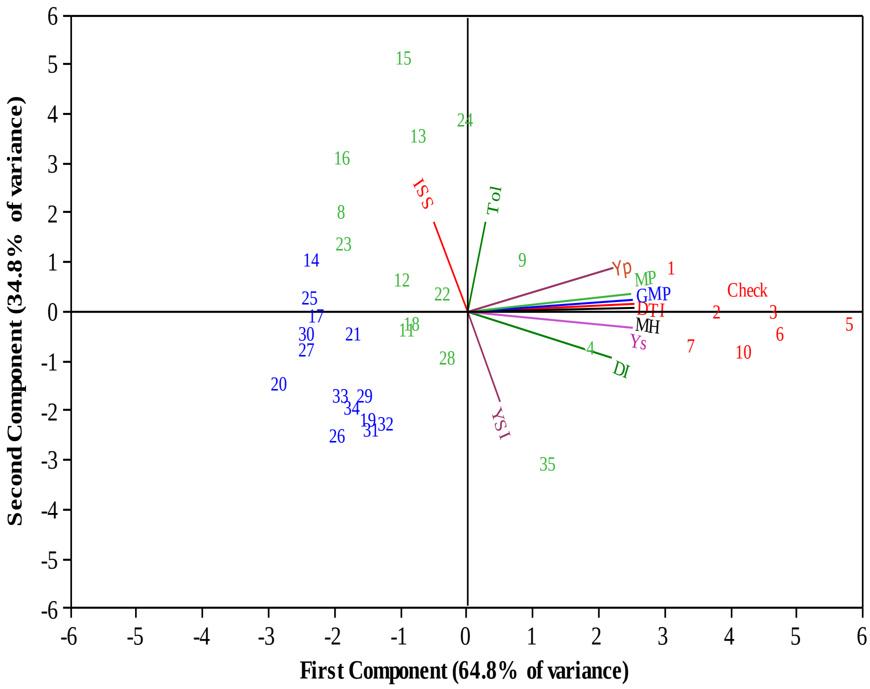

Figure 2. Biplot diagram of the first two components resulting from the principal components analysis of the lines based on drought resistance indices.

3.7. Three-dimensional evaluation of two environments yield and MP index

In Fig. 3, the three-dimensional diagram of the line distribution based on the yield of rainfed and supplementary irrigation environments and the MP index, as well as Fernandez's grouping, is presented. According to the graph, it was observed that the lines of 5, 3, 6, 2, 10, 1, 7, 4, 9 and the check cultivar had higher than average yield in two environments and were located in region A based on Fernandez's grouping. Also, these lines showed more resistance to drought. Lines 24, 15, 13 and 16 had high yield in supplementary irrigation environments and low performance in stress environments, and based on Fernandez's grouping, they were placed in zone B, which also showed moderate resistance to drought based on drought resistance indices. Line 35 was placed alone in zone C., This line had a high yield in rainfed conditions and showed a lower yield than average in supplementary irrigation conditions, this line can be considered as a line with low sensitivity to drought, which it does not have high yield potential in irrigation conditions. Other lines were located in zone D based on Fernandez's grouping, and in other words, they performed poorly in both environmental conditions, and these lines also showed low resistance to drought.

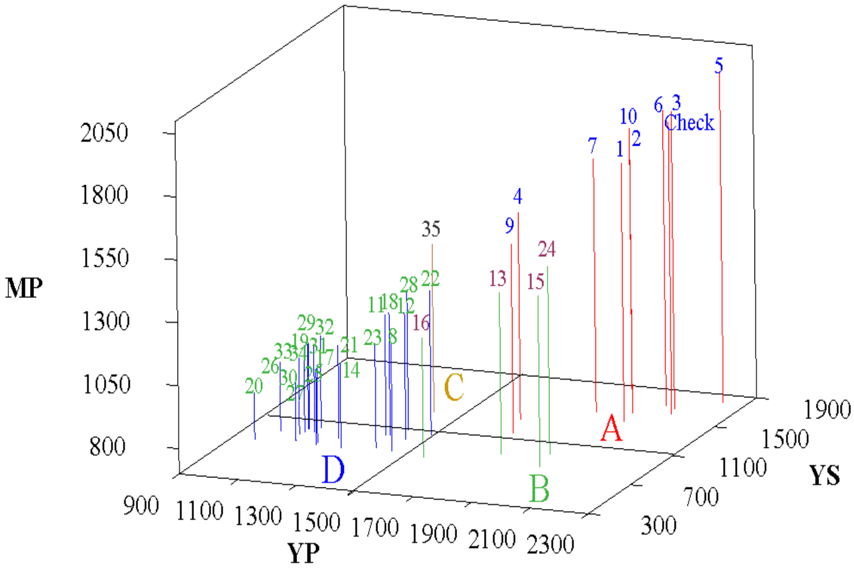

Figure 3. The three-dimensional diagram of the distribution of lines based on the performance of two environments and MP.

4. Discussion

The interaction effect of genotype×location was highly significant for all drought resistance indices, which were calculated based on the yield of both environments. Therefore, it is difficult to identify the ideal genotype for selection in different conditions. Similarly, previous research showed that the low heritability of yield in breeding programs is always influenced by the genotype and environment interaction (Esmaeili *et al*., 2023). On the other hand, the existence of a significant effect for all indices among the studied lines indicates the existence of potential among these genotypes for selecting drought-resistant lines. In other words, it was observed that the difference in the genetic background of the studied lines caused a significant variation in their resistance to drought, which was consistent with the report of Borzoo et al. (2021b). It has been reported that the yield reduction caused by water deficiency can be due to less absorption of substances for carbohydrate production under stress conditions, which the genetic background of the plant can affect (Borzoo *et al*., 2021a). Also, it was observed that among the investigated regions, for three indices that the bases of were the average of two environments (MP, GMP and MH), there is a significant difference at the level of 1%, and for DTI, there is also a significant difference at the level of 5%. For other indices (SSI, Tol, YSI and DI) there was no significant difference between environments. This conclusion can be because these four indices were highly correlated with the yield of the two environments and because the yield of the two humidity environments was different in the different tested locations, therefore significant variation was observed for these indices among the locations.

The research results showed that SSI, Tol and YSI indices had more repeatability over the years (Farshadfar *et al*., 2013), which was consistent with the results of this research. Based on this, considering the correlation of indices with the yield of two environments, it was observed that the four indices of MP, GMP, MH and DTI, along with the DI index had a significant correlation with two humidity environments. It has been stated in many reports that indicators for selecting drought-resistant genotypes are desirable and have a significant correlation with the yield of stress and non-stressed environmental conditions (Sangi *et al*., 2021; Solat Petloo *et al*., 2023).

As a result, it can be said that in the current research, the indices of MP, GMP, MH, DTI and DI were more suitable for checking the drought resistance of the lines, this conclusion is in agreement with the report of Esmaeili et al. (2023) in the investigation of the camelina drought resistance. Camelina lines showed a match. However, among the three investigated regions, it was observed that based on the three indicators of MH, MP and GMP, the drought resistance of lines was higher in Mehrgan and the lowest drought resistance was observed in Eslamabad-e Gharb.

On the other hand, based on the DTI, Mahidasht showed the highest level of drought tolerance for lines, and Mehrgan had the lowest level of drought tolerance based on this index. No significant difference was seen in the other four indices between the three locations. In total, based on drought resistance indices, lines 1, 2, 3, 5, 6, 10, 7 and the check variety were the best lines in terms of drought resistance based on seed yield. This conclusion was based on the mean comparison, cluster analysis, principal components analysis and finally, the three-dimensional distribution diagram of the yield of the two environments and the MP index, and it was observed that these lines were in group A based on Fernandez's grouping, so the yield in the two environments is high and showed more resistance to drought. Esmaeili et al. (2023) introduced 6 lines as drought-resistant lines among 40 doubled haploid camelina lines. It is necessary to explain that 40 investigated lines, 10 lines were similar to the lines of this research, which were found to be drought resistant among the common lines of the Sohail variety in both reports, and two lines 6 and 7, which were doubled haploids 18 and 20, were among the lines based on the conclusion of this research, the joint of two researches had high resistance to drought, line 20 was resistant according to report of Esmaeili et al. (2023), but line 18 was not resistant.

Other resistant lines in the two studies were among non-shared lines. In any case, research has shown that camelina's resistance to drought is due to its morphological and physiological characteristics, and this issue is one of the most important advantages of this plant for cultivation in dry conditions (Kim *et al*., 2019; Rostami Ahmadvandi *et al*., 2021b). Although camelina is a drought-resistant plant, it is very sensitive to waterlogging (Stasnik *et al*., 2022).

5. Conclusion

According to the obtained results, there was a high genetic potential among the studied lines for selection in order to increase drought resistance. Also, among the three studied regions, drought resistance indices showed different performances. Finally, lines 1, 2, 3, 5, 6, 10, and 7 and the control variety (Soheil) showed better drought resistance and seed yield performance, therefore, it is possible to choose and release some varieties among these lines for the climates conditions of Kermanshah province.

Conflict of Interests

All authors declare no conflict of interest.

Ethics approval and consent to participate

No human or animals were used in the present research.

Consent for publications

All authors read and approved the final manuscript for publication.

Availability of data and material

All the data are embedded in the manuscript.

Authors' contributions

All authors had an equal role in study design, work, statistical analysis and manuscript writing.

Informed Consent

The authors declare not to use any patients in this research.

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